Life History and Habitat Use of the Juvenile Alabama Shad (Alosa alabamae) in Northern Gulf of Mexico Rivers

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LIFE HISTORY AND HABITAT USE OF THE JUVENILE ALABAMA SHAD

(ALOSA ALABAMAE) IN NORTHERN GULF OF MEXICO RIVERS

by

Paul Fraser Mickle

Abstract of a Dissertation
Submitted to the Graduate School
of The University of Southern Mississippi
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy

December 2010
ABSTRACT

LIFE HISTORY AND HABITAT USE OF THE JUVENILE ALABAMA SHAD

(ALOSA ALABAMAE) IN NORTHERN GULF OF MEXICO RIVERS

by Paul Fraser Mickle

December 2010

The Alabama shad, Alosa alabamae, is an anadromous species that is in decline and has seen extirpations from impoundments as well as decreased water quality. Alabama shad live in the Gulf of Mexico and ascend Northern Gulf of Mexico Drainages to reproduce early in the year (January-May). The juveniles spend the majority of the year in these freshwater systems before emigrating out to the Gulf of Mexico as late as December.

This dissertation focuses on the juvenile life stages that occur within the Northern Gulf of Mexico drainages. Spawning conditions of the river, as well as the habitat and diet, are studied and documented. Habitat use of the juvenile Alabama shad shifted from sand bars to open channel and banks which was seen in progression as the juveniles increased in size and maturity. Important physicochemical parameters that influenced the presence of Alabama shad within these habitats ranged from temperature, flow velocity, and conductivity. Diet of the juvenile Alabama shad consisted of particulate detritus within Alabama shad <50mm and a host of terrestrial and aquatic insects as the Alabama shad matured. Hatch timing was documented between the drainages sampled from early January through March. Spring flows followed a falling trend with increasing temperatures.

These findings suggest that the management of these drainages should be done
independently on a drainage-by-drainage basis. Habitats are consistent between

drainages, but the physicochemical factors driving the presence of this species are unique
to each drainage. It is also suggested that maintaining natural flows for habitat

maintenance and reproductive cues is important toward conservation of the species.
LIFE HISTORY OF THE JUVENILE ALABAMA SHAD *ALOSA ALABAMAE* IN
NORTHERN GULF OF MEXICO RIVERS

by

Paul Fraser Mickle

A Dissertation
Submitted to the Graduate School
of The University of Southern Mississippi
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy

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Dean of the Graduate School

December 2010
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CHAPTER I
LIFE HISTORY AND HABITAT USE OF THE JUVENILE ALABAMA SHAD (ALOSA ALABAMAE) IN NORTHERN GULF OF MEXICO RIVERS

Abstract

In recent years Alabama shad (Alosa alabamae) have declined in abundance and been extirpated from portions of their native range. The Pascagoula River contains the only population remaining in Mississippi. Habitat degradation and barriers to migration are considered contributing factors to range contraction. Understanding and protecting the habitats that support Alabama shad is essential to preserving this rare species. I collected physicochemical data in three dominant habitat types (sandbar, open channel and bank) used by Alabama shad in June and October in three Northern Gulf of Mexico drainages: Pascagoula (2004-2007), Apalachicola (2007-2008), and Suwannee (2007-2008) rivers. I developed models from the data to identify parameters correlated with Alabama shad presence within each drainage. Understanding the recruitment needs of Alabama shad can provide important information in the management and conservation of this species.

Introduction

The life history and autecology of a species are fundamental determinants of population size and the potential for long term viability in the face of anthropogenic disturbances (Waite and Carpenter 2000; Kemp 2008). Conservation of habitat-specialist species through effective management practices requires an understanding of habitat use and biotic interactions over meaningful spatial and temporal scales (Owen and Karr 1978). For diadromous fish species, it is important to understand the ecological
interactions from a variety of disparate ecosystems encountered through successive ontogenetic stages (Limburg 2001). For example, studies have shown that anthropogenically increased temperatures and hypoxia have had negative effects on migration success of several diadromous species at different life stages. These anthropogenic changes add stresses that ultimately decrease reproductive success within populations (Bannon and Ling 2003).

Due to their linear and directional nature, river ecosystems do not fit within the traditional landscape ecology model. Much of the ecological work done in river systems has been on shorter spatial and temporal scales that do not account for unique properties of the riverscape (Fausch et al. 2002). Modern tools and larger datasets have allowed for a more integrative and complete understanding of river ecosystems as they pass from small headwater streams to the marine environment (Angelier 2003). This holistic approach to river ecosystem management has the additional benefit of providing more cost effective conservation by focusing on the preservation of habitats that may be necessary to numerous sensitive species, even those without legal protection.

