PREDATION RISK AND ECONOMIC IMPACT OF LESSER SCAUP AND PISCIVOROUS WATERBIRDS ON COMMERCIAL BAITFISH AND CATFISH PRODUCTION

Reporting Period

July 1, 2017 – August 31, 2018

Funding Level Year 1……………………………………..$142,971
Year 2…………………………………......$157,021

Participants University of Arkansas at Pine Bluff………………..Luke Roy, Project Leader
Anita Kelly
Mississippi State University………………………...Brian Davis
USDA/WS/NWRC…………………………………Brian Dorr
Virginia Polytechnic Institute & State University…..Michael Schwarz
Carole Engle

PROJECT OBJECTIVES

Objective 1. Evaluate the impact of lesser scaup predation and predation risk on commercial baitfish farms. Such evaluations may include assessment of:

a. Surveys of the distribution and abundance of lesser scaup on baitfish ponds
b. Quantification of potential prey items in ponds
c. Quantification of prey items consumed by lesser scaup
d. Economic impact of fish predation by lesser scaup on baitfish ponds

Objective 2. Evaluate the impact of piscivorous waterbirds on catfish production. Such evaluation may include an assessment of:

a. Surveys to identify cormorant night roost locations that contribute disproportionately to current aquaculture depredation as a means to improve roost harassment efficiency
b. Assessment of economic impact of fish predation by piscivorous waterbirds on catfish production ponds

ANTICIPATED BENEFITS

Lesser scaup and piscivorous waterbirds, such as double-crested cormorants, consume fish raised via aquaculture and result in economic losses on commercial fish farms. This research will improve understanding of utilization of baitfish ponds by lesser scaup, species and sizes of fish consumed, and will ultimately generate an economic analysis of baitfish losses. This project will generate contemporary information on cormorant roost locations, numbers of birds per roost, and roost distance from active and inactive catfish ponds in Mississippi as well as reveal how cormorants modify their use of roost sites as commercial aquaculture decreases. Ultimately, results from this study will allow researchers to estimate economic losses of fish caused by these birds, and generate management recommendations for producers to ameliorate depredation of fish by waterbirds.

PROGRESS AND PRINCIPAL ACCOMPLISHMENTS

Objective 1. Evaluate the impact of lesser scaup predation and predation risk on commercial baitfish farms. Such evaluations may include assessment of:
Subobjective 1a: Surveys of the distribution and abundance of lesser scaup on baitfish ponds.
Subobjective 1b: Quantification of potential prey items in ponds.

University of Arkansas at Pine Bluff

Year 1 (July 1, 2016 – August 31, 2016)

Activities in Arkansas included preliminary contact with Arkansas fish producers to inform them of this project. Farmers were informed by phone or in one-on-one encounters that they may be contacted in the near future by scientists at Mississippi State University and USDA/WS/NWRC concerning the availability of their farm to serve as one of the collection sites for the study. During this period, we also performed logistical planning to provide lodging for the graduate student and research team from Mississippi during weeks that sampling would occur in the fall.

Year 2 (September 1, 2016 – August 31, 2017)
Activities in Arkansas for the reporting period included continued contact with Arkansas fish producers to inform them of this project. During this period, we also performed logistical planning in support of the graduate student and research team from Mississippi during weeks that sampling would occur in the fall and winter.

Year 3 (September 1, 2017 – August 31, 2018)
As in Year 2 of this project, project personnel stationed in Arkansas continued to provide logistical support to the Mississippi State and USDA team performing research on baitfish farms. Constant communication was maintained with Arkansas fish producers involved in the project as well as USDA APHIS Wildlife Services personnel stationed in Arkansas so that baitfish producers would remain well informed of progress on the project.

Mississippi State University & USDA/WS/NWRC

<u>Justification</u>

Commercial baitfish producers have been reporting increased numbers of fish-eating waterbirds using their farms in the past several years. Some species of fish-eating migratory birds, such as lesser scaup, are federally protected, and controlling them at the farm level can be problematic. Most commercial baitfish farms in Arkansas are located along the Mississippi River Flyway which at times naturally attracts large numbers of migratory birds to farms during winter. These aquaculture producers have expressed that scaup by far appear to be the most detrimental to their operations, feeding extensively on fathead minnows and golden shiners. For this reason, our study aims to estimate the abundance and distribution of scaup on commercial baitfish and sportfish farms in Arkansas.

Year 1 (July 1, 2016 – August 31, 2016)

During the first two months of this project, which constitute the reporting period (July-August 2016), Mr. Stephen Clements, a M.S. student, was hired for the scaup portion of the study and enrolled in the Department of Wildlife, Fisheries & Aquaculture, Mississippi State University (MSU) in August 2016. Stephen's graduate committee met with him and introduced the project and its scope of work. Mr. Clements initiated a literature review of this topic and read prior reports and literature on waterbird use of aquaculture ponds, all of which will be synthesized in preparation for his required Master's graduate study proposal.

This scaup project will invoke a similar study approach and design to that conducted in previous studies (2004- 2005) that indexed abundances of all species of fish-eating birds that used baitfish aquaculture ponds in Arkansas. Developing a similar protocol in the current study will allow us to detect potential changes in bird abundances or other important dynamics between these two time periods. Also during July and August 2016, there was extensive collaborative effort among scientists on this project. A meeting was convened in Arkansas to allow project personnel (Mississippi State University and USDA/WS/NWRC) to become familiar with the study area and to meet several Arkansas baitfish producers. Future work in the fall will entail refinement of methods and study area designation so that surveys can be initiated in November 2016. Surveys of scaup on Arkansas baitfish ponds will continue through late winter 2017, and results of these surveys will be presented in forthcoming reports.

Year 2 (September 1, 2016 – August 31, 2017)

<u>Methods</u>

We contacted 15 baitfish and sportfish producers in Lonoke and Prairie Counties, Arkansas, and gained permission to conduct bird surveys on their facilities during winters 2016-2017 and 2017-2018. Those 15 farms, representing approximately 40% of the total number of baitfish and sportfish farms in Arkansas, were selected based on their participation in similar historical surveys or were randomly chosen from a list of producers in these counties to make up for farms that are no longer in operation. We mapped these farms on ArcGIS and divided them into 38 different "clusters" on which we would conduct bird surveys. Two randomly selected ponds from each cluster (n = 76 ponds) were surveyed for $\geq$ 5 minutes each day that we conducted surveys. For surveyors to sample all 76 ponds in a given day, the 38 clusters were subdivided into two routes. Teams of two people conducted surveys bimonthly via pickup trucks or ATV's provided by Mississippi State University and USDA's National Wildlife Research Center. During surveys all fish-eating birds were counted using spotting scopes and binoculars. Data were used later to examine bird use over time by comparing our results with those of an unpublished study from 2005. Additionally, abundance estimates of scaup were used to quantify total amount of fish consumed by scaup on commercial baitfish and sportfish aquaculture in Arkansas.

Following surveys, we contacted farmers to gather pond- and farm-level information about the ponds that were surveyed. This information included: species of fish in pond, size of fish, stocking rates, and disease/die-off information. Despite apparent ease in collecting such data, it has proven more difficult than originally anticipated as commercial fish farming in many instances does not follow cookbook-style procedures because they must respond to dynamic market demands. While some farmers stock fish in one spring and harvest the whole pond during the subsequent spring, other farmers may leave some fish in a pond and restock on top of them, confounding our ability to obtain a specific fish count. Given these challenges, we developed seven fish density categories from which to work. We considered density ranges of fish that are meaningful to producers and broad enough for farmers to more accurately describe under which category a particular pond falls.

