NOAA Technical Memorandum NMFS-SEFSC-620

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Introduction

The Alabama shad, *Alosa alabamae*, is a small euryhaline and anadromous herring species in the Family Clupeidae. Historically, Alabama shad have been recorded as far north as the Ohio River in West Virginia and were commonly found in other Mississippi River tributaries including the Red, Arkansas, Missouri, and Tennessee Rivers (Kreiser and Schaefer, 2009). At present, they are believed to only occupy northern Gulf of Mexico rivers from the Mississippi River east to the Suwannee River in Florida. Currently, the largest spawning population of Alabama shad is hypothesized to reside in the Apalachicola-Chattahoochee-Flint River Basin (Ely et al., 2008; Young, 2010).

Over the last several decades, habitat fragmentation as a result of locks and dams blocking access to spawning areas and altering hydrology and river substrates has resulted in declines in the range of Alabama shad (Boschung, 1992; Adams et al., 2000; McBride, 2000; Musik et al., 2000; Mettee and O'Neil, 2003; Quinn and Kwak, 2003; Barko et al., 2004a). The Alabama shad's rarity throughout much of its former range and on-going threats such as dams, poor water quality, siltation, habitat alteration, dredging, bycatch, and thermal stress caused the National Marine Fisheries Service to add Alabama shad to the Candidate Species List under the Endangered Species Act in 1997. On April 15, 2004, National Marine Fisheries Service announced the establishment of a Species of Concern list, a description of the factors that it will consider when identifying Species of Concern, and revision of the Endangered Species Act Candidate Species List (69 FR 19976). NMFS transferred 25 candidate species, including Alabama shad, to the Species of Concern list.

Mettee and O'Neil (2003) provided an overview of the available information to date concerning the distribution and life history characteristics of Alabama shad. However, despite their extensive review, most of their information was gathered from available publications or reports. While this data is largely available, further information from anecdotal reports, unpublished survey data, and personal observations may provide a more accurate reflection of the current distribution of Alabama shad. Moreover, no studies have been conducted to determine the current population viability of the Alabama shad. Herein, we evaluate new sources of data to provide an update as to whether Alabama shad should be retained or removed from the Species of Concern list. We use the current criteria (71 CFR 55431) that include:

(1) Life-history characteristics: Vulnerable life history strategies (e.g., low fecundity, late maturity, slow growth), resilience to environmental variability and catastrophes, and loss of unique life-history traits.

(2) Abundance: magnitude of decline, natural rarity, and endemism.

(3) Distribution: Population connectivity, limited geographic range, and endemism.

(4) Threats: Extraction and harvest, habitat degradation and loss, disease, predation, and other natural or man-made factors.

Life-history characteristics

Taxonomy

Alabama shad was first described by David Star Jordan and Barton Warren Evermann in 1896 in the Black Warrior River near Tuscaloosa, Alabama (Jordan and Evermann, 1896). Alabama shad was depicted earlier as “white shad” in documents from the U.S. Commission on Fish and Fisheries circa 1860 and was often confused with other shad even after it had been described (Daniels, 1860; Barkuloo et al., 1993). Ohio shad (*Alosa ohiensis*), described by Evermann and Kendall (1900), was once thought to be different from the Alabama shad.

However, Hildebrand (1964) later found the Ohio shad to be congruent with the Alabama shad due to analogous physical traits. Alabama shad may also have been described as "gulf shad" in historical literature (e.g. Gunter, 1956).

Besides physical differences, Alabama shad are considered a separate species from the closely related American shad (*Alosa sapidissima*) based primarily on mtDNA molecular data (Bowen, 2005; Bowen et al., 2008; Kreiser and Schaefer, 2009). Because of limited genetic difference, it is theorized that the two species have only recently diverged from a common ancestor. Alabama shad is its own monophyletic group due to limited genetic differences among the clupeid family and allopatric speciation (Bowen et al., 2008). There has been no significant genetic differentiation among different stocks of Alabama shad geographically and there is no evidence of hybridization between any of the aforementioned *Alosa* species and Alabama shad (Kreiser and Schaefer, 2009).

Habitat Use and Migration

Though Alabama shad are found in marine environments, there is very little information about their marine habitat use in the Gulf of Mexico. Following the anadromous life cycle, adult Alabama shad migrate up river in the spring to spawn and then return to the Gulf of Mexico. First year (age 0) juveniles stay up river in freshwater environments until late summer or fall and eventually migrate downstream to the Gulf of Mexico. Juveniles coming from natal rivers located in the northernmost extent of their range (e.g. Ouachita River in Arkansas) begin downstream migration throughout the summer reaching the Gulf of Mexico by autumn. Juveniles located in southern rivers, such as the Pascagoula River, will remain in natal rivers as late as December before beginning their downstream migration to the Gulf of Mexico. Alabama shad do not overwinter in freshwater river systems (Mickle et al., 2010).

Alabama shad prefer cooler river waters with high dissolved oxygen and pH levels (Mickle et al., 2010). Though there have been no studies on the thermal tolerances of Alabama shad, other *Alosa* species cannot tolerate higher water temperatures (>32° C); therefore, it can be concluded that Alabama shad cannot tolerate high water temperatures (Beitinger et al. 1999). Mickle et al. (2010) found spawning adults in waters as low as 10˚ C, but juveniles have been collected in waters as warm as 32˚ C (Mickle et al., 2010; Young, 2010).

Water velocity is also believed to be an important habitat feature, as this species is rarely found in still or backwater portions of rivers. It is hypothesized that spring floods (increased river flow) are a vital environmental cue for spawning adults as well as an important aspect for successful hatching. Juveniles tend occupy moderate to fast moving water (~0.5-1.2 m s^{-1}) that is less than one meter deep (Mickle, 2010). Clear water with minimal benthic algal growth also appears to be preferred by this species (Buchanan et al., 1999).

Smaller, younger shad tend to prefer the slightly shallower, more protected areas over sandbars, while the older, larger shad can be found in channel and bank habitats. Sandbars within the bends of rivers that are less and than 2 m deep often support juveniles in the early summer (Mickle, 2010). As the fish grow, they move to bank (>2.5m deep) and channel (1.5-2.5m deep) habitats, though the shift is not always consistent (Mickle, 2010). Presumably, this allows the juveniles to avoid predators, fulfill foraging needs, or provide suitable thermal habitat that might be present in deeper waters (Byström et al., 2003; Mickle et al., 2010; Mickle, 2010).

Age and Growth

Like many clupeids, egg hatching period and growth of subsequent larvae varies by location and environmental factors. Mickle (2010) found those Alabama shad that hatched in the Apalachicola River had a longer successful hatch window (mean 58 days) compared to those in the Pascagoula River (mean 33.8 days).

Alabama shad juveniles exhibit rapid growth, though the size of juveniles varies across the range of the species. Typical juvenile Alabama shad increase in size from about 4.7 cm (total length, TL) to about 10.1 cm (TL) over the summer but variation can occur depending on the river drainage. For example, juvenile Alabama shad from the Apalachicola River grew faster than those in the Pascagoula River despite similar environmental conditions (Laurence and Yerger, 1967; Mickle, 2010). In the Chipola River in Florida, juveniles migrate downstream at an average size of 6.5 cm (TL), while those migrating down the Apalachicola River averaged 11.5 cm (TL) (Laurence and Yerger, 1967).

Adult female shad are typically longer and heavier than adult males of this species, specifically those in the Apalachicola and Choctawhatchee Rivers in Florida (Laurence and Yerger, 1967; Mills, 1972; Mettee and O'Neil, 2003). Age 1-3 males on average weigh 250 grams and age 1-4 females weigh around 650 grams before spawning (Mettee and O'Neil, 2003; Ingram, 2007).

Two studies have aged otoliths of Alabama shad but only one study has fit growth models to observed age data. In the Pascagoula River, maximum observed age was recorded to be six years based on otoliths (Mettee and O'Neil, 2003), while Ingram (2007) aged shad to only 4 years in the Apalachicola River. Von Bertalanffy growth model estimates by Ingram (2007) indicates females had a higher growth coefficient (K=2.32 yr^{-1} ±1.20 95% CI) than males (K=2.17 yr^{-1} ±2.25 95% CI), and higher theoretical maximum size (L_∞=389.5±13.0 mm for females vs 359.6 ±23.0 mm for males). Mean back-calculated lengths for each sex were similar to observed values for males ($F = 7.71$; $df = 5$; $P > 0.05$) and females ($F = 5.99$; $df = 7$; $P > 0.05$).

Reproduction

Alabama shad are fluvial specialists, depending on flowing water for reproduction, and thus prefer unimpounded rivers and streams. Shad spawn in February to April in southern rivers and May to June in the northern rivers, usually over sandy bottoms, gravel shoals, or limestone outcrops (Laurence and Yerger, 1967; Mills, 1972; Barkuloo et al., 1993; Kreiser and Schaefer, 2009; Mickle et al., 2010). Water temperatures between 18˚ to 22˚ C and moderate current velocities (0.5-1.0 m s^{-1}) promote successful spawning (Laurence and Yerger, 1967; Mills, 1972). Specific spawning behaviors are unknown for this species and have been widely unobserved. If environmental circumstances are unfavorable, often times, mature Alabama shad will abandon their migration upstream to spawn (Young, 2010).

Spawning males range in age from 1 to 5 years and females from 2 to 6 years (Mickle et al., 2010). While some age 1 male Alabama shad return to freshwater for their first spawning, the primary spawning age classes tend to be 2 to 3 for males and 2 to 4 for females; age 4 Alabama shad present in rivers are almost always female (Laurence and Yerger, 1967; Mettee and O'Neil, 2003; Ingram, 2007). Males arrive to the spawning sites first and increase in abundance as the spawning season continues, while females appear in large groups slightly later in the spawning season (Mills, 1972; Mettee and O'Neil, 2003). It is unknown whether females arrive with ripened eggs, as suggested by Mills (1972), or if their gonads ripen as river temperatures increase (Laurence and Yerger, 1967). Females tend to release their eggs (between 26,000-250,000 per female in the Apalachicola River and between 36,000-357,000 in the Choctawhatchee River) in late April and early May when the water temperatures are between 20-

21˚C (Mettee and O'Neil, 2003; Ingram, 2007). Fecundity is related to size with larger females producing more eggs (Ingram, 2007; Young, 2010). Ingram (2007) indicated this relationship was linear and followed the equation (Fecundity=545.02*(TL) –115112). After spawning, the younger (age 2-3) Alabama shad migrate back to marine waters. The older spawners (>age 4) either die or are preyed upon by other piscivorous fish (Laurence and Yerger, 1967).