Major rivers in the U.S. have become some of the most impacted ecosystems within the last century. With growing demands on water resources in the western and southeastern U.S., it appears that this trend will not diminish. Anthropogenic effects on river systems include, but are not limited to, decreased water quality (increases in nutrients and suspended solids and alterations of thermal and hydrologic regimes) and fragmentation of the riverscape by impoundments and other navigational structures (Nilsson et al. 2005). Given these influences, documenting life history characteristics of rare or declining species may be a crucial step towards implementation of successful management strategies.
Broadly distributed species with declining abundance and shrinking ranges present a unique conservation challenge. Conservation plans for narrow endemics can often be based on detailed ecological studies of the entire range. While similarly detailed range-wide studies for broadly distributed species are not practical, habitat variability and local adaptation may result in very different ecological interactions across the range. Conservation efforts are often based on detailed studies in one portion of the range and extrapolation to other, unstudied areas. This approach may be counterproductive if the biology of the species demands unique conservation strategies for genetically and ecologically disparate populations.

A number of threatened aquatic species exemplify this situation, including the gilt darter (*Percina evides*). This species is historically widespread but has been declining in abundance while its range shrinks (Hatch 1985; Wheeler et al. 2002). Studies of gilt darter ecology have focused on single populations (Hatch 1985; Skyfield and Grossman 2008). Skyfield and Grossman (2008) reported some basic similarities in affinity for cobble-sized substrate between Georgia and Minnesota gilt darter populations. However, they also reported some differences among these populations (e.g., movement patterns and population size estimates) and concluded that the ecological comparison was tenuous. Such disjunct populations distributed across regionally diverse habitats increase the complexity of creating an effective, broad-based conservation plan. Individual populations may need custom recovery strategies to address the unique restricting factors within the confined range (Margulies et al. 1980).

*Study Species*

Alabama shad (*Alosa alabamae*) is an anadromous fish. Adult Alabama shad live in the Gulf of Mexico and migrate up large rivers to spawn during the early months of the
year (January through May). After hatching, the juveniles spend up to nine months in the river before emigrating to the marine environment as subadults. Because they require both marine and riverine environments to complete their life cycle, they are particularly vulnerable to degradation in either system (Limburg and Waldman 2003). Currently the Alabama shad is listed as endangered by the International Union for the Conservation of Nature (IUCN) and threatened by the American Fisheries Society. Many states list the Alabama shad as a species of greatest conservation need including: AL, AR, FL, GA, KY, LA, MS, and MO (Meadows et al. 2006).

Like the gilt darter, Alabama shad is a broadly distributed species that may need to be studied and managed differently across its range. How anthropogenic impacts within the marine environment might be influencing this species is largely unknown. For example, the 2010 Gulf of Mexico oil spill could have the potential of disrupting the adult life stage of the Alabama shad on a large scale. With unknown amounts and locations of oil and dispersant, the overall life cycle of this anadromous fish may be greatly affected.

Spawning habitat of the Alabama shad was described in the Apalachicola River as sand and pebble substrate as well as submerged limestone outcroppings in the headwaters of rivers with moderate to fast current velocities (Laurence and Yerger 1967; Mettee and O’Neil 2003). This spawning site is the only documented site for Alabama shad and is described by multiple studies (Laurence and Yerger 1967; Mills 1972). Alabama shad is a unique species among anadromous fishes in Gulf of Mexico drainages in that it is relatively short-lived (4-6 years). Alabama shad is iteroparous, and many adult Alabama shad have been documented with multiple (> 4) spawn marks on their scales (Laurence and Yerger 1967).
Once abundant enough to support commercial fisheries in Alabama, Kentucky, Indiana, and Iowa, the Alabama shad is now rare throughout much of its former range (Evermann 1902, Coker 1930, Hildebrand 1963, Huntsman 1994). Historically, spawning and juvenile habitat ranged from the upper Mississippi River drainage in the West, to the Suwannee River in the East and the Missouri River in the Northwest (Buchanan 1999) (Figure 1.1). A population genetic study of Alabama shad revealed genetic patterns consistent with natal homing to Gulf Coast drainages and inland drainages (Bowen 2005). Impoundments and subsequent habitat loss are blamed for declines in many parts of the range (Burkuloo et al. 1993).