Results

During winter 2016-2017, more than 800 individual ponds were surveyed over 11 survey trips from mid-November through March. We counted 1,740 scaup during all surveys combined. These scaup abundances are relatively low considering that the previous unpublished study counted over 7,000 scaup in one winter using comparable techniques. For our winter 2016-2017 work, average scaup/acre was 0.277, 0.300, 0.005, and 0.026 on golden shiner, fathead minnow, goldfish, and sportfish ponds, respectively. In both the present and previous studies, greatest scaup densities were observed on fathead minnow ponds and least densities occurred on goldfish ponds. In total, we counted over 14,000 water birds that could potentially be consuming fish from these ponds including great blue herons, great egrets, double-crested cormorants, and ring-billed gulls. Further analysis of survey data will continue after the 2017-2018 field season is completed to compare bird use between ponds containing varying fish densities and sizes.

Low scaup numbers observed during our surveys corroborated grower observations in 2016-2017. Several producers mentioned viewing fewer scaup during 2016-2017 than in any recent winter. The general consensus was that the mild weather greatly reduced numbers of scaup observed. Fortunately, we will have a replicate year of surveys, winter 2017-2018, to help us compare with the first-year trends observed.

Year 3 (September 1, 2017 – August 31, 2018)

Methods

We repeated pond survey procedures from Year 2 from November 2017 through March 2018 on 35 of our original 38 clusters. One farm, containing 3 clusters, was dropped during the second winter per request of the farmer. Two randomly selected ponds from each cluster (n = 70 ponds) were surveyed for $\geq$ 5 minutes each of the days that we conducted surveys. For surveyors to sample all 70 ponds in a given day, the 35 clusters were subdivided into two routes. Teams of two people conducted surveys bimonthly via pickup trucks or ATVs provided by Mississippi State University and USDA's National Wildlife Research Center. During surveys all fish-eating birds were counted using spotting scopes and binoculars. Data will be used later to examine bird use over time by comparing our results with those of an unpublished study from 2005. Additionally, abundance estimates of scaup were used to quantify total amount of fish consumed by these ducks on commercial baitfish and sportfish aquaculture in Arkansas.

Following surveys, we contacted farmers to gather pond- and farm-level information about the ponds that were surveyed. This information included: species of fish in the pond, size of fish, stocking rates, and disease/die-off information. Despite apparent ease in collecting such data, it has proven more difficult than originally anticipated as fish farming in many instances does not follow cookbook-style procedures as farmers adjust continuously to changing market conditions and demand. While some farmers stock fish in one spring and harvest the whole pond during the subsequent spring, other farmers may leave some fish in a pond and restock on top of them, confounding our ability to obtain a specific fish count. Given these challenges, we developed seven fish density categories from which to work. We considered density ranges of fish that are meaningful to producers and broad enough for farmers to more accurately describe under which category a particular pond falls.

Based on scaup distribution and diet analysis during our first field season, we hypothesized that chironomid densities in ponds influenced to some degree pond selection by scaup. To further explore this, we collected over 300 sediment samples in November, January, and March of winter 2017-2018. Sediment samples were collected from golden shiner, goldfish, and *Lepomis* spp. ponds that contained low, medium, and high densities of fish relative to the typical stocking practices of each species. Twenty-seven ponds were sampled each of the 3 sampling months. Samples were extracted using a 4-inch diameter core sampler and placed in labeled Ziplock^{R} bags, then deposited in coolers with ice until they were returned to Mississippi State for immediate processing. Each sample was rinsed through 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 and weighed. Weights were used to estimate total biomass per pond.

<u>Results</u>

During winter 2017-2018, 628 pond surveys were conducted on 423 individual ponds over 9 survey trips from mid-November through March. We counted 4,746 scaup during all surveys combined which was a substantial increase from the 1,740 scaup counted (173% increase) during all surveys in winter 2016-2017. Scaup abundances in winter 2017-2018 were much more consistent with numbers previously reported by farmers in a typical winter, while much lower than in a past study that observed over 7,000 scaup in one winter using comparable techniques. For winter 2017-2018, average scaup/pond was 12.0, 5.4, 0.2, 6.7, and 2.3 on golden shiner, fathead minnow, goldfish, *Lepomis* spp. and other sportfish ponds, respectively. Low scaup numbers on goldfish ponds were consistent across both winters of this study. In total, we counted over 5,500 waterbirds that may consume fish from these ponds including scaup, great blue herons, great egrets, double-crested cormorants, and ring-billed gulls, and an additional 8,800 other diving ducks that could potentially consume fish. We will use the survey data collected from these two winters to estimate the total number of scaup and other waterbirds using our survey ponds during winter. Additionally, we will use pond surveys to investigate the effects of pond characteristics on the distribution and abundance of scaup using Arkansas' aquaculture.

Results from sediment sampling indicated that the greatest chironomid biomass was found in goldfish ponds, where scaup tended to not be found. Chironomid biomass was least on golden shiner ponds during all months. This trend suggests that the biomass of available invertebrate prey types is less influential on the distribution of scaup on ponds than perhaps other pond characteristics.

Objective 1. Evaluate the impact of lesser scaup predation and predation risk on commercial baitfish farms. Such evaluations may include assessment of:
Subobjective 1c. Quantification of prey items consumed by lesser scaup.

Justification

Scaup naturally feed in ponds, lakes, and other permanent bodies of water, but typically are not regarded as heavy consumers of fish. Scaup collected in previous studies from natural wetlands, lakes, or rivers mostly contained small crustaceans and other invertebrates. Just two studies have examined foraging by scaup in commercial baitfish ponds, both of which determined fish to comprise some portion of their diet. These studies, however, were conducted over 15 years ago and did not have corresponding scaup abundance data with which to compare to their collection data. As a result, this contemporary rigorous study was warranted to more precisely estimate total amount of fish consumed by wintering scaup on Arkansas' commercial baitfish and sportfish aquaculture.

Year 2 (September 1, 2016 – August 31, 2017)

Methods

To quantify prey items consumed by scaup, we collected foraging scaup from at least 3 of the 38 clusters each week that we went afield. We observed birds through a spotting scope from a distance, or up close if we were concealed before collecting birds. Birds were observed feeding for at least 10 minutes, and when foraging was confirmed, the shooter(s) harvested as many scaup as possible (goal was 5-10 birds/cluster) using shotguns. The goal was to collect 30 birds per trip, or 300 birds per year. Harvesting a scaup quota of 30 early in the fall was difficult because so few birds were present on ponds. To reach our target number of birds, we increased collections later in winter when more birds were present.

Immediately after harvest, scaup esophagi were injected with up to 60 ml of phosphate buffered saline and a zip-tie applied around the neck. Birds were kept in an icy slush until they were returned to Mississippi State University for processing. During processing, birds were weighed, sexed, and aged. The esophagus and gizzard was removed and frozen for further diet analysis. During further dissection, the esophagi and gizzards were treated separately. Gizzards were checked for presence/absence of fish parts, but because of bias associated with recognizable food items found in gizzards, contents will not be used in the overall diet proportions for each bird. Food items found in the esophagi were sorted and recorded as fish, invertebrate, or vegetation, then dried and weighed to estimate the proportion of each item in the birds' total diet. Fish and invertebrates were identified to the most specific taxonomic group possible. Much like our survey ponds, information regarding the prey (fish) availability in the pond, such as fish species, size, and stocking density was obtained from the producer for each pond in which scaup are collected. Pond information will be used to reveal potential patterns of fish consumption by scaup. We hypothesize that there may be particular pond characteristics that enable scaup to effectively capture fish, such as species, density, or pond size.