Because of the age range among the spawning fish, it is believed that individuals may spawn more than once in a lifetime (Laurence and Yerger, 1967; Mettee and O'Neil, 2003; Ingram, 2007; Mickle et al., 2010). Mills (1972) found that up to 38% of the Alabama shad population in the Apalachicola River were repeat spawners based on spawning marks on their scales. However, due to the observed lack of markings on scales in recent studies, it is believed some fish may die after spawning in the Apalachicola River (T. Ingram, personal observation). Alabama shad appear to be philopatric and return to the same rivers to spawn, resulting in slight genetic differences among river drainages (Meadows et al., 2008; Mickle, 2010). These genetic differences may result in characteristics (e.g., faster growth rates, higher temperature tolerance, etc.) that lead to variable spawning strategies among river drainages. Kreiser and Schaefer (2009) found slight genetic distinctions between populations from the Mississippi River basin and coastal Gulf of Mexico drainages due to Alabama shad straying from their natal rivers, but only at a rate of about 10 migrants per generation.

Population viability analysis

Population viability analysis (PVA) is a modeling tool that estimates the future size and risk of extinction for populations of organisms (Coulson et al., 2001). A wide range of modeling approaches are used in PVA, from simple extrapolation of current trends to complex, individual-based models (Beissinger and McCullough, 2002). Software to conduct PVAs is widely available (e.g. RAMAS and Vortex), but models built specifically for a given species have also been utilized (Legault, 2005). Whatever approach is taken, the purpose is to predict the probability of the population persisting into the future, as population size has been shown to be the best predictor of extinction risk (O'Grady et al., 2004). However, PVA results should not be taken as absolute truth. Rather, PVA should be used as a tool to explore potential consequences of management actions in the light of an uncertain future. In this regard, we need to understand what is most uncertain about a particular case and be able to create plausible, but different, scenarios for examination.

Methods

Given the limited amount of data available for Alabama shad and the questions being asked, a sex-specific (females only), age-structured Leslie matrix model was developed in a commercially available software package (RAMAS Metapopulation; Akakaya 2005). Like most clupeids, Alabama shad have one annual spawning period and data on adults were collected before or during the spawning migration. Thus, a model using data in the form of a pre-breeding census (i.e. data collected just prior to the onset of spawning) was developed. This model implements a standard Leslie matrix (*L*) that provided age-specific inputs of fecundity (*Fx*) and survival (*Sx*):

$$L=\begin{pmatrix} F_1 & F_2 & F_3 & \dots \\ S_1 & 0 & 0 & \dots \\ 0 & S_2 & 0 & \dots \\ 0 & 0 & S_3 & \dots \end{pmatrix}$$

The population size (specified as a vector of abundance by age) from one time step (*N(t)*) to the next (*N(t+1)*) is given by:

$$N(t+1) = L(t)N(t)$$

Inputs to the model were derived from data available in the literature and through unpublished reports and personal communications (Table 1). Age at maturity was assumed to be 2 for females and fecundity at age was assumed to follow the relationship in Ingram (2007). Although a maximum age of 6 years was derived for fish in the Choctawhatchee River (Mettee and O'Neil 2003), maximum age was set at 4 years based on fish aged in the Apalachicola River (Ingram, 2007). As there are no estimates of mortality derived from fish in the wild, the instantaneous rate of natural mortality (converted to survivorship) for Ages 1-4 was estimated through four indirect life-history methods. Hoenig's (1983) method relies on estimates of longevity, whereas two of the methods (Pauly, 1980; Jensen, 1996) use parameters estimated through the von Bertalanffy growth model. The fourth method (Lorenzen, 1996) estimates M based on body mass. All required parameter estimates (i.e., age at maturity, L_{∞}, K, t_0) were taken from Ingram (2007). Body mass of Alabama shad at age was estimated by converting age into length through the growth model, and length into weight $_t$ (Ingram, 2007). To incorporate uncertainty into estimates of survivorship (age 1-4; S_1-S_4) and fecundity, we conducted Monte Carlo simulation by randomly selecting a set of inputs (e.g. weight, maximum age, K) from the probability density functions describing each individual trait. All simulations were run with Microsoft Excel spreadsheet software equipped with risk analysis and matrix algebra software and Microsoft Visual Basic. The mean and standard deviations from all simulations were used as inputs to the matrix of standard deviations that matched the dimensions of the Leslie matrix.

Estimates of survivorship from eggs to age 1 (S_0) were initially derived from estimates in Crecco et al. (1983) and Crecco and Savoy (1985) for American shad, *Alosa sapidissima*, in the Connecticut River. However, these values produced unrealistic estimates of population growth rates (λ) given values obtained for other *Alosa* species (e.g. ASMFC 2007; Harris, 2010). To accommodate for more realistic estimates of population growth, a simulation was constructed varying values of S_0 given inputs of fecundity and survivorship from age 1-4 until the population produced a stable distribution (J.E. Hightower, North Carolina State University, personal communication). We derived a value of 0.00025 for S_0 using this methodology, which is within the range of values of survivorship from eggs to larvae obtained for other teleost fishes (see review in Dahlberg 1979).

As habitat is the most likely limiting factor in population growth for Alabama shad, the baseline scenario specified density dependence as a ceiling model, where the population grows exponentially until reaching a ceiling population size (i.e., carrying capacity) and remains at that level (Akcakaya, 2002). We specified that all vital rates (survival and reproduction) were affected by density dependence in the model. However, scenarios were also examined assuming density dependence followed a Beverton-Holt stock recruitment relationship:

$$R(t)=R\max \cdot e^{(-\ln(R\max).N(t)K)},$$

where $R(t)$ is the population growth rate at time t, R_{max} is the maximum population increase rate, $N(t)$ is the abundance vector at time t, and K is the carrying capacity. The scenario assumed density dependence affected all vital rates in all ages of the matrix with $R_{max} = \lambda$.

While potentially viable populations of Alabama shad occur in the Escambia-Conecuh, Choctawhatchee, Suwanee, and Pascagoula river systems (see Distribution and Abundance), data on population size is only available from mark-recapture experiments in the Apalachicola River.

As shad appear to be philopatric to specific riverine basins, the PVA conducted was restricted to the Apalachicola-Chattahoochee-Flint River Basin. From 2005-2010, the migrating shad population in the Apalachicola River was estimated between about 2,368 and 98,469 spawning fish (Ely et al., 2008; Young, 2010). As populations of shad are known to fluctuate on an annual basis, the mean of these estimates (~12,400 returning female shad assuming a 1:1 sex ration) was used as a value of initial population size. We assumed the initial population was composed of a stable age distribution.

Estimates of carrying capacity were calculated from models developed from information on American shad stock sizes in the Connecticut River (St. Pierre, 1979; Hightower and Wong, 1997; Weaver et al., 2003). These models determined a carrying capacity of 124/ha. Although this number is regarded as a benchmark for American shad restoration, these models did not take account the quantity or quality of spawning habitat or any other physical or environmental factor that could affect the population size (Hightower and Wong, 1997). Therefore, a sensitivity analysis was run using a revised estimate of 49/ha (Harris, 2010). Available habitat for spawning was taken from the Alabama Shad Restoration and Management Plan for the Apalachicola-Chattahoochee-Flint River Basin (2008). Currently habitat on the Flint and Chattahoochee River is about 603 and 620.5 ha, respectively. Sensitivity runs to test for recovery potential under various scenarios of increasing available habitat were performed. The most plausible scenario currently would be to allow fish passage on the Flint River, which only has 2 dams, as opposed to the Chattahoochee River that has 13 dams. According to the Alabama Shad Restoration and Management Plan for the Apalachicola-Chattahoochee-Flint River Basin (2008), approximately 4,470 ha could support spawning fish.

Stochasticity was incorporated into the model using both measurement error (surveys) and process error (vital rates). Measurement error was set by specifying a coefficient of variation (CV) of 0.3 to surveys. Actual values used in calculating new abundance vectors (N(t+1)) were randomly drawn from lognormal distributions with a mean of the value specified in the Leslie matrix and a standard deviation from the standard deviation matrix. Sensitivity tests were used to test for the effects of no correlation between the variability of vital rates, and the application of stochasticity to survival rates only.

Anthropogenic mortality from the outmigration though the Jim Woodruff Lock and Dam was incorporated into the model for juveniles and adults (age 1-4). During normal and drought years, shad returning to the Gulf of Mexico must pass through the turbines with an associated mortality. While this source of mortality is known, the magnitude of its effect is unknown. Thus a range of mortalities were tested as M=0.1, M=0.15, and M=0.2. As drought does not occur every year, the effect of mortality was assigned every 3rd year and every 2^{nd} and 3^{rd} year based on rainfall data from the US Army Corp of Engineers website (http://water.sam.usace.army.mil/acfframe.htm).

Since there are limited life history data, sensitivity tests were used to examine the effects of different values, usually describing the potential range of parameters. Scenarios used to test sensitivity to life history parameters included varying survival (ages 1-4) by 10%. Table 2 provides a summary of the range of baseline and sensitivity tests conducted. Each scenario was run 10,000 times to provide estimates of the range of possible values under the stochastic conditions specified. The result reported here is the estimated returning female population size as the proportional increase or decrease in the population after 20 years from the initial population size. Quasi-extinction rates were measured as the probability that less than 420 females will return at least once over 20 years. As we have no information on the historical size of the Alabama shad population in the Apalachicola-Chattahoochee-Flint River Basin, the value of 420 females was chosen as the approximate lowest measure (lower 95% confidence limit; Ely et al., 2008) determined for this population over the last 5 years.

PVA Results

In most scenarios, the proportion change in mean abundance from initial abundance was positive and averaged about 250% for positive scenarios (Figure 1). The scenarios where mean population abundance showed the greatest increase were for the scenario when survivorship of ages 1-4 was increased by 10% (scenario f). Conversely, the scenario that resulted in the greatest proportional decrease in abundance was when survivorship was decreased by 10% (scenario g). Scenarios where the proportional change was at or close to one included those scenarios with mortality (e.g. M=0.10 and 0.15 every 2nd and 3rd year) associated with the outmigration through the Jim Woodruff Lock and Dam (scenarios k, l, q, r). The number of returning females still increased even under limited mortality (mortality every 3rd year) from the outmigration through the Jim Woodruff Lock and Dam. In scenarios where anthropogenic mortality was highest, population scenarios indicated decreases of about 40% from initial.

The baseline model assuming a ceiling type density dependence and assuming a carrying capacity of 75,857 females, predicted the population to be approximately 23% of carrying capacity (124 fish/ha) after 5 years and 37% after 10 years (Figure 2). When introducing potential mortalities from passage through dams on the outmigration under different scenarios (M=0.1, M=0.15, M=0.2) the number of females was still 16-37% of current carrying capacity in 10 years. The only scenario that resulted in significant declines was under the highest level of mortality with the most occurring frequency.

Although scenarios with significant mortality resulting in negative proportional changes from initial abundance, only one scenario (g) that decreased survivorship resulted in the probability of median time to quasi-extinction that was 50% or higher during the 20 year projection (median time=14.5 years) (Figure 3). The remaining scenarios (m and s) with population declines did not drop below the quasi-extinction level more than 50% of the time throughout the scenario.