Impoundments are hypothesized to hinder upstream migration to spawning habitat. The Pearl River (southern portion of Mississippi-Louisiana border, Fig. 1) was sampled before and after the construction of two sills (low dams) in the 1960s. Alabama shad abundance steadily declined until 1981, when the species was considered extirpated from the drainage (Gunning and Suttkus 1990). Additionally, locks built in the Tombigbee River (northeastern MS and northwestern AL) preceded the species’ extirpation from that river (Mettee and O’Neil 2003). The Apalachicola River now has the largest population of Alabama shad despite the fact that system is impounded; there is believed to be a large spawning ground below the dam (Mettee and O’Neil 2003).

In a life history study within the Pascagoula River drainage, juvenile Alabama shad were found primarily in three habitat types: sand bar habitats, which are gently sloping sand deposits (<30°) within the bends of the river (typically < 2 m deep); channel habitats, which are open water or pelagic zones between the two sides of the river (typically 1.5-2.5 m deep); and bank habitats that are found on the outside of the river bends and have steep slopes (>45°) and deep water (> 2.5 m deep) (Mickle et al. 2010).
Mickle et al. (2010) found juvenile Alabama shad in sand bar habitat early in the summer. By mid-summer (July), juveniles shifted habitat use to channels and banks. These three habitat types are described as essential to juvenile Alabama shad recruitment and are identified as Essential Fish Habitat (EFH) (Mickle et al. 2010). Physicochemical parameters (primarily temperature) were also found to be predictors of presence absence for Alabama shad in this particular system. Juvenile Alabama shad were distributed throughout the drainage all summer and fall in a pattern suggesting there was no gradual downstream migration such as that hypothesized by Mills 1972 (Mickle et al. 2010).

The purpose of this study was to compare the detailed habitat data from the Pascagoula River drainage to similar data from other Gulf of Mexico drainages to assess whether similar patterns exist. Addressing this question will give insight into how effective management practices for broadly distributed species can be formed from data collected in a limited portion of the range. The specific objectives were to compare data among three Gulf of Mexico drainages with extant Alabama shad populations to determine if:

1. Habitat (Alabama shad EFH) use differs among drainages, and if
2. Temporal patterns of habitat use and ontogenetic shifts in habitat use differ among drainages.

*Study Systems*

The Pascagoula River was chosen as the baseline study system because a previous study detailed juvenile ecology and habitat use there (Mickle et al. 2010). The mean daily discharge in the Pascagoula River is 2607 m³/s, and it is the last large river system in the contiguous United States that does not have a dam on it (Dynesius and Nilsson 1994). The drainage lies entirely within the Gulf Coastal Plain province, and is
characterized by sinuous channels dominated by large sandbar, open channel, and steep bank habitats, the latter typically containing large woody debris. Land use within the drainage consists of forestry and agriculture, with limited industrial and urban development (USGS 2001). There is periodic dredging of mouth of the Pascagoula River but constitutes only the lower five miles of the east mouth.

The Apalachicola River is nearly twice the size of the Pascagoula with a mean daily discharge of 5608 m³/s and has the largest remaining population of Alabama shad (Mettee and O’Neil 2003). The Apalachicola River is also a commercial shipping waterway with periodic dredging the entire length of the river below the dam to allow navigation (USGS 2001). Two tributaries, the Flint and Chattahoochee rivers, empty into an impoundment on the Apalachicola River. The major habitat types and seasonal discharges are proportionally similar to those in the Pascagoula River. Land use within the Apalachicola basin is primarily forestry (USGS 2001).

The Suwannee River is the easternmost river within the distribution of Alabama shad and has the smallest mean daily discharge (1122 m³/s). Although there is similar habitat to the other two rivers, the Suwannee River is primarily a ground water fed and has slower flows, higher water clarity, higher conductivity and is much deeper than the latter two drainages (Table 2) (Katz et al. 2007). Land use within the Suwannee basin consists of suburban, rural, and forestry (USGS 2001).