Results

We collected 294 scaup in winter 2016-2017. Of those, only 2% (n = 6 birds) contained any sign of fish parts, and 5 out of 6 of those scaup only contained fish parts in the gizzard, so there was little fish biomass to quantify. Of the 294 scaup collected, 230 contained identifiable prey items in the esophagus. In those 230 scaup, 84% contained midge larvae, the most common prey item found (Figure 1a). Midge larvae also accounted for approximately 72% of the scaup diet by weight. Low numbers of fish in collected scaup, much like the few numbers of scaup counted, are attributed to the mild winter in 2016-2017. When winter temperatures are unseasonably warm, waterfowl energy demands are much less. It could be that scaup opted to consume prey that were easier to catch, rather than consume a high energy fish diet. Additionally, we believe that alternative prey items may have been abundant in the ponds, including midge larvae, because of the warmer than average water temperatures and reduced intraspecific competition for prey. Prey availability in ponds will be further investigated during the 2017-2018 field season. The apparent influences of environmental variability on abundance and feeding habits of scaup on Arkansas' commercial aquaculture ponds demonstrates the importance of multi-year monitoring to account for such variability. Conducting our study over two winters will allow us to investigate influences of environmental conditions on fish consumption by scaup and better inform estimates of loss and management recommendations.

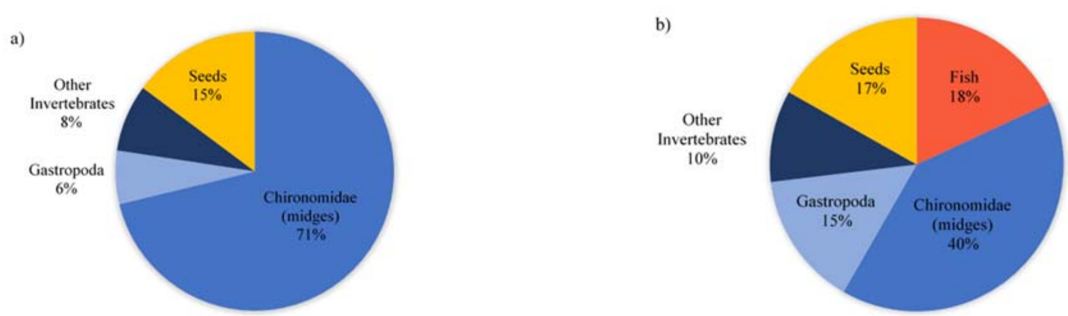

Figure 1. Aggregate % dry weight of food items detected in (a) 165 scaup collected from 50 bait- and sportfish ponds in eastern Arkansas during winter 2016-2017 and (b) 225 scaup collected from 68 bait- and sportfish ponds in eastern Arkansas during winter 2017-2018.

Year 3 (September 1, 2017 – August 31, 2018)

Methods

To quantify prey items consumed by scaup, we collected foraging scaup from at least 3 of the 35 clusters each week that we went afield. We observed birds through a spotting scope from a distance, or up close if we were concealed before collecting birds. Birds were observed feeding for at least 10 minutes, and when foraging was confirmed, the shooter(s) harvested as many scaup as possible (goal was 5-10 birds/cluster) using shotguns. The goal was to collect 30 birds per trip, or 300 birds per year. Typically scaup were collected from randomly selected clusters that met a minimum total scaup abundance (150 scaup during our survey day). In some instances, birds were collected outside of these constraints, either before surveys were completed or on clusters that did not meet the minimum criteria, but had scaup foraging on ponds that had been observed by farmers. These "targeted "collections were typically completed to either add to low overall collection numbers due to low numbers of birds or to obtain additional samples from under-represented pond types (e.g. goldfish ponds).

Immediately after harvest, scaup esophagi were injected with up to 60 ml of phosphate buffered saline and a zip-tie applied around the neck. Birds were kept in an icy slush until they were returned to Mississippi State University for processing. During processing, birds were weighed, sexed, and aged. The esophagus and gizzard were removed and frozen for further diet analysis. During further dissection, the esophagi and gizzards were treated separately. Gizzards were checked for presence/absence of fish parts, but because of bias associated with recognizable food items found in gizzards, contents will not be used in the overall diet proportions for each bird. Food items found in the esophagi were sorted and recorded as fish, invertebrate, or vegetation, then dried and weighed to estimate the proportion of each item in the birds' total diet. Fish and invertebrates were identified to the most specific taxonomic group possible.

<u>Results</u>

We collected 267 scaup in winter 2017-2018. Of those, 29% (n = 77 birds) contained signs of fish parts, and the majority of those (n = 71) contained fish in the esophagus that we could use to estimate total fish consumption. Of the 267 scaup collected, 15% (n = 39) contained <5mg of dried identifiable prey items and were not used in subsequent analysis. Much like the first winter collections, midge larvae was the most common prey item found in birds collected during the second winter and made up 40% of the diet by weight in winter 2017-2018 (Figure 1b). Unlike collections in the first winter, 2016-2017, fish comprised 18% of lesser scaup diet by weight in winter 2017-2018. Mean fish lengths consumed were 1.7, 1.6, and 1.9 inches for golden shiners, goldfish, and *Lepomis* spp. respectively and the maximum number of fish found in a single bird was 112 identifiable golden shiners. No identifiable fathead minnows were found in any collected scaup; however, we did find fish parts in some scaup collected from fathead minnow ponds. Fathead minnows did appear in birds collected in a previous study (Philipp and Hoy 1997) and from preliminary collections in 2014 (Roy et al. 2015), so we are left to speculate that fathead minnows are consumed proportionally to other species. We attribute the lack of evidence in our study to a relatively small number of scaup (n = 22) collected from fathead minnow ponds, particularly during months with elevated fish consumption in year 2 (i.e. December, January, February; n = 12 scaup during those months).

Winter temperatures during 2017-2018 were much more representative of weather in our study area, compared to winter 2016-2017. We observed the greatest fish consumption during December, January, and February when temperatures were the coldest. We believe that the differences in winter temperatures between the two years was a primary influence of the substantial differences in fish consumption between years. We believe this greater fish consumption was influenced because of increased energy demands of scaup during cold periods, or that fish became a more available prey type during the coldest times when their mobility was restricted, or some combination of these factors.

Objective 1. Evaluate the impact of lesser scaup predation and predation risk on commercial baitfish farms. Such evaluations may include assessment of:
Subobjective 1d. Economic impact of fish predation by lesser scaup on baitfish ponds.

Justification

Baitfish and catfish farmers have reported increased pressure and losses from fish-eating birds in recent years. As a result, the Southern Regional Aquaculture Center funded a project to develop estimates of losses on baitfish farms due to predation by scaup and to predation by double-crested cormorants on catfish farms. Past emphasis on the economic effects of such depredation was on the value of the fish that were lost due to depredation. However, the lost fish constitute only a portion of the costs incurred by fish farmers because farmers expend money and time to prevent depredation through implementing a variety of bird-scaring techniques. In addition, given that the fixed costs of production tend to be proportionately greater on baitfish/sportfish farms than on other types of aquaculture facilities, changes in yield have a proportionately greater effect on overall farm economics than on other types of aquaculture farms. Thus, analysis of the overall farm-level economic effect is needed. This study is the first to include direct farm-level measures of the costs incurred on baitfish farms to scare birds.

Virginia Polytechnic Institute & State University

Year 1 (July 1, 2016 – August 31, 2016)

Emphasis for this reporting period was to initiate the development of a template for the economic analysis of the effects of fish predation on baitfish production. The focus was on details related to costs incurred and activities related to preventing bird depredation on farms. This included collection of data on farm expenditures including guns, ammunition, and bird scaring activities. Time spent (and its corresponding value) by farm personnel to scare birds was monitored, and costs associated with truck (or other vehicle use on farms) estimated.