Distribution and Abundance

To evaluate the current distribution and abundance of Alabama shad, we conducted an extensive search of all publications, technical reports, and theses presently available. Because shad may be captured in surveys designed for other fish species and not reported, we surveyed scientists at Universities, state and federal facilities, and non-profit organizations throughout the Alabama shad's historic range for any recent recorded captures. Surveys were sent by e-mail and information was requested on capture dates, location, and number of Alabama shad captured, if available (Appendix 1). A summary of recent records compared with river systems where shad were historically reported is found in Table 3. Data by state is summarized below.

Alabama

Only five Alabama shad have been collected on five separate occasions from rivers in this state in the past 25 years (Mettee and O'Neil, 2003). In the Black Warrior River of Alabama, where the species was first described in 1896, the only other Alabama shad to be collected was found over one hundred years later in 1998 (Mettee and O'Neil, 2003). Despite the existence of a thorough historical fisheries record of the Cahaba River system, no recent captures of Alabama shad from the upper reaches of the Cahaba River are documented. Both the Pierson et al. (1989) general fish faunal survey of the river from 1983 to 1988 and the Onorato et al. (1998 and 2000) sampling from 1995 to 1997 found no Alabama shad present in the upper region of the Cahaba River. In fact, no Alabama shad have been collected since 1968 with the only previously record fish reported in the Cahaba River at Centreville, Alabama in 1965 (Onorato et al., 2000; Boschung, 1992).

Before several impoundments were constructed, numerous juvenile Alabama shad were recorded in the Alabama River in 1951, the late 1960s, and the early 1970s (Boschung, 1992; Mettee and O'Neil, 2003). Only two individuals have been caught in the Alabama River since, one in 1993 below Claiborne lock and dam and one in 1995 below Miller's Ferry lock and dam. The Alabama Division of Wildlife and Freshwater Fisheries conducted a year-long study in 2009. This study did not collect any Alabama shad. Currently Alabama shad is considered to be extirpated from this river drainage (Adams et al., 2000; Steve Rider, ALDWFF, pers. comm., December 2010).

Alabama shad were once prevalent in the Mobile River (Evermann and Kendall, 1897). Sampling in Mobile Bay in 1972 yielded no Alabama shad, and before that, only one (15.3 cm) was captured from Dog River in 1964 (Williams and Gaines, 1974; Boschung, 1992; Hammerson, 2007). Most recently, in February 2004, a single specimen (32.8 cm) was captured by the Alabama Department of Conservation and Natural Resources, Marine Resources Division in Heron Bay (adjacent to Mobile Bay), presumably making its upstream spawning migration (Kevin Anson, Alabama Marine Resources Division, pers. comm., January 2011). Though Alabama shad were once prevalent in the Mobile River basin, limited captures over the past 25 years indicate that no significant population remains and this species could be extirpated from this system.

Alabama shad have not been found in the Tombigbee River since the construction of the Tombigbee lock system in the waterway in 1901 (Mette and O’Neil, 2003). The last specimen to be captured from the Coosa River was in 1966 (Boschung, 1992), and no Alabama shad have been caught in the Tallapoosa River in the last decade (Freeman et al., 2001). Some studies indicate there are small populations of Alabama shad in the Choctawhatchee, Pea, and Conecuh Rivers in southern Alabama (Barkuloo et al., 1993; Adams et al., 2000; Mettee and O’Neil, 2003; Ely et al., 2008). However, only one Alabama shad was caught in the Conecuh River in 2010 by Alabama Department of Wildlife and Fisheries (Steve Rider, pers. comm., December 2010) and recent reports from Auburn University (Steve Szedlmayer, pers. comm., December 2010), US Geological Survey (Pat O'Neil, pers. comm., December 2010), and the Department of Environmental Management (Fred Leslie, pers. comm., December 2010) have found no Alabama shad in the rivers they sample in the state of Alabama. While some recent reports indicate few or no captures of Alabama shad in rivers where other studies report them (e.g. Mette and O’Neil, 2003), difference could be related to sampling bias as few fish faunal surveys are directed towards Alabama shad. Nevertheless, the species is listed by the state as “threatened” and is illegal to capture and obtain without proper permitting (Alabama Shad Restoration and Management Plan, 2008).

Arkansas

The Alabama shad is the only anadromous species potentially present in the state of Arkansas. Arkansas, being a non-coastal state, contains the only potential spawning populations of Alabama shad in the Mississippi River Basin. The species once occurred throughout the state, but Alabama shad have only been collected in five locations in the state over the last 100 years (Buchanan et al., 1999). It was first seen in the Ouachita River in 1869 (Daniels, 1860; Evermann, 1901). The species was also reported, though not officially sampled for, in the Washita River by Laurence and Yerger (1967). A compilation of 20 years of fish collection data from Arkansas riverine systems by Matthews and Robison (1988) indicated no records of Alabama shad. No Alabama shad were found in White River tributaries from 1972-1973 or 1981-1983 (Matthews, 1986). However, Buchanan et al. (1999) collected over 300 juvenile Alabama shad from the Ouachita River and the Little Missouri River between 1997 and 1998. Of the shad collected, he preserved 71 specimens and released over 100 juveniles. The Ouachita and Little Missouri Rivers may be the only rivers in Arkansas where spawning populations of Alabama shad still occur (Buchanan et al., 1999). During a six-year sampling period from 1996-2001, no Alabama shad were caught in the Red River (Buchanan et al., 2003). Although the Saline River in Arkansas is the only free flowing river left in the state, there have been no recent reports of Alabama shad (Buchanan et al., 1999). Throughout the year, Arkansas State University conducts general fish sampling in the state's rivers with no captures of Alabama shad being reported (Jennifer Bouldin, ASU, pers comm., December 2010)

Florida

Alabama shad were documented in Pensacola and reported in the Suwanee, Apalachicola, and Escambia rivers as early as 1900 (Evermann and Kendall, 1900). Today, the Apalachicola-Chattahoochee-Flint River (ACF) Basin likely contains the largest spawning population of Alabama shad within its range. In 2005, population estimates in the ACF Basin hovered around

26,000 individuals, but decreased to less than 10,000 in both 2006 and 2007 (Ely et al., 2008). However, in 2010, Young (2010) estimated the population has increased to approximately 98,469 (95% CI: 51,417-127,251) individuals. The Choctawhatchee, Pea, and Conecuh rivers, which extend north into Alabama state and drain into the Gulf of Mexico through Florida's panhandle, are believed to contain small spawning populations (Mettee and O'Neil, 2003; Young, 2010).

Sporadic sampling in the Suwannee River has shown that a few Alabama shad still use the river (Mettee and O'Neil, 2003), with the most recent collections (n=6) made by Mickle (2010). Historically, the Suwannee River has been the easternmost boundary of the Alabama shad's range and the species is not likely to be found in additional collections from rivers to the south and east (Herald and Strickland, 1946; McBride, 2000).

The last specimens to be collected in the Ochlockonee River was in 1977 below Jackson Bluff Dam (Swift et al., 1977), the fish was present in the Yellow and Shoal Rivers in 1961 and 1962 (Barkuloo et al., 1993), and two were captured in the Escambia River in 1954 (Bailey et al., 1954). In 2009 and 2010, Alabama shad were caught in the Escambia River by the U.S. Fish and Wildlife Service and made up 0.03% of the total catch (Eric Nagid, FFWCC, pers. comm., December 2010; Knight et al., 2010). The Florida Fish and Wildlife Conservation Commission also caught fifteen Alabama shad on the Withlacoochee River in late November 2010 (Eric Nagid, FFWCC, pers. comm., December 2010). Though Alabama shad are present in most major rivers throughout the Florida panhandle, Florida's Comprehensive Wildlife Conservation Strategy considers their population to be low and declining as of 2005 (Alabama Shad Restoration and Management Plan, 2008).

Georgia

While there are few studies available for the species in this state, some of Georgia's southern rivers contain small numbers of spawning Alabama shad each year. Alabama shad were known to have migrated up the Chattahoochee River to Walter F. George Reservoir in the early 1970s, though many dams block their passage today (William Shelton, University of Oklahoma, pers. comm., December 2010). Individuals have been reported in the Chattahoochee River and the Flint River in recent years (2008-2010) by the Georgia Department of Natural Resources (Alabama shad Restoration and Management Plan, 2008; Travis Ingram, GDNR, pers. comm., December 2010). Approximately 16,000 fish were said to have moved into the Flint River in the spring of 2010 (Young, 2010). The U.S. Army Corps of Engineers has reported Alabama shad in Lake George W. Andrews in the Chattahoochee River during recent sampling of the area (Tyrone Ragan, USACE, pers. comm., December 2010). These fish migrate into Georgia during spawning runs via the Apalachicola River in Florida. Using the Natural Heritage Program (NatureServe, 2005), the Alabama shad is listed as "threatened" on Georgia's list of protected species as of February 2007 (Alabama Shad Restoration and Management Plan, 2008).

Illinois

While there are historic records of shad within the state's rivers (Scott Yess, USFWS, pers. comm., December 2010), the historic abundance of Alabama shad in Illinois is not known. Alabama shad now appear to have been extirpated from many Illinois Rivers and are considered rare in the state. The Wabash River was said to have a "very limited number" of Alabama shad in its waters even in the mid-1800s (Daniels, 1860). In a thorough report of the biodiversity of the state's rivers and streams, Page et al. (1991) found no evidence of Alabama shad. Burr et al.

(1996) reported two juvenile Alabama shad, one (7.69 cm) near the mouth of the Marys River in 1994 and one (7.54 cm) in the Grand Tower in Devils Backbone Park in 1995. These two captures support the hypothesis that some adult shad were able to spawn in these areas during that time. Before these two captures, the last Alabama shad to be captured in Illinois was a juvenile (6.62 cm) in 1962 from the Mississippi River (Burr et al., 1996). A species richness study conducted by Koel (2004) indicates that the Upper Mississippi River (UMR) in the state of Illinois does not support Alabama shad. The Upper Mississippi River Conservation Committee also indicated that there are only historic records of Alabama shad in the UMR, and none have been caught in the last ten years (Steuck et al., 2010). Lastly, annual field studies conducted by Illinois State University in the Illinois River and the UMR have resulted in no additional records of Alabama shad (Mike Retzer, ISU, pers.comm., December 2010).