Materials and Methods

Fish were collected using an electro-fishing boat. Sampling was conducted in June and October at four sites (Fig. 1, see also Mickle et al. 2010) within the Pascagoula drainage from 2004- 2007. Three sites in the Apalachicola and three sites in the Suwannee rivers were sampled in June and October of 2007-2008 (Figure 1). Sites were
chosen based on boat access and the presence of the three dominant habitat types identified in the Pascagoula River drainage. A total of 193 habitat samples were completed in the three rivers, 112 in the Pascagoula, 56 in the Apalachicola, and 22 in the Suwannee (Table 1.1). Although overall effort was highest in the Pascagoula River, the three habitat types were sampled roughly equally in June and October of each year (69 sand bars, 61 channels, and 60 banks). Earlier work in the Pascagoula River (Mickle et al. 2010) involved monthly sampling and documented ontogenetic shifts in habitat from sandbars (early summer) to channel and banks in late summer and fall. For logistic reasons, the present analysis was limited to June and October samples, a time span more than adequate to capture ontogenetic shifts in habitat use across all drainages.

During each site visit, fish were collected and physicochemical variables were measured in all three habitat types. Physicochemical measurements were taken within the center of the site and included water temperature (°C), dissolved oxygen (DO, mg/L), conductivity (µS/cm), pH, water clarity (Secchi depth, m), depth (m) and current velocity (m/s) at the surface and subsurface (0.5 m) following the methods of Mickle et al. (2010). Current velocity was measured sub-surface at the top and bottom of a single transect (long ways in relation to the river) of each habitat. If one or more Alabama shad was collected within the site sampled then it would be categorized as a shad present sample and the opposite for a shad absent sample.

Fish were sampled with a Smith-Root™ SR-14EB electrofishing boat at 5,000 watts and 16 amps. Pulses-per-second varied from 7.5-120, depending on water conditions, but were 120 for most electrofishing runs. Electrofishing effort was typically 400 s for each habitat type in each site. Sand bars and banks averaged 550 m in length and could be sampled effectively in 400 s. Some of the larger sand bars were
electrofished an additional 50-75 s. Boat electrofishing was the only means of standardizing effort across all three habitat types that were often deep and fast flowing. This sampling approach was effective for a number of species, yielding reliable community data (Schaefer et al. 2006).

Analysis

Principal Components Analysis (PCA) was used to reduce dimensionality of the measured physicochemical variables. An analysis of variance (ANOVA) of sample PCA scores was used to identify differences among rivers, habitats, and river*habitat interactions. Akaike’s Information Criterion corrected for small sample size (AICc) was used to find the best predictive models of Alabama shad presence or absence at habitats within each site sampled. Models were logistic regressions (presence/absence of Alabama shad as the response variable) with spatial, temporal, habitat, and physicochemical predictor variables. Models with low ΔAICc and high Akaike weights (wi) have the best combination of parsimony (fewer parameters) and fit (accuracy) for the data (Burnham and Anderson 2006, Grossman et al. 2006).

A two-tiered modeling approach was followed to address study objectives. The first set of models (Table 1.2) included data from all drainages and combinations of predictor variables including river, month, habitat type, and summarized physicochemical variables (PCA scores, Table 1.3). If patterns of habitat use were similar among drainages, the most parsimonious models would not include river as a variable since it would add no explanatory power and would increase model complexity. However, if patterns of habitat use differed among rivers, then river would be included in the best model(s). The second set of models focused on each drainage individually (Table 1.4). These models included month, habitat type and individual physicochemical variables.
The goal of this second set of models was to assess whether the same variables formed the best predictive models across drainages. All analyses were done in the R statistical software language (R Development Core Team, 2009).

Results

I collected 205 Alabama shad in the Pascagoula River, 187 in the Apalachicola River, and six in the Suwannee River. Physicochemical parameters were comparable between rivers with the exception of the Suwannee River which had higher conductivity, pH, and clarity and lower velocity than the other two rivers (Table 1.3, Figure 1.2). The Pascagoula and Apalachicola rivers were similar with no physicochemical differences. When comparing a two-way Analysis of Variance of the PCA scores, significant differences were detected between all the different habitats and rivers (Rivers p < 0.005 $F_{2,189} = 161.06$, Habitats p < 0.005 $F_{2,189} = 22.54$).

A temporal shift in habitat use occurred in all three drainages as the growing season progressed. In June, Alabama shad predominantly used sand bar habitats but shifted to bank habitats by October (Figure 1.3). Low sample size in the Suwannee River resulted in fish only being collected in October, when all were found in bank habitats.

The first AIC analysis, containing all rivers, resulted in four interpretable models ($W_i > 10\%$ of the largest $W_i$), three of which contained “RIVER” as a variable (Table 1.5). The two best models (numbers 13 and 15 in Table 1.4) contained a combination of river and summarized physicochemical variables (PCA scores). Thus, patterns of presence/absence of Alabama shad differed across drainages.