By the end of Year 1, the basic templates for the economic analyses of the effects on baitfish were completed. These included two farm sizes (< 202 ha and > 202 ha) for: 1) golden shiners; 2) fathead minnows; 3) goldfish; and 4) sportfish.

Year 2 (September 1, 2016 – August 31, 2017)

Methods
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n this project, there were two phases to estimate the economic impact of fish predation by lesser scaup on baitfish ponds. Part of the economic impact is the value of the fish lost directly to depredation by lesser scaup on baitfish ponds. These values were obtained from the on-going

field data collection efforts. The second part of the estimation was to collect farm-level data on the costs incurred by baitfish farmers to scare depredating birds from their ponds. To obtain farm-level data on bird-scaring costs, those baitfish farmers participating in the study were surveyed. A questionnaire was developed, reviewed by all project participants, revised, and e-mailed to all baitfish farms participating in the study. Follow up telephone calls were made as necessary. Data were collected on purchases of firearms, ammunition, pyrotechnics, optics, eye and ear protection, exclusion devices, levee repairs, gravel, and expenses of trucks and drivers. The overall response rate from baitfish farms participating in the project was 93%. Data were coded, entered into spreadsheets and costs summed within cost categories that included: manpower, usage of trucks and other vehicles (fuel, repairs & maintenance, and annual depreciation), levee repair and maintenance (including gravel purchases to maintain all levees passable to chase birds), firearms and ammunition (including shipping), and bird-scaring devices (pyrotechnics, optics, eye and ear protection, and exclusion devices).

Results

Of the costs reported, manpower composed 56% of the cost of scaring birds, followed by 32% for the costs of truck usage, 9% for levee upkeep, 2% for firearms and ammunition, and only 1% of costs were for pyrotechnics and exclusion devices (Figure 2). On average, for the 2016-2017 bird-scaring season, baitfish farmers reported an average per-acre cost of $246/acre (range of $24/acre to $956/acre).

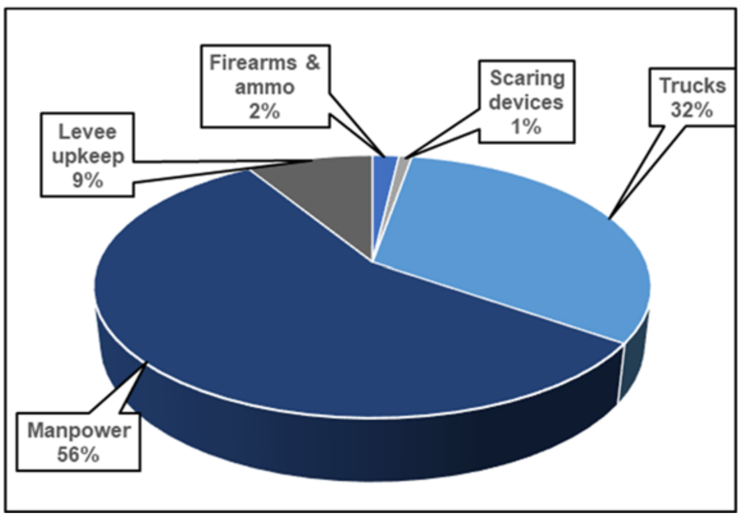

Figure 2. Percentage of cost components of bird-scaring costs on baitfish farms.

Work for this coming year will focus on modeling the fish losses due to depredating birds on various sizes and types of baitfish farms, once the field data collection has ended and all data made available for the economic analysis. Basic templates for the economic analyses of the fish losses due to bird depredation have been developed.

Year 3 (September 1, 2017 – August 31, 2018)

Methods

The first part of the economic assessment of the on-farm costs associated with fish-eating birds on baitfish/sportfish, to measure the direct costs incurred on baitfish and sportfish farms to scare birds, was completed in Year 2. The emphasis in Year 3 was to calculate the farm-level economic effect of losses due to fish consumed by depredating birds, and to model the economic effect of the combination of bird-scaring costs with the effects of losses of the fish consumed.

Comprehensive whole-farm enterprise budgets were developed for golden shiners, fathead minnows, sportfish, and goldfish. Whole-farm enterprise budgets were used as the basis for this analysis due to the proportionately greater on-farm economic effects of variations in yield on breakeven prices on baitfish/sportfish farms than on other types of aquaculture farms. A farm size of 300 acres was used for all four species to standardize fixed costs across analyses. Given that golden shiner and fathead minnow farms exhibit a broader range of farm sizes, additional enterprise budgets were developed for 1,200-acre farms for both golden shiners and fathead minnows.

The field data collected on losses due to scaup on golden shiner, fathead minnow, and sportfish farms as part of Sub-objectives 1a and 1c were provided to the VT economist by project team members. The goldfish field data analysis has not yet been completed. The whole-farm enterprise budgets reflect farm realities in which farms incur costs to scare scaup from their ponds but continue to lose fish to depredating scaup in spite of intensive bird-scaring efforts. Thus, the economic effects of the costs to scare birds and the reduced yields resulting from fish consumed by birds are embedded in the average costs of production (breakeven price above total costs) on baitfish/sportfish farms. The enterprise budgets were used to separate out the effects of bird-scaring costs and the farm-level effects of reduced yields on the average costs of production (breakeven price above total costs).

The numbers of birds feeding on baitfish/sportfish farms differed substantially between the two years of field work as did the numbers of birds feeding on different farms. To more fully understand the farm-level economic effects, given the variability of bird pressure, the analyses were run separately for: a) Year 1 average fish losses; b) Year 2 average fish losses; c) greatest losses observed on a farm; and d) fewest losses observed on a farm.

Results

Table 1 shows results of the economic effects only of the fish losses. In Year 1, with low numbers of depredating birds, the economic effect was quite low. In Year 2, however, with greater bird pressure, the economic effects were greater. For example, the average production cost (breakeven price above total costs) on golden shiner farms in Year 2 was $0.18/lb greater than it was in Year 1, reflecting the effect of lower yields resulting from the greater fish losses in that year. The lower yields result in proportionately greater fixed costs per pound of production. The degree of risk involved in whether or not birds land on specific farms in any given year is also evident in Table 1 from the variation between the economic effect of the greatest and the lowest fish losses observed.

Table 1. Change in breakeven price of baitfish/sportfish due only to fish losses from depredation by scaup, 300-acre farm. Values in $/lb.

Scenario	Golden shiners	Fathead minnows	Sportfish
Year 1 average fish losses	$0.00	$0.04	$0
Year 2 average fish losses	$0.18	$0.70	$0.01
Greatest losses observed on a farm	$0.35	$2.08	$0.01
Fewest losses observed on a farm	$0	$0	$0

Table 2 shows the much greater combined economic effects of fish losses and bird-scaring costs. For example, in Year 1, even with low bird pressure and low fish losses, the average production cost (breakeven price above total costs) of golden shiners would have been $0.59/lb lower if there were no losses of fish and farmers did not have to attempt to scare birds.

Table 2. Change in breakeven price of baitfish/sportfish due to combined effect of losses from depredation by scaup and bird-scaring costs, 300-acre farm. Values in $/lb.

Scenario	Golden shiners	Fathead minnows	Sportfish
Year 1 average fish losses	$0.59	$1.37	$0.12
Year 2 average fish losses	$0.75	$1.95	$0.13
Greatest losses observed on a farm	$0.91	$3.16	$0.15
Fewest losses observed on a farm	$0.59	$1.34	$0.12

Results to date of this project reflect only losses due to scaup. Data were also collected on fish consumption by other birds that will subsequently be incorporated into this analysis.

Objective 2. Evaluate the impact of piscivorous waterbirds on catfish production. Such evaluation may include an assessment of:
Subobjective 2a. Surveys to identify cormorant night roost locations that contribute disproportionately to current aquaculture depredation as a means to improve roost harassment efficiency.