Iowa

Alabama shad are considered extirpated from the state of Iowa, though historically the species reached portions of eastern Iowa via the Upper Mississippi River. In 1915, 48 Alabama shad were collected from the Keokuk River and it was reported that some of these fish were able to make it past the Keokuk Dam, further upstream (Coker, 1928). In the Upper Mississippi River, Alabama shad were recorded in the 1994 Annual Status Report: A Summary of Fish Data in Six Reaches of the Upper Mississippi River, a report compiled by USGS, Minnesota DNR, Wisconsin DNR, Iowa DNR, Illinois Natural History Survey, and the Missouri Department of Conservation; however no specific (i.e., number of fish caught, gear used, area etc) were provided (Gutreuter et al., 1997). Presently, there are ten locks and dams on the Upper Mississippi River (north of the confluence with the Ohio River) that border the state and an additional seven locks and dams south of the state that would prevent Alabama shad from reaching historic spawning grounds within Iowa (Steuck et al., 2010). The Iowa Department of Natural Resources has collected no Alabama shad in the Upper Mississippi River in the areas between lock and dam #16 and lock and dam #19 in the last 25 years (Bernard Schonhoff, IADNR, pers. comm., December 2010).

Louisiana

Alabama shad are only caught sporadically in the state of Louisiana, and there is limited data for the fish in its rivers. Historic data indicates some Alabama shad were collected between 1976 and 1988 in the Bogue Chitto River in western Louisiana, but none have been recorded within the river since (Stewart et al., 2005). No Alabama shad were captured in a thorough aquatic habitat study of the Lower Mississippi River performed by the U.S. Army Corps of Engineers that extended from Louisiana into Mississippi (Pennington et al., 1980). In the Thibodaux Weir on Bayou Lafourche, between Donaldsonville and Raceland, Louisiana, a single Alabama shad (42.8 cm) was caught using a gillnet in March of 2006 (Dyer 2007).

In areas around New Orleans, no Alabama shad were caught in the Tangipahoa tributary of Lake Pontchartrain in 1994 (Knight and Hastings, 1994) and no specimens were collected in Lake Pontchartrain between 1996 and 2000. However, individuals were collected in Lake Maurepas from 1983 to 1984 and in 2009 using trawl and gillnets, indicating that some fish still pass through Lake Pontchartrain (Hastings et al., 1987; O'Connell et al., 2004; O'Connell et al., 2009). Records of Alabama shad in the Pearl River system are fairly complete and show a steady decline of the species. Consistent sampling occurred in several sections of the river: 16.1 km of the river above and below Bogalusa, La. for 25 years, a 64.4 km section of the West Pearl

River for 16 years, and 64.4 km portion of the East Pearl River for 16 years. From 1963 to 1965, 384 Alabama shad were caught in all sections of the river, the next fourteen years only produced 33 Alabama shad, and in a nine-year period (1979-1988) only one Alabama shad was caught in the Pearl River (Gunning and Suttkus, 1990).

Three Alabama shad were caught in Louisiana just west of Atchafalaya Bay between 1992 and 1996 by the Louisiana Department of Wildlife and Fisheries (Brain Alford, LDWF, pers. comm., December 2010). However, no records of shad have been reported in recent years in annual fish surveys conducted by several of the state's universities in the Pearl River (Hank Bart, Tulane University; William Kelso, Louisiana State University, pers. comm., December 2010) and US Geological Survey in other Louisiana streams and rivers (Charlie Demas, pers. comm., December 2010).

Mississippi

Studies indicate that the only Alabama shad present today in the state of Mississippi occur in the Pascagoula, Leaf, and Chickasawhay Rivers (Schaefer et al., 2006; Mickle et al., 2010; Mickle, 2010). The Leaf and Pascagoula Rivers contain the highest populations of Alabama shad in the state of Mississippi due to their unimpounded waters and variety of habitats, while the populations in the Chickasawhay River are smaller (Mickle et al., 2010; Mickle, 2010). Outside these rivers, data shows a slow and steady decline of the species in Mississippi. In the Bogue Chitto River system, numbers have decreased since 1971 and the species is now considered extirpated from the Bogue Chitto River (Stewart et al., 2005). Studies conducted by Tulane University have not captured Alabama shad in the Pearl River system, upstream and downstream from Monticello, Mississippi, throughout the 1970s and 1980s. Historical records document 300 captures of Alabama shad from 1963 to 1965 within the Pearl River (Gunning and Suttkus, 1990). Small numbers of Alabama shad were caught in Black Creek in the late 1990s and prior to that in 1986 (Adams et al., 2000). Although historically present in the Tombigbee River in the northeastern part of the state, recent records indicate Alabama shad no longer occupy that system (Mettee and O'Neil, 2003). Alabama shad historically used the Mississippi River as a means to reach many of its tributaries, but none have been found in the lower portion of the waterway in recent years. Technical reports conducted by the U.S. Army Corps of Engineers on the Lower Mississippi River (north of Baton Rouge, La.) in the early 1980s show a slow decline in the number of adult and juvenile Alabama shad (Pennington et al., 1980; Conner et al., 1983; Jack Killgore, USACE, pers. comm., December 2010).

Missouri

The Lower Missouri River and its tributaries, located in the center of the state, probably supported the greatest number of Alabama shad for the state, though the records are limited (Kevin Dacey and Harold Deckerd, Natural Resources Conservation Commission, pers. comm., December 2010). A study determining the habitat use of juvenile fish in the Lower Missouri River indicated no Alabama shad were present between 1987 and 1988 (Brown and Coon, 1994). However, Galat et al. (2005) recorded the presence of the species in the Lower Missouri River in 2005, and claimed that Alabama shad are rare in the Ozark Plateaus region in southern Missouri. In 2005, the Missouri Department of Conservation (Phil Pitts, pers. comm., December 2010) captured five Alabama shad from the lower Gasconade River, but as of 2009 Missouri Department of Conservation had not collected any additional shad (Nick Girondo, pers. comm., December 2010; Kevin Dacey, Missouri Natural Resources Conservation Commission, pers.

comm., December 2010).

In the Upper Mississippi River, north of the confluence with the Ohio River and along Missouri's eastern border, Alabama shad were recorded in the 1994 Annual Status Report: A Summary of Fish Data in Six Reaches of the Upper Mississippi River, a report compiled by USGS, Minnesota DNR, Wisconsin DNR, Iowa DNR, Illinois Natural History Survey, and the Missouri Department of Conservation but specifics (i.e., number of fish , gear type used, size etc.) were not reported (Gutreuter et al., 1997). No shad were captured in the same area (rkm 45-129) between 1993-2001 and 1994-2000 (Barko and Herzog, 2003; Barko et al., 2004b). In 2010, the Missouri Department of Conservation determined that Alabama shad is "imperiled" throughout the state (Steuck et al., 2010). In addition, the January 2011 Missouri Species and Communities of Conservation Concern Checklist lists Alabama shad as an "Imperiled" species, meaning that there are less than 3,000 individuals remaining due to "factors making the species vulnerable to extirpation from the state" of Missouri (Robert Hrabik, Missouri Department of Conservation Resource Science Division, pers. comm., December 2010).

Ohio

Although the species was present and abundant enough to support a small and brief commercial fishery during the late 19th century and early 20th century in Ohio (Daniels, 1860), by 1989 the majority of Alabama shad had been extirpated from the Ohio River (Pearson and Pearson, 1989). The United States Geological Survey in the state has not collected any Alabama shad from the Ohio River since 1993 (John Tertuliani, USGS, pers. comm., December 2010) and the United States Fish and Wildlife Service in the state has no records of Alabama shad in their database (Jeromy Applegate, USFWS, pers. comm., December 2010). Barko's study (2004b) in the Upper Mississippi River, near the confluence of the Ohio and Missouri Rivers, found no Alabama shad between 1994 and 2000. Thus, there have been no recorded captures of Alabama shad in the Ohio River system in over 15 years.

Oklahoma

The status and presence of Alabama shad in Oklahoma is unclear. The first collections in the state were from the Illinois River, when 47 fish were taken in 1950 (Moore, 1973). A few specimens were captured from the Poteau River in the same decade, but it is unknown if the species was ever established in the river (Lindsey et al., 1983). Thirty years later, in a study on the effects of land alterations on fish assemblages, Rutherford et al. (1992) found no shad in the Little River. Presumably, Alabama shad are no longer able to reach their former spawning grounds in the Little River due to degradation of river habitat as a result of land modification (Buchanan et al., 2003). No Alabama shad were collected from Lake Texoma or any of its adjoining rivers (Red and Washita Rivers) between 1948 and 1958 (Riggs and Bonn, 1959). The Denison Dam likely resulted in the extirpation of this species from these areas. The Altus Dam also likely expedited the extirpation of the species from Red River tributaries, including the North Fork (1978-1987), Brier Creek (1969-1986), and Kiamichi River (1981-1986), all which contain no Alabama shad (Winston et al., 1991; Matthews et al., 1988). In recent years the University of Oklahoma has not collected Alabama shad during their general river and stream diversity surveys conducted throughout southeast and central Oklahoma (Greg Summers, William Mathews, and William Shelton, University of Oklahoma, pers. comm., December 2010). No additional studies indicate the presence of Alabama shad in any other Oklahoma river.

Tennessee

Despite increased sampling in the 1970s and 1980s, there was an apparent decline in Alabama shad numbers. Accordingly, Tennessee recognized in 1980 that Alabama shad required improved management (Adams et al. 2000). Although the species was once present in the Clinch and Stone Rivers, no collections of Alabama shad had been made in these systems after 1993 (Hammerson 2007). Presently, there have been no observations or collections of the species in Tennessee rivers (James Widlak, U.S. Fish and Wildlife Service, pers. comm., December 2010).

Indiana

No recent studies have been conducted and no Alabama shad have been recorded in Indiana river systems (Darrell Nicholson, Natural Resources Conservation Service, pers. comm., December 2010).

Kentucky

The last observation of Alabama shad in Kentucky was in 1995 (Ryan Evans, Kentucky State Nature Preserves Commission, pers. comm., December 2010).

Texas

No Alabama shad have been recorded in any Texas river (Tim Grabowski, USGS, pers. comm., December 2010).

Discussion and Conclusions

Alabama shad has declined, and in some cases, has been extirpated from portions of its historical range (Figure 4). Historically, the species once reached into freshwater systems as far inland as eastern Oklahoma, Iowa, and West Virginia. Present distributions extend up the Mississippi River drainage into eastern Arkansas and central Missouri. Alabama shad are found in some Gulf coast drainages, but are thought to be extirpated from those drainages west of the Pascagoula River in Mississippi (Adams et al., 2000; Mettee and O'Neil, 2003). The majority of states falling within the historical range of the species contain fewer Alabama shad today than that which is indicated in historic records (Figures 5-13).

The decline and fragmentation of the Alabama shad population has likely been due to the modification and impoundment of riverine systems. Almost all rivers in the United States are modified in some way with locks, dams, navigational passages, and levees which all have impacts on the environment, including: disruptions in water flow, benthic topographical changes, and water temperature fluctuations. The construction of these water modification projects increased rapidly in the 1930s due to the Flood Control Act of 1928, but continues today (Benke, 1990; Baker et al., 1991). In fact, most of the rivers within the species' historic range have been impounded, especially those over 1000 km in length. Since Alabama shad migrate far upstream to spawn, their vulnerability to the affects of habitat modification is more severe (McDowall, 1999).