Justification

Double-crested Cormorants (*Phalacrocorax auritus*) have historically impacted commercial aquaculture across the United States and are considered the greatest avian predators of catfish at aquaculture facilities. Cormorants are especially problematic where catfish production is concentrated in the 18,000 km^2 region of western Mississippi (the Delta). The highly visible, densely-stocked aquaculture ponds provide ideal wintering and foraging areas for cormorants. Despite informative prior research, recent changes in aquaculture practices, regulatory policy, and cormorant populations have heightened the need for new research on cormorant and aquaculture facility dynamics. Specifically, declines in aquaculture acreage from a peak of 45,608 ha in 2001 to 13,921 ha in 2016, changes in fish stocking densities, use of hybrid catfish, and a reduction in average pond size may affect use and impact by cormorants. Given this need, we devised a two-year study to assess cormorant depredation of commercial catfish to address these concerns.

Mississippi State University & USDA/WS/NWRC

Year 1 (July 1, 2016 – August 31, 2016)

July and August of 2016 represented the first two months of this 2-year research project. Terrel W. Christie was hired in July as a M.S. student in the Department of Wildlife, Fisheries, and Aquaculture at MSU to oversee the double-crested cormorant section of the project. Terrel was introduced to his graduate committee in August to discuss responsibilities for the project and all associated work. After completion of initial safety training courses, Terrel began to review journal articles and previous reports that are pertinent to cormorant use of aquaculture. These reports will be summarized into a Master's graduate study proposal.

In August of 2016, an aerial survey method was developed which included using GIS to map all known night roosts and active aquaculture units in the Mississippi Delta region. An appropriate flight route was planned to maximize the number of roosts surveyed within three hours of sunrise and sunset. The distance from the roosts to the nearest aquaculture unit were measured. These measurements were utilized to assign roosts into three distance categories in 10-kilometer increments. These distance categories will be used for harvest protocols for the food habits portion of the study. Surveys will occur twice a month from October through April and following each survey a harvest, and necropsy of cormorants will occur to analyze diet content. The night roost surveys are coordinated with flights evaluating fish-eating bird distribution and abundance on catfish ponds conducted by NWRC staff. This data will be utilized to determine how cormorants are distributed on major pond and production types (e.g. foodfish, fingerling, broodfish, split ponds, etc.) to support economic loss estimates. Results from surveys and diet analysis will be presented in forthcoming reports.

Year 2 (September 1, 2016 – August 31, 2017)

<u>Methods</u>

To address this sub-objective of the project, we divided the overarching project objective into three sub-objectives that will be analyzed separately, which include:

1. Estimate abundance and distribution of cormorants at their night roosts and determine use of catfish aquaculture in the Mississippi Delta for two winters.
2. Assess cormorant diet forage selection in relation to night roost site.
3. Construct a bioenergetics model for wintering cormorants to identify night roost sites with greatest probability of causing economic losses through fish depredation.

For the first objective, we flew aerial surveys of cormorant night roosts bi-monthly from October through April 2016-2017. Each survey was divided into a morning and evening flight so that all birds counted were considered to be at their night roost, and not a day roost. All active night roosts in the Mississippi Delta (85 night roosts) were counted for each survey. In forthcoming analyses, survey results will be corrected for observer bias and bias associated with the time of day the individual roost was counted.

Our second objective addresses forage selection of cormorants, which we accomplished by examining stomach contents. We divided all night roosts into three categories based on the minimum distance from the night roost to the nearest aquaculture facility (0-10 km, 10-20 km, and +20 km). Using the night roost survey data, a roost that represented each distance category that contained $\geq$200 cormorants was randomly selected for harvest. This was accomplished by having a team visit their assigned night roost the next evening following the aerial survey. Teams would arrive at their roost three hours before sunset to harvest cormorants as they returned to their night roost following a day of foraging. Harvested birds were preserved on ice and transported back to a campus laboratory for necropsies. Once in the lab, we identified a cormorant's sex and then removed the stomach. Later, stomach contents would be identified to the lowest possible taxa with length and weight measurements taken when possible. We used length-weight relationship formulas to calculate the weight of partially digested fish to estimate total prey biomass consumed.

Our third objective addresses the bioenergetics of cormorants with an emphasis on their consumption of catfish. We will develop a model using previously published information and models constructed from previous field data. The bioenergetics model will ultimately consist of individual energy demands, population energy demands, and catfish mass consumed to finally determine the total estimated number of catfish consumed.

Results

Results herein are derived from our first field season, fall-spring 2016-2017. We completed 13 aerial surveys and counted 112,239 cormorants across 67 different night roosts in our first year of study. Roosts ranged from 0.1 to 39 kilometers to the nearest aquaculture facility. A total of 390 cormorants were harvested from 20 different night roosts (Figure 3). Stomach contents contained 3,895 identifiable prey specimens, of which 1,212 were measurable. Catfish (*Ictalurus spp*.) represented 55% of the total prey biomass after length-weight formulas were applied to partially digested fish specimens (Figure 4). Shad (*Dorosoma spp*.) comprised 38% of the total prey biomass, while bream and freshwater drum constituted most of the remaining 7% of detected fish. Our results are preliminary but suggest that a trend in catfish consumption related to the proximity of a roost to aquaculture facilities exists. However, we will more rigorously assess this relationship at the end of the study when two full years of data will be available for analyses.

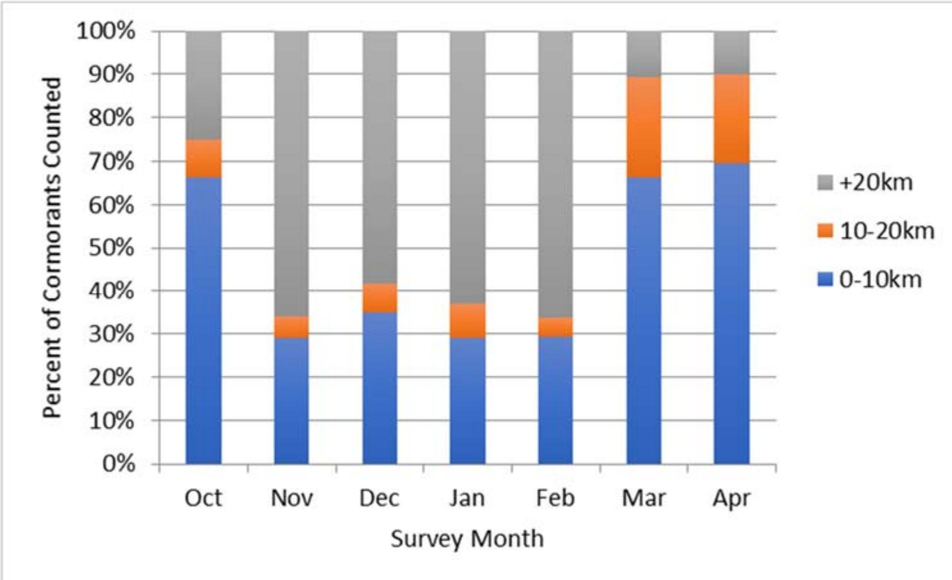

Figure 3. Percentage of cormorants counted in night roosts from aerial surveys flown in the Delta region of Mississippi, October 2016 to April 2017 and grouped by month and minimum distance to catfish aquaculture.

Year 3 (September 1, 2017 – August 31, 2018)

Methods

We divided the overarching project objective into three sub-objectives which include:

1. Estimate abundance and distribution of cormorants at their night roosts and determine use of catfish aquaculture in the Mississippi Delta for two winters.
2. Assess cormorant diet forage selection in relation to night roost site.
3. Construct a bioenergetics model for wintering cormorants to identify night roost sites with greatest probability of causing economic losses through fish depredation.

For the first objective, we repeated aerial night roost survey procedures in winter 2017-2018 that were conducted in the first winter, 2016-2017. Six night roosts were dropped from the bi-weekly surveys because of low occurrence and abundance of birds, which left us with 79 night roosts per survey. Surveys were conducted from October 2017 through April 2018. Each survey was divided into a morning and evening flight so that all birds counted were considered to be at their night roost. Survey starting points were randomized to reduce count bias associated with time of day. Final survey counts will be corrected for two forms of bias including observer bias and methods bias associated with aerial versus ground counts.

Our second objective addresses forage selection of cormorants, which we accomplished by examining stomach contents. We divided all night roosts into three categories based on the minimum distance from the night roost to the nearest aquaculture facility (0-10 km, 10-20 km, and +20 km). Using the night roost survey data, a roost that represented each distance category that contained ≥200 cormorants was randomly selected for harvest. This was accomplished by having a team visit their assigned night roost the next evening following the aerial survey. Teams would arrive at their roost three hours before sunset to harvest cormorants as they returned to their night roost following a day of foraging. Harvested birds were preserved on ice and transported back to a campus laboratory for necropsies. Once in the lab, we identified a cormorant's sex and then removed the stomach. Later, stomach contents would be identified to the lowest possible taxa with length and weight measurements obtained when possible. We used length-weight relationship formulas to calculate the weight of partially digested fish to estimate total prey biomass consumed.

Our third objective addresses the bioenergetics of cormorants with an emphasis on their consumption of catfish. A previously developed cormorant bioenergetics model will be updated from previously published literature and models constructed from field data. The bioenergetics model will ultimately consist of individual energy demands, population energy demands, and catfish mass consumed to finally determine the total estimated number of catfish consumed.

Results

Results herein are derived from our second field season, fall-spring 2017-2018. As of this writing we are currently analyzing the data to prepare for drafts of publications. We completed 12 aerial surveys and counted 130,684 cormorants across 68 different night roosts in our second year of study. Roosts ranged from 0.1 to 39 kilometers to the nearest aquaculture facility. A total of 338 cormorants were harvested from 22 different night roosts. Stomach contents contained 7,901 identifiable prey specimens, of which 3,333 were measurable (Figure 4). Catfish (*Ictalurus spp*.) represented 33% of the total prey biomass after length-weight formulas were applied to partially digested fish specimens. Other notable species found in the diet included shad (*Dorosoma spp*.), which comprised 57.6% of the total prey biomass, and sportfish, which comprised 9.2% of the diet. Consumption of channel and hybrid catfish did not differ with the average length of catfish consumed being ~7.9 inches (200 mm). We were able to model catfish consumption using two different variables including month and area of aquaculture surrounding a night roost within a 30.6 km forage radius. The greatest consumption of catfish occurred in March (Figure 5). Our night roost model showed that catfish consumption increases until there is approximately 3,000 ha of aquaculture surrounding the roost then it levels off (Figure 6). More rigorous analysis of these relationships will be tested and compared before results are used to build the bioenergetics model.

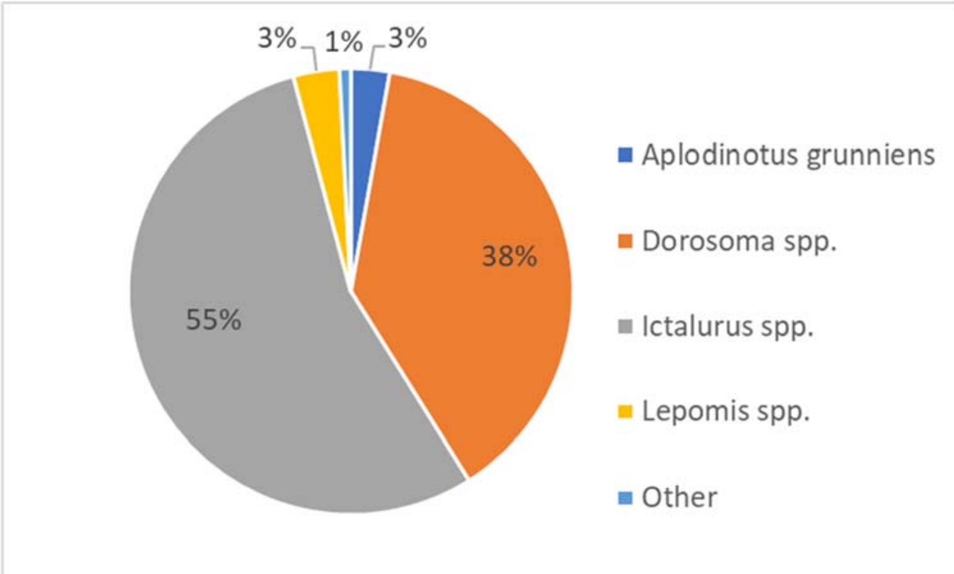

Figure 4. Percentage of prey biomass detected in cormorant stomachs from cormorants collected from their night roosts in the Delta region of Mississippi, October 2016 to April 2017.

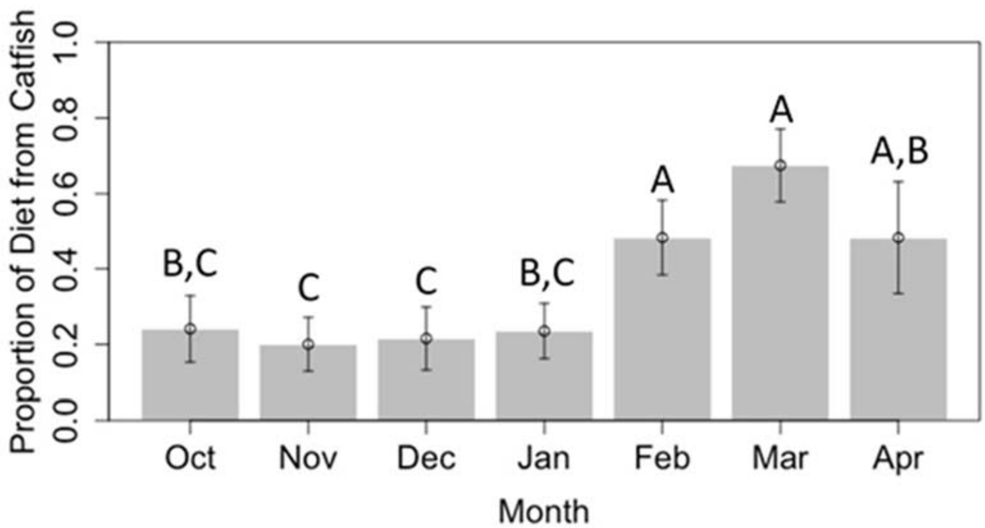

Figure 5. Mean proportion of a cormorant's diet consisting of catfish and 95% confidence limits for birds sampled from the Mississippi Delta, pooled across winters of 2016-2018. Letters represent Tukey's HSD test results for determining significant differences.