While Alabama shad have undergone fragmentation and reductions in abundance, the results from this study suggest that the current range of Alabama shad is stable, with populations in some riverine systems possessing the capability to increase. Surveys conducted herein suggest that Alabama shad spawning populations persist in the Suwannee River, Apalachicola-

Chattahoochee-Flint River Basin, Choctawhatchee River, Escambia River, and Pascagoula River (Figure 4d). While population estimates are only available for the Apalachicola River, the 2010 population size was the highest determined over a 5-year monitoring period.

An increase in abundance of Alabama shad in the Apalachicola River could be due to any number of reasons, as *Alosa* species often have wide fluctuations in populations (Gibson and Myers, 2003). However, beginning in 2008 the locks on the Jim Woodruff Lock and Dam were left open during certain times of the day that allowed passage of fish upstream and enabled the species to reach their historical spawning habitat in lower sections of the Chattahoochee and Flint Rivers. Increased water flow in South Georgia and North Florida may have also supported better recruitment for the species and could have been significant enough to increase the population size in the Apalachicola, Chattahoochee, and Flint River Basin (Young, 2010).

Alabama shad populations could increase if favorable environmental conditions are restored throughout its range. Potential spawning habitat exists on the Suwannee River, Choctawhatchee River, and Pascagoula River and efforts are underway to restore these habitats and advance the unabated passage of fish upstream as part of the Gulf sturgeon (*Acipenser oxyrinchus desotoi*) recovery plan (USFWCC and GSMFC, 1995). Gulf sturgeon is listed as "threatened" under the Endangered Species Act. Alabama shad and Gulf sturgeon are both anadromous fish that occur in some of the same spawning rivers; consequently any fish passage efforts targeting Gulf sturgeon would likely be beneficial to Alabama shad.

Alabama shad is listed on NMFS Species of Concern List and some states have enacted conservation plans for Alabama shad. Illinois recommended that the species be protected as early as 1996 under the state's rare fishes list and the species is also protected in Georgia under a similar endangered and threatened list (Burr et al., 1996; Pringle, 1997). In Florida, gillnetting in rivers was reduced in 1992 because of the regulation for increased mesh size to prevent the capture of striped bass (*Morone saxatilis).* In 1997 Florida implemented regulations prohibiting the harvest of *Alosa* species with any other gear besides hook and line. The Alabama Division of Wildlife and Freshwater Fisheries lists the Alabama shad on their Nongame Species Regulation, which acts as the state's rare and endangered species list (Rider et al., 2010).

The population viability simulation experiments indicated that juvenile survivorship and increased habitat availability are the most important variables for the prospects of the population. Increasing survivorship by only 10% resulted in the largest proportion change in mean abundance. After spawning, adult fish spend a considerable portion of their life cycle at sea where almost nothing is known regarding survivorship. Current fishing mortality is assumed to be negligible as there are no directed fisheries for shad. Gillnets have been banned off Florida's coast since 1994 and gillnet use has been limited in Alabama, Mississippi, and Louisiana. However, until a better understanding of their marine survivorship is obtained, their capability to fully increase in abundance will remain uncertain.

The level of mortality associated with the outmigration of shad through the Jim Woodruff Lock and Dam was a significant factor effecting population increase. While the current levels of mortality are unknown, the proportion lost to passage through the turbines was set at levels determined for American shad (~17%; Steven Herrington, Nature Conservancy, pers. comm., January 2011). Moreover, periods of drought, while cyclic in nature, may increase or decrease the levels of mortality over time. A better understanding of the levels and sources of mortality while fish are found within their riverine habitats will be essential elements in the species strategy for recovery.

When examining potential scenarios for the recovery of a species, other features besides abundance and mortality must be considered. In the case of Alabama shad, the distribution of fish among rivers is an important attribute that mitigates against catastrophic risks and provides diversity within the population. Current data suggest Alabama shad are philopatric to certain riverine basins that could lead to the potential for genetic bottlenecks. Similarly, while management options have examined the potential for hatchery stocking of natural populations (Alabama Shad Restoration and Management Plan, 2008), supplementation of natural stocks may in fact be detrimental to natural populations (e.g., Fleming and Peterson, 2001).

Results from this study indicate that Alabama shad do meet the criteria outlined in the Species of Concern list (71 CFR 55431). Alabama shad are limited in their distribution and their population has declined from historic levels. However, the potential for recovery of this species is high especially in systems that are unimpounded or where management actions have already allowed upstream passage of fish (e.g. Jim Woodruff Lock and Dam). Our PVA model predicts that the Alabama shad population in the Apalachicola-Flint-Chattahoochee river system is increasing and under present conditions could reach carrying capacity in about 40 years. Further mitigating actions independent or through other species recovery plans (i.e. Gulf sturgeon) for the enhanced movement of fish upstream will foster the recovery of Alabama shad. Owing to their higher productivity coupled with research and management options derived herein, this species would have a faster recovery potential than other species of concern (e.g. Atlantic sturgeon, *Acipenser oxyrinchus oxyrinchus*). For example, after only a few years of enhanced upstream passage on the Apalachicola River, the numbers of returning fish have dramatically increased from the 5-year average. Positive results such as these provide incentives to advance research and develop management plans to enable the species to increase in abundance and re-occupy historic systems.

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Table 1. Inputs parameters used in the Alabama shad population viability analysis. Values in parenthesis are estimates of standard deviation used in the Leslie matrix.

Parameter	Value	Source
Age 0 survivorship (So)	0.00025	This study
Age 1 survivorship (S1)	0.27 (0.03)	Ingram (2007)
Age 2 survivorship (S2)	0.28 (0.03)	Ingram (2007)
Age 3 survivorship (S3)	0.29 (0.03)	Ingram (2007)
Age 4 survivorship (S4)	0.29 (0.03)	Ingram (2007)
F1	44309.2 (10088.8)	Ingram (2007)
F2	47949.1 (10541.0)	Ingram (2007)
F3	48540.1 (10607.5)	Ingram (2007)
Initial population size	12,400 females	Ely et al. (2008); Young (2010), T. Ingram, personal communication.
Carrying capacity (K)	75,867 females (767)	Alabama Shad Restoration and Management Plan for the Apalachicola-Chattahoochee-Flint River Basin (2008)

Table 2. Summary of baseline and sensitivity tests for Alabama shad population viability analysis.

Scenario	Description
Baseline	No anthropogenic mortality Density dependence effects all vital rates Current carrying capacity (124 fish/ha)
Sensitivity	
a	No anthropogenic mortality Beverton-Holt stock-recruitment relationship Density dependence all vital rates Current carrying capacity (124 fish/ha)
b	No anthropogenic mortality Density dependence all vital rates Current carrying capacity (49 fish/ha)
c	No anthropogenic mortality Density dependence effects survivorship Current carrying capacity (124 fish/ha)
d	No anthropogenic mortality Density dependence effects fecundity of females Current carrying capacity (124 fish/ha)
e	No anthropogenic mortality Density dependence effects all vital rates Current carrying capacity (124 fish/ha) No correlation between the variability of vital rates
f	No anthropogenic mortality Density dependence all vital rates Current carrying capacity (124 fish/ha) Increase in survivorship
g	No anthropogenic mortality Density dependence all vital rates Current carrying capacity (124 fish/ha) Decrease in survivorship
h	Outmigration mortality=0.1 every 3rd year Density dependence all vital rates Current carrying capacity (124 fish/ha)

i	Outmigration mortality=0.15 every 3rd year Density dependence all vital rates Current carrying capacity (124 fish/ha)
j	Outmigration mortality=0.2 every 3rd year Density dependence all vital rates Current carrying capacity (124 fish/ha)
k	Outmigration mortality=0.1 every 2nd and 3rd year Density dependence all vital rates Current carrying capacity (124 fish/ha)
l	Outmigration mortality=0.15 every 2nd and 3rd year Density dependence all vital rates Current carrying capacity (124 fish/ha)
m	Outmigration mortality=0.2 every 2nd and 3rd year Density dependence all vital rates Current carrying capacity (124 fish/ha)
n	Outmigration mortality=0.1 every 3rd year Density dependence all vital rates Increased carrying capacity (124 fish/ha)
o	Outmigration mortality=0.15 every 3rd year Density dependence all vital rates Increased carrying capacity (124 fish/ha)
p	Outmigration mortality=0.2 every 3rd year Density dependence all vital rates Increased carrying capacity (124 fish/ha)
q	Outmigration mortality=0.1 every 2nd and 3rd year Density dependence all vital rates Increased carrying capacity (124 fish/ha)
r	Outmigration mortality=0.15 every 2nd and 3rd year Density dependence all vital rates Increased carrying capacity (124 fish/ha)
s	Outmigration mortality=0.2 every 2nd and 3rd year Density dependence all vital rates Increased carrying capacity (124 fish/ha)

Table 3. Recent records (since 2000) of Alabama shad as reported by personal communication. Data is summarized by state and historic distribution. References to specific data are found in the text. Number is the number of individuals reported by year (in parentheses). If the number of Alabama shad collected was not recorded (i.e. presence/absence data only), the information is considered unavailable.

State	River	Historic	Present	Number
Alabama	Alabama	Yes	No	--
	Black Warrior	Yes	No	--
	Cahaba	Yes	No	--
	Conecuh	Yes	Yes	11 (2000) and 1 (2010)
	Coosa	Yes	No	--
	Choctawhatchee	Yes	Yes	400 (2000)
	Mobile Bay	Yes	Yes	1 (2004)
	Pea	Yes	Yes	Unavailable
	Tallapoosa	Yes	No	--
	Tombigbee	Yes	No	--
Arkansas	Little Missouri	Yes	No	--
	Ouachita	Yes	No	--
	Red	Yes	No	--
	Saline	Yes	No	--
	Washita	Yes	No	--
	White	Yes	No	--
Florida	Apalachicola	Yes	Yes	Population estimate=98,000 (2010)
	Choctawhatchee	Yes	Yes	Unavailable
	Conecuh	Yes	Yes	Unavailable
	Escambia	Yes	Yes	Unavailable
	Ochlockonee	Yes	No	--
	Pea	Yes	Yes	Unavailable
	Suwannee	Yes	Yes	6 (2010)
	Withlacoochee	Yes	Yes	13 (2010)
Georgia	Chattahoochee	Yes	Yes	Unavailable
	Flint	Yes	Yes	Population estimate=16,000 (2010)

Illinois	Marys	Yes	No	--
	Upper Mississippi	Yes	No	--
Iowa	Keokuk	Yes	No	--
	Upper Mississippi	Yes	No	--
Louisiana	Bouge Chitto	Yes	No	--
	Lake Maurepas	Yes	Yes	Unavailable
	Lake Pontchartrain	Yes	Yes	Unavailable
	Lower Mississippi	Yes	No	--
	Pearl	Yes	No	--
	Tangipahoa	Yes	No	--
	Thibodaux Weir	Yes	Yes	1 (2006)
Mississippi	Black Creek	Yes	No	--
	Bouge Chitto	Yes	No	--
	Chickasawhay	Yes	Yes	24 (2004-2006)
	Leaf	Yes	Yes	200 (2004-2006)
	Lower Mississippi	Yes	No	--
	Pascagoula	Yes	Yes	307 (2004-2007)
	Pearl	Yes	No	--
	Tombigbee	Yes	No	--
Missouri	Gasconade	Yes	Yes	5 (2005)
	Lower Mississippi	Yes	No	--
	Lower Missouri	Yes	Yes	Unavailable
Ohio	Ohio	Yes	No	--
	Upper Mississippi	Yes	No	--
Oklahoma	Briar Creek	Yes	No	--
	Illinois	Yes	No	--
	Kiamichi	Yes	No	--
	Lake Texoma	Yes	No	--
	Little	Yes	No	--
	North Fork	Yes	No	--
Oklahoma	Poteau	Yes	No	--
	Red	Yes	No	--
	Washita	Yes	No	--

Figure 1. Average proportion change from abundance at the end of the 20-year scenario to the initial abundance.