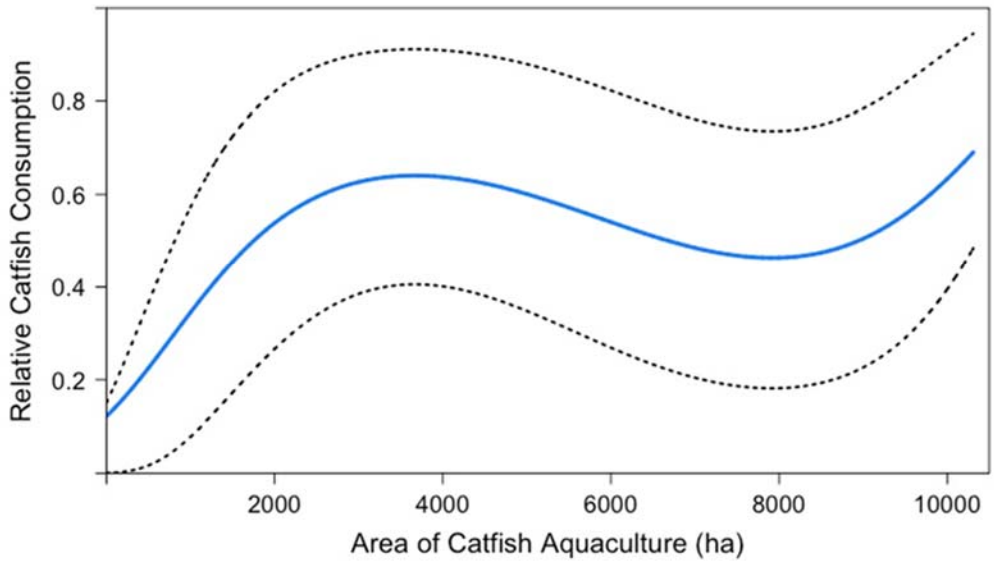

Figure 6. Predictive model for the proportion of a cormorant's diet consisting of catfish in the Mississippi Delta based on the area of aquaculture within a 30.6 km forage buffer of the cormorant's night roost location. The average (blue line) and the 25 and 75% quartiles (dotted lines) for catfish in the diet are shown.

Objective 2. Evaluate the impact of piscivorous waterbirds on catfish production. Such evaluation may include an assessment of:
Subobjective 2b. Assessment of economic impact of fish predation by piscivorous waterbirds on catfish production ponds.

Virginia Polytechnic Institute & State University

Justification

Baitfish and catfish farmers have reported increased pressure and losses from fish-eating birds in recent years. As a result, the Southern Regional Aquaculture Center funded a project to develop estimates of losses on baitfish farms due to predation by scaup and to predation by double-crested cormorants on catfish farms. Past emphasis on the economic effects of such depredation was on the value of the fish that were lost due to depredation. However, the lost fish constitute only a portion of the costs incurred by fish farmers because farmers expend money and time to prevent depredation through implementing a variety of bird-scaring techniques. This study is the first to include direct farm-level measures of the costs incurred on catfish farms to scare birds.

Year 1 (July 1, 2016 – August 31, 2016)

By the end of Year 1, the basic templates for the economic effects of predation on catfish were completed. These included three farm sizes: 33 ha, 124 ha, and 590 ha for each of the following scenarios: 1) channel catfish; 2) hybrid catfish; 3) split ponds; and 4) intensively aerated ponds.

Year 2 (September 1, 2016 – August 31, 2017)

Methods

In this project, there were two phases to estimate the economic impact of fish predation on catfish ponds. Part of the economic impact is the value of the fish lost directly to depredation on catfish ponds. These values will be obtained from the on-going field data collection efforts. The second part of the estimation is to collect farm-level data on the costs incurred by catfish farmers to scare depredating birds from their ponds. To obtain farm-level data on bird-scaring costs, catfish farmers participating in the study were surveyed. A questionnaire was developed, reviewed by all project participants, revised, and e-mailed to all catfish farms participating in the study. Followup telephone calls were made as necessary. Data were collected on purchases of firearms, ammunition, pyrotechnics, optics, eye and ear protection, exclusion devices, levee repairs, gravel, and expenses of trucks and drivers. The overall response rate from catfish farms participating in the project at the time this report was written was 86%. Data were coded, entered into spreadsheets and costs summed within cost categories that included: manpower, usage of trucks and other vehicles (fuel, repairs & maintenance, and annual depreciation), levee repair and maintenance (including gravel purchases to maintain all levees passable to chase birds), firearms and ammunition (including shipping), and bird-scaring devices (pyrotechnics, optics, eye and ear protection, and exclusion devices).

Results

Of the costs reported by catfish farmers, manpower composed 48% of the costs of scaring birds, followed by 29% for the costs of truck usage, 15% for levee upkeep, firearms and ammunition 7%, and only 1% of costs were for pyrotechnics and exclusion devices (Figure 7). On average, for the 2016-2017 bird-scaring season, catfish farmers reported an average per-acre cost of $200/acre (range of $15/acre to $553/acre), an increase of 10% from the previous year. In addition to the costs of bird scaring and the direct fish losses, the problem of depredating birds has led to increased inefficiencies in the way farms are managed. As stated by one respondent, "We have changed how we manage our entire farm due to birds, not efficiency; we schedule seining of ponds with the greatest bird pressure first; anyone going into town drives by ponds with birds one way in and comes back a different way."

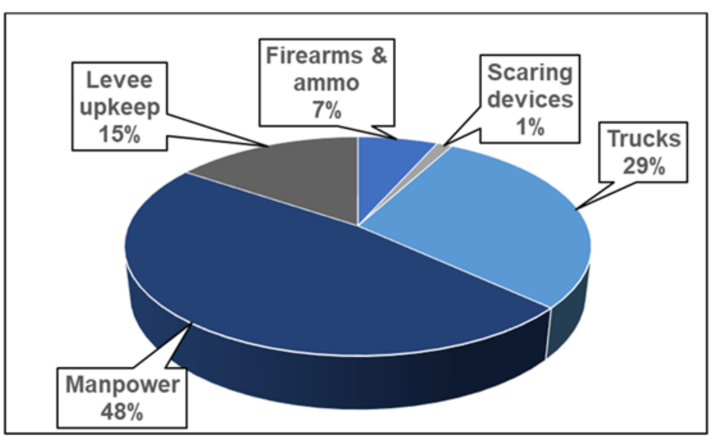

Figure 7. Percentage of cost components of bird-scaring costs on catfish farms.

Work for this coming year will focus on modeling the fish losses due to depredating birds on various sizes and types of catfish farms, once the field data collection has ended and all data made available. Basic templates for the economic analyses of the fish losses due to bird depredation have been developed.

Year 3 (September 1, 2017 – August 31, 2018)
Economic data collected during the project period is still in the process of being analyzed. Hence, no information is reported for this project period.

Potential Impacts

This study will be the first to combine scaup diet data and concurrent abundance estimates that will allow researchers to estimate the total amount of fish consumed annually by scaup across Arkansas' baitfish and sportfish industries. Unique pond information gathered during this study will potentially reveal characteristics that are associated with larger quantities of fish consumed by scaup. This could enable farmers to avoid conditions favorable for scaup and manage their farms in ways that make them less susceptible to depredation.

This study will provide contemporary knowledge on cormorant population and foraging habits that will enhance our efforts to manage cormorant predation on commercial catfish. The models developed through this study will inform managers on the most problematic roosts and when a cormorant's diet will shift and subsequently consume more catfish. Ultimately, this information will be used in an economic analysis to provide managers and catfish producers an estimate of monetary loss attributed to cormorant consumption of catfish product.

This is the first study to develop on-farm costs of attempts by farmers to prevent losses due to bird depredation. Results demonstrate that the greatest costs are for the trucks and manpower used to chase birds and that farmers are spending more money and more time than had previously been thought in efforts to scare birds from their ponds. This information can be used in discussions with policy-makers and in attempts to identify ways to reduce the harm to fish farmers from piscivorous birds.

Results of the economic analysis show that the economic effects on baitfish/sportfish farms caused by both the fish losses due to consumption by scaup and efforts by farmers to scare birds off their farms are quite high. Even in years with less bird pressure, the risk of severe losses to birds prompts farmers to fully implement bird-scaring efforts that cost approximately $250/acre. In spite of efforts by farmers to scare birds, fish are still lost to depredating birds. On farms that are targeted by birds in any given year, losses are substantial even with intensive efforts and resources devoted to scaring them.