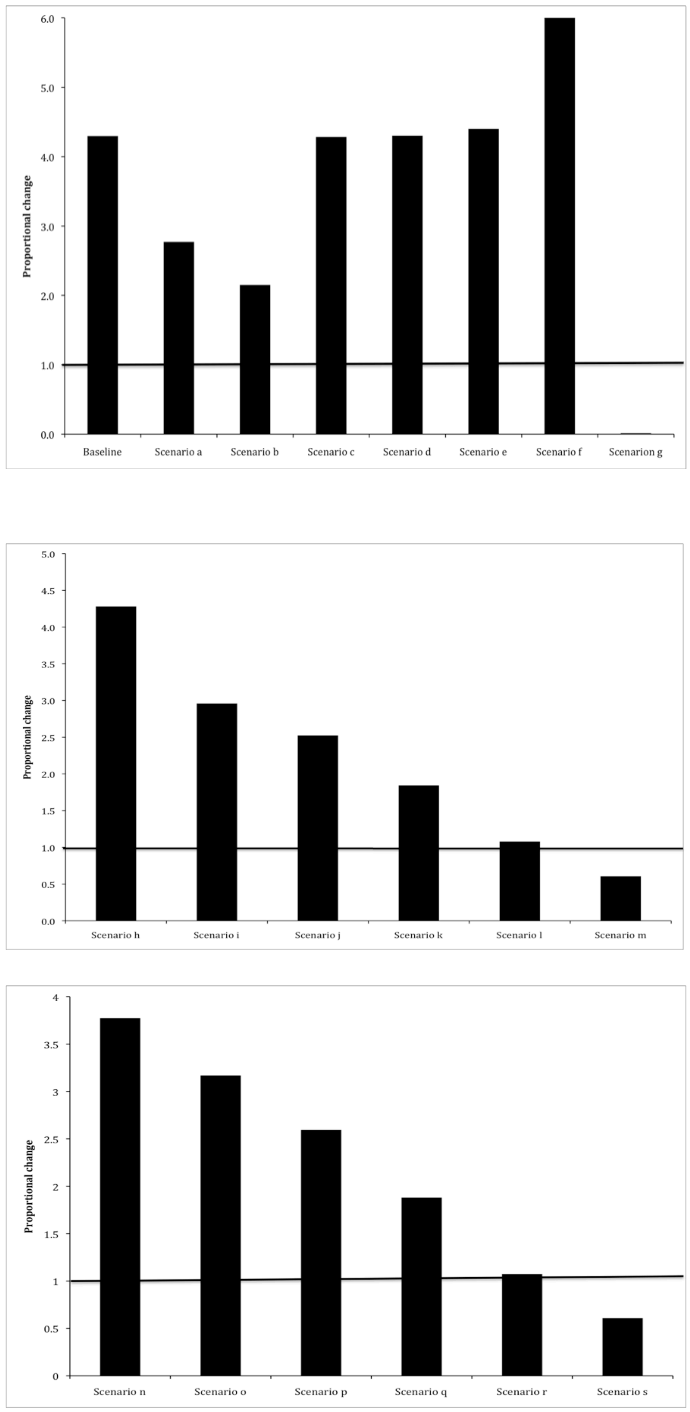


Figure 2. Population trajectories for all scenarios.

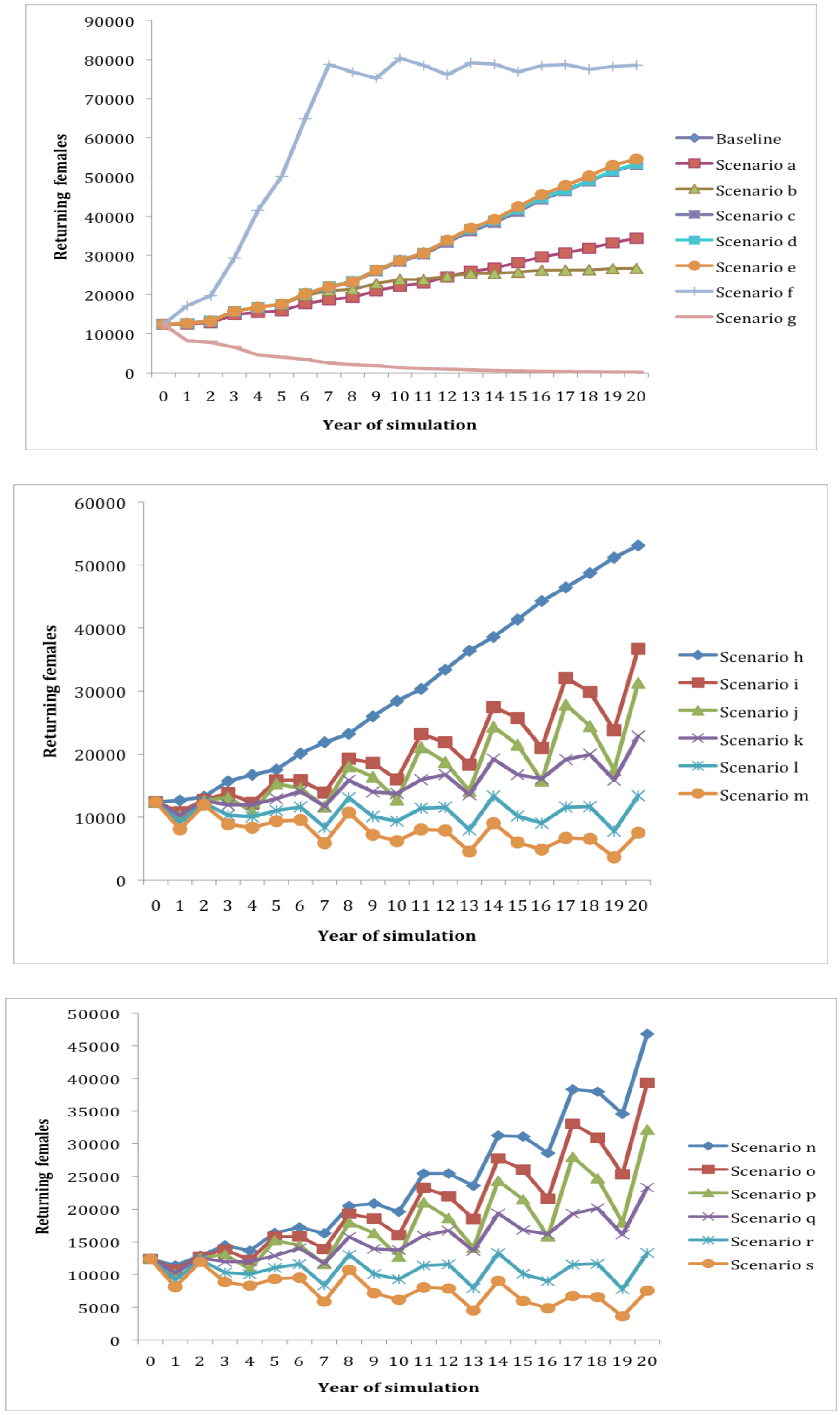
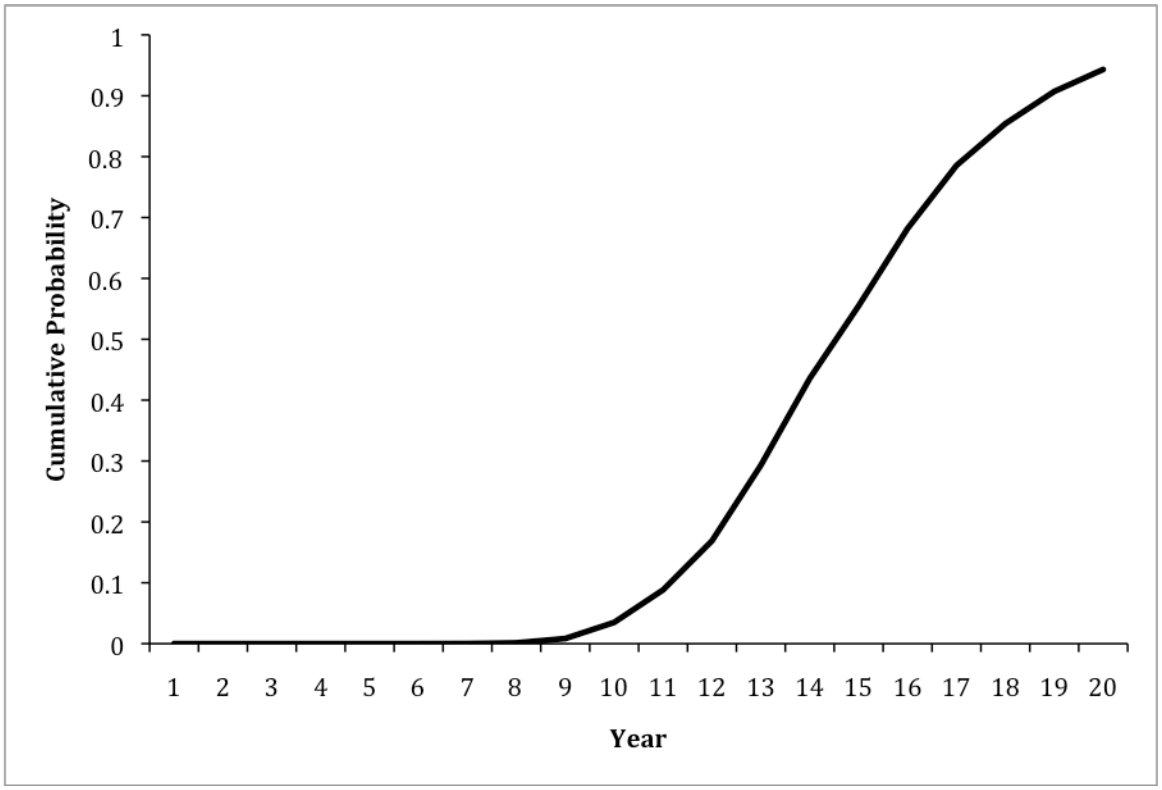


Figure 3. Cumulative probability of quasi-extinction, the predicted number of years that will pass before the population falls below the 420 females for scenario g.



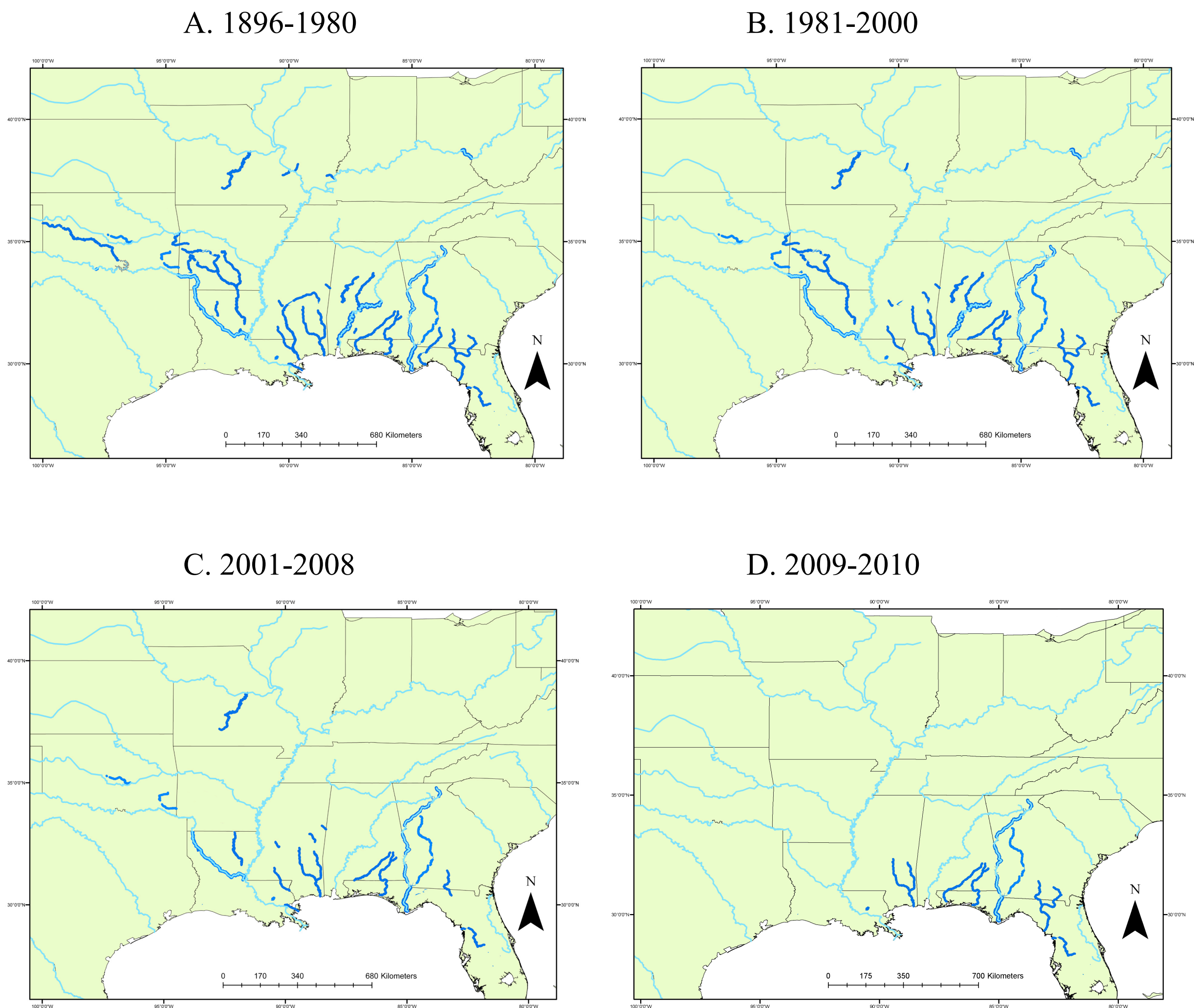


Figure 4. Historical distribution of Alabama shad from 1896-2010. Light blue lines depict the major rivers in the region of the United States shown, some of which might be used by Alabama shad to reach other, smaller tributaries. Dark blue lines indicate the rivers or areas in which Alabama shad have been found. It should be noted that the presence of Alabama shad may only be the result of capturing a few fish in any one system; therefore these maps should not be used as a means of determining abundance

Figure 5. The rivers in the state of Alabama where data (historic or present) have been collected for Alabama shad, indicated by blue lines.

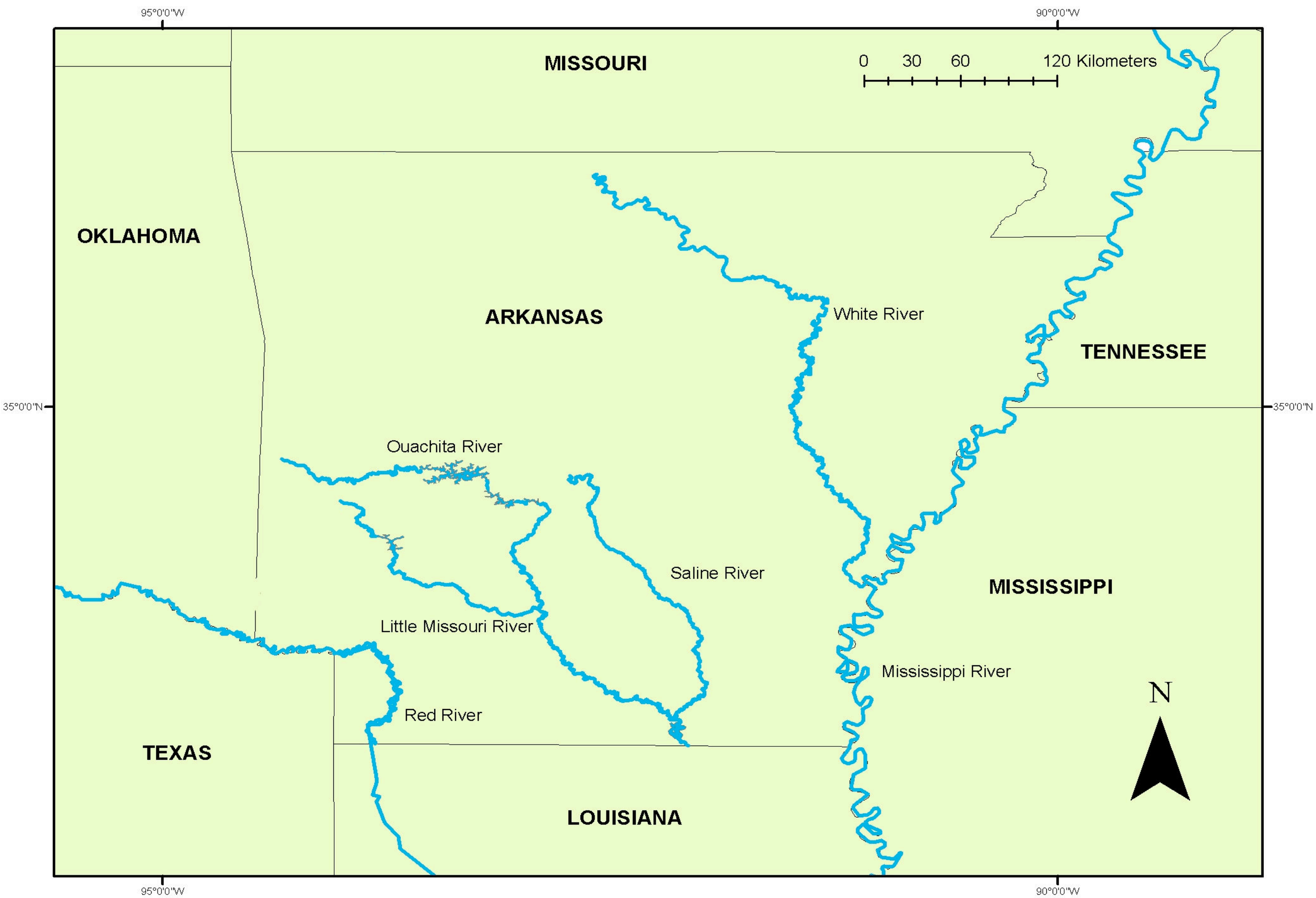


Figure 6. The rivers in the state of Arkansas where data (historic or present) have been collected for Alabama shad, indicated by blue lines.

Figure 7. The rivers in the state of Florida where data (historic or present) have been collected for Alabama shad, indicated by blue lines.

Figure 8 The Rivers in the state of Georgia where data (historic or present) have been collected for Alabama shad, indicated by blue lines.