PUBLICATIONS, MANUSCRIPTS OR PAPERS PRESENTED

Articles

Clements, S. A., B. Davis, B. S. Dorr, L. A. Roy, A. M. Kelly, and C. R. Engle. 2016. New study underway to estimate the impact of lesser scaup on Arkansas' baitfish industry. *Arkansas Aquafarming 33*(3):2.

Clements, S. A., B. Davis, B. S. Dorr, K. C. Hanson-Dorr, L. A. Roy, A. M. Kelly, and C. R. Engle 2017. Collaborative research on foraging habits and the economic impact of scaup on commercial baitfish and sportfish farms in Arkansas. *The Wildlife Society Southeastern Section 59*(3):13.

Abstracts

Clements, S. A., B. Davis, B. S. Dorr, K. C. Hanson-Dorr, L. A. Roy, A. M. Kelly, C. R. Engle. 2017. Foraging habits of lesser scaup (*Aythya affinis*) and greater scaup (*Aythya marila*) on commercial baitfish and sportfish farms in eastern Arkansas. Abstract. Alabama and Mississippi TWS Joint Conference, Meridian, Mississippi.

Clements, S. A., B. Davis, B. S. Dorr, K. C. Hanson-Dorr, L. A. Roy, A. M. Kelly, C. R. Engle. 2018. Foraging habits of lesser scaup (*Aythya affinis*) and greater scaup (*Aythya marila*) on commercial baitfish and sportfish farms in eastern Arkansas**.** Abstract. 2018 Annual Meeting of the Arkansas Bait and Ornamental Fish Growers Association, Lonoke, Arkansas.

Christie, T. W., B. Davis, B. S. Dorr, K. C. Hanson-Dorr, L. A. Roy, A. M. Kelly, C. R. Engle. 2018. Predation Risk of Double-crested Cormorants (*Phalacrocorax auritus*) on Commercial Catfish Production in the Mississippi Delta. Abstract. Alabama and Mississippi TWS Joint Conference, Meridian, Mississippi.

Engle, C.R., L. Roy, B. Dorr, B. Davis, A. Kelly, S. Clements, and T. Christie. 2018. Baitfish farm costs of scaring birds. Abstract. 2018 Annual Meeting of the Arkansas Bait and Ornamental Fish Growers Association, Lonoke, Arkansas.

Clements, S. A., B. Davis, B. S. Dorr, K. C. Hanson-Dorr, L. A. Roy, A. M. Kelly, C. R. Engle, S. C. Barras. 2018. Foraging Ecology and Depredation Impact of Scaup on Commercial Baitfish and Sportfish Farms in Eastern Arkansas. Mississippi Academy of Sciences, Summer Student Science Symposium 2018, July 26, 2018, Bost Conference Center, Mississippi State University, Starkville, MS.

Clements, S. A., B. Davis, B. S. Dorr, K. C. Hanson-Dorr, L. A. Roy, A. M. Kelly, C. R. Engle. 2018. Foraging Ecology and the Resulting Economic Impact of Lesser and Greater Scaup on Commercial Baitfish and Sportfish Farms in Arkansas. Aquaculture Workshop and Arkansas Bait and Ornamental Fish Growers Association Annual Meeting. February 8th, 2018 Lonoke, AR.

Clements, S. A., B. Davis, B. S. Dorr, K. C. Hanson-Dorr, L. A. Roy, A. M. Kelly, C. R. Engle. 2017. Foraging Habits of Lesser Scaup (Aythya affinis) and Greater Scaup (Aythya marila) on Commercial Baitfish and Sportfish Farms in eastern Arkansas. The Wildlife Society, Mississippi Chapter Annual Meeting, September 7-8, 2017 at the MSU Riley Center in Meridian.

Christie, T. W., B. Davis, B. S. Dorr, K. C. Hanson-Dorr, L. A. Roy, A. M. Kelly, C. R. Engle.

2017. Predation Risk of Double-crested Cormorants (*Phalacrocorax auritus*) on Commercial Catfish Production in the Mississippi Delta. Abstract. Mississippi Academy of Science Summer Student Science Symposium. Starkville, MS. July 26.

Presentations

Clements, S. A., B. Davis, B. S. Dorr, L. A. Roy, A. M. Kelly, and C. R. Engle. 2017 Foraging ecology and the resulting economic impact of lesser and greater scaup on commercial baitfish and sportfish farms in Arkansas. Oral presentation. 2017 Annual Meeting of the Arkansas Bait and Ornamental Fish Growers Association, Lonoke, Arkansas.

Clements, S. A., B. Davis, B. S. Dorr, K. C. Hanson-Dorr, L. A. Roy, A. M. Kelly, C. R. Engle. 2017. Foraging habits of lesser scaup (*Aythya affinis*) and greater scaup (*Aythya marila*) on commercial baitfish and sportfish farms in eastern Arkansas. Poster presentation. Alabama and Mississippi Chapters of The Wildlife Society Joint Conference, Meridian, Mississippi.

Clements, S. A., B. Davis, B. S. Dorr, K. C. Hanson-Dorr, L. A. Roy, A. M. Kelly, and C. R. Engle. 2018. Foraging habits of lesser scaup (*Aythya affinis*) and greater scaup (*Aythya marila*) on commercial baitfish and sportfish farms in eastern Arkansas**.** Oral presentation. 2018 Annual Meeting of the Arkansas Bait and Ornamental Fish Growers Association, Lonoke, Arkansas.

Christie, T. W., B. Davis, B. S. Dorr, K. C. Hanson-Dorr, L. A. Roy, A. M. Kelly, C. R. Engle. 2017. Predation Risk of Double-crested Cormorants (*Phalacrocorax auritus*) on Commercial Catfish Production in the Mississippi Delta. Poster presentation. Alabama and Mississippi Chapters of The Wildlife Society Joint Conference, Meridian, Mississippi.

Engle, C.R., L. Roy, B. Dorr, B. Davis, A. Kelly, S. Clements, and T. Christie. 2018. Farm costs of scaring birds. Oral presentation, 2018 Catfish Farmers of Arkansas Annual Convention, Hot Springs, Arkansas.

Engle, C.R., L. Roy, B. Dorr, B. Davis, A. Kelly, S. Clements, and T. Christie. 2018. Baitfish farm costs of scaring birds. Oral presentation, 2018 annual meeting of the Arkansas Bait and Ornamental Fish Growers Association, Lonoke, Arkansas.

Clements, S. A., B. Davis, B. S. Dorr, K. C. Hanson-Dorr, L. A. Roy, A. M. Kelly, C. R. Engle, S. C. Barras. 2018. Foraging Ecology and Depredation Impact of Scaup on Commercial Baitfish and Sportfish Farms in Eastern Arkansas. Mississippi Academy of Sciences, Summer Student Science Symposium 2018, July 26, 2018, Bost Conference Center, Mississippi State University, Starkville, MS.

Christie, T. W., B. Davis, B. S. Dorr, K. C. Hanson-Dorr, L. A. Roy, A. M. Kelly, C. R. Engle. 2018. Predation Risk of Double-crested Cormorants (*Phalacrocorax auritus*) on Commercial Catfish Production in the Mississippi Delta. Poster presentation. Mississippi Academy of Science Summer Student Science Symposium. Starkville, MS. July 26. (Placed second in the Graduate Student Division).

NOTE: The bird-scaring costs on catfish farms were included in the following talk:

Kumar, G. 2018. Research update on split ponds and economic impact of bird predation. Fall Seminar, Thad Cochran National warmwater Aquaculture Center, Mississippi State University.