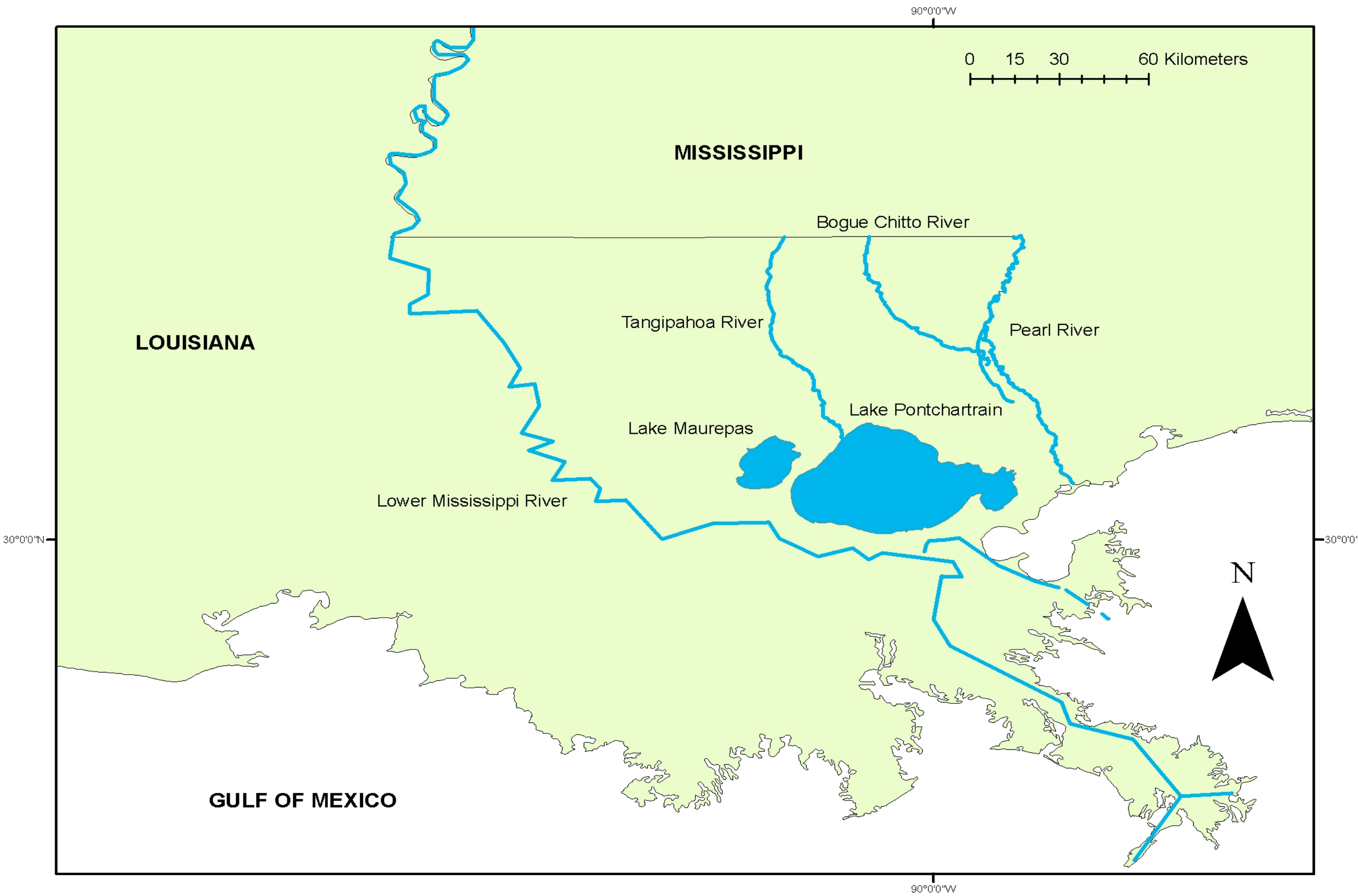


Figure 9. The rivers in the state of Louisiana where data (historic or present) have been collected for Alabama shad, indicated by blue lines.

Figure 10 The Rivers in the state of Mississippi where data (historic or present) have been collected for Alabama shad, indicated by blue lines.

Figure 11. The rivers in the state of Missouri and Illinois where data (historic or present) have been collected for Alabama shad, indicated by blue lines.

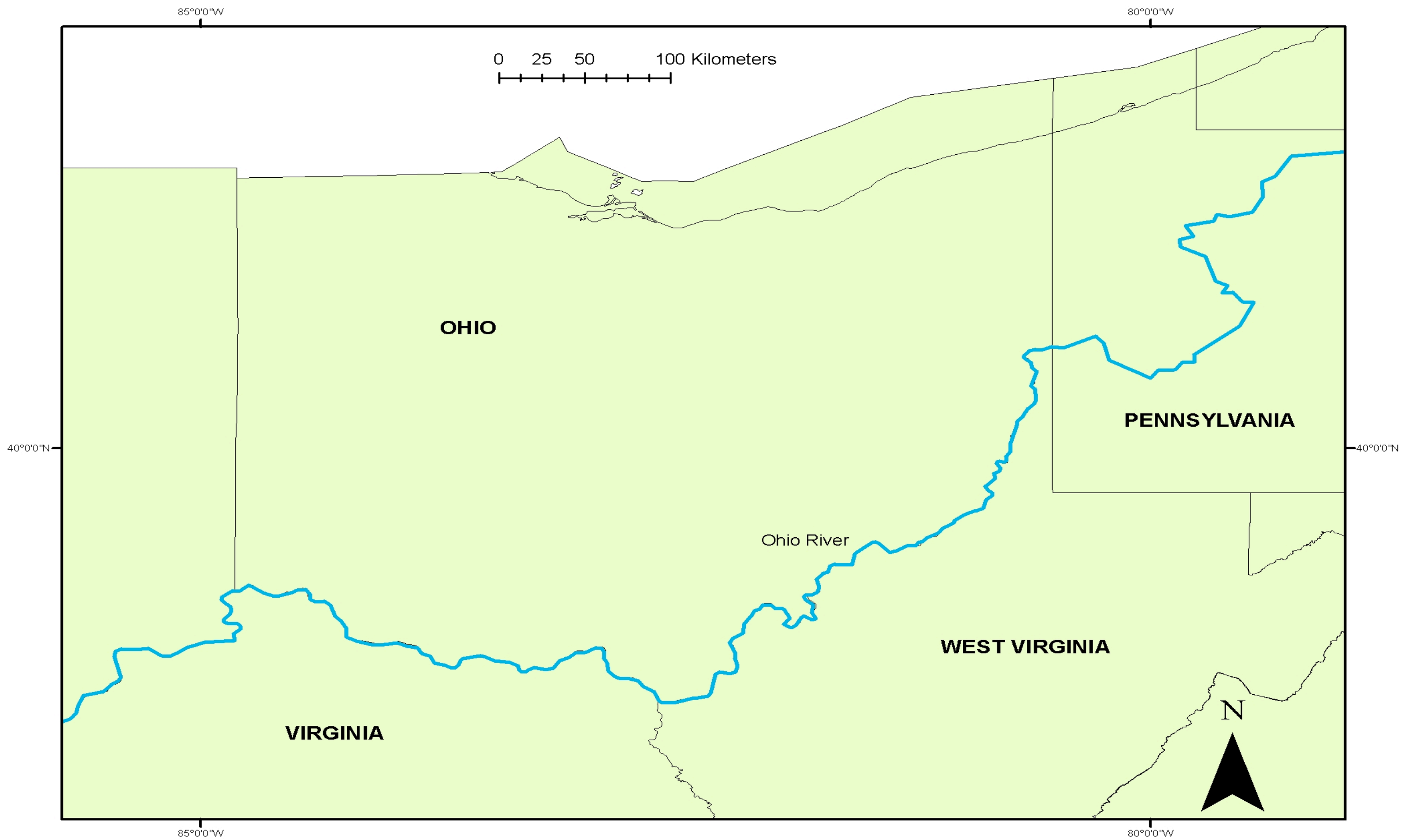


Figure 12. The rivers in the state of Ohio where data (historic or present) have been collected for Alabama shad, indicated by blue lines.

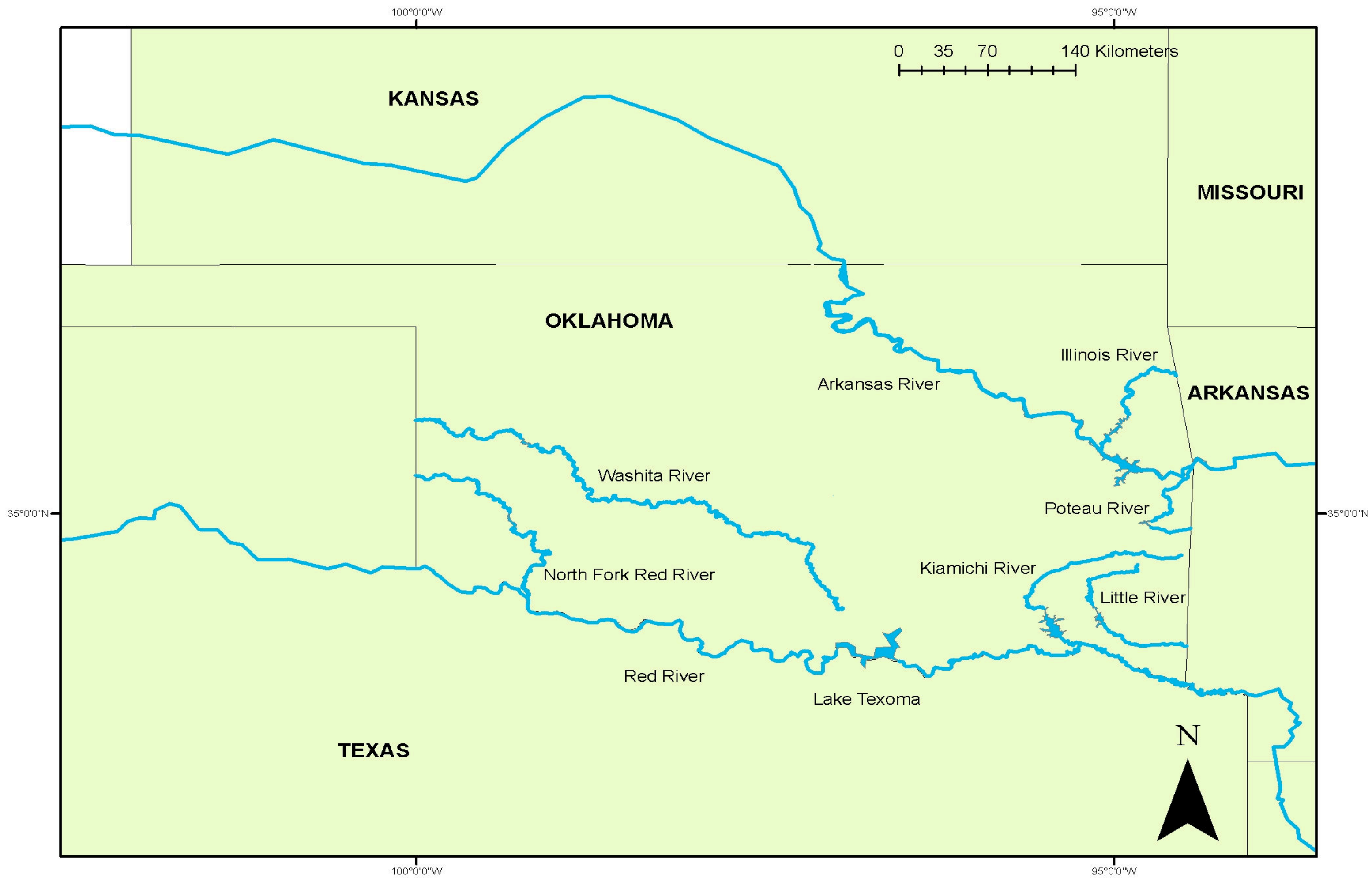


Figure 13. The rivers in the state of Oklahoma where data (historic or present) have been collected for Alabama shad, indicated by blue lines.

Appendix 1. Example of email sent to potential researchers requesting information on Alabama shad

Dear colleague

NOAA Fisheries Service is currently conducting a review of the status of Alabama shad (Alosa alabamae) as a Species of Concern. While there is some information available in the primary literature (e.g. Mickle et al. 2010) and in unpublished theses and reports (Ingram 2007), NOAA Fisheries is interested in any recent reports or surveys that have encountered Alabama shad or have recent information on its biology.

if you or any of your colleagues has information pertinent to Alabama shad, we would appreciate a response indicating the type of data or report available. Conversely, if your institution has not encountered Alabama shad in recent years. That information would be extremely useful as well.

Thank you and I look forward to hearing from you