The second AICc analysis identified the best predictors of presence/absence within each river system. In each system the best model contained a single, but different, physicochemical variable (Table 1.6). For each river system, I obtained other
interpretable models but their weights \( W_i \) were substantially lower. In the Pascagoula River model, presence was best explained by temperature (Figure 1.4, Table 1.6). In the sand bar and channel habitats, sand bar and channel samples with Alabama shad present were significantly cooler than those where shad were absent. In all three habitat types in the Apalachicola River, velocities were higher in samples containing Alabama shad than in those lacking them. Also in the Apalachicola River, bank habitat samples containing Alabama shad were cooler than those lacking them (Figure 1.5, Table 1.6). The Suwannee River was the most unique system in that the only parameter that was weighted heavily in the model comparison was conductivity (Figure 1.6, Table 1.6). In that system, shad were collected in habitats that had high conductivities (> 180 microsiemens) compared to sites without shad (< 160 microsiemens).

**Discussion**

The modeling outcomes revealed that each drainage was unique in relation to the factors that may influence the presence or absence of juvenile Alabama shad. Further, the physicochemical variables influencing patterns of presence/absence differed across drainages. Physicochemical parameters such as temperature, flow, and conductivity may be influencing the presence of Alabama shad in each drainage, but they also may be limiting factors within some drainages and not others. These differences in water quality suggest that habitat use and recruitment success may be directly related to drainage-specific conditions.

The Pascagoula River habitat analysis revealed that lower temperature was the leading factor in predicting the presence of Alabama shad within the three habitat types (Table 1.6). This could be important within this particular drainage for Alabama shad. The detailed habitat use study within the Pascagoula (Mickle et al. 2010) also identified
temperature as an important predictor of shad presence and hypothesized that thermal refugia within the drainage may be crucial to recruitment success. Late in the summer (dry season), discharge levels decrease due to lower surface water input. This would increase temperatures drainage wide and possibly drive juvenile Alabama shad to seek out microhabitats that feature cooler ground water input or deeper waters in thermally stratified areas. It is also possible that higher temperatures are in part responsible for the habitat shift away from shallow sandbar habitats in early summer. While the thermal physiology of Alabama shad is not well known, other member of the genus are known to be quite temperature sensitive (McCauley and Binkowski, 1982).

The Apalachicola River has the largest discharge of the rivers studied and supports the largest remaining population of Alabama shad (Mettee and O’Neil 2003). Although this system is impounded, spawning and juvenile habitat remaining below the dam are sufficient to support a viable population. Analyses indicated that current velocity was the best predictor of shad presence in this system (Table 1.6). This river, like the Pascagoula River, has less groundwater input and runoff later in the summer. Lake Seminole, above the impoundment, is a shallow lake and tends to increases river temperatures (Van Den Avyle and Evans 1990). Further, the Apalachicola is a wide river with low flow velocity that has the potential to increase temperature from solar input. These mechanisms could potentially combine to alter natural thermal regimes and increase temperatures in vital Alabama shad habitat. While the best model for the Apalachicola River contained only current velocity as a variable, the two other interpretable models included temperature. Altered temperature regimes affect anadromous fish migrations within other impounded systems (Legget and Whitney 1972, Quinn and Adams 1996). When extreme low water events occur, the refugia within these
habitats may vanish and disrupt recruitment. Having minimum flow requirements within the river could allow sufficient flows to sustain these refugia.

The Suwannee River was the most unique of the three rivers sampled in that the wet season is during the summer months and the majority of the input is from groundwater aquifers throughout the drainage (USGS 2001). This smaller river has less flow and naturally lower temperatures due to greater canopy cover and groundwater input. It is not surprising that models with conductivity, and not temperature, were the best predictors of shad presence/absence (Figure 1.6). Conductivity has been found in other systems to impact presence of species on different trophic levels such as plankton, aquatic insects, shads, and basses (McInerny and Cross 1982; Jones and Clarke 1987; Claramunt and Wahl 2000). Although conductivity may not directly influence the presence of Alabama shad, there may be a diet or predator response to the conductivity regime of this groundwater system. However, it should be pointed out that Alabama shad abundance is apparently low in this system with only six individuals captured, all in bank habitat in October. It is possible that conductivity is confounded with other extraneous variables (e.g., recent rain events). Given the low abundance and low sample size, any conclusions for this particular system should be viewed cautiously.

The ontogenetic habitat shift seen in all rivers supports the idea that some similar processes are taking place across the range. By extension, the presence of these different habitat types is likely crucial to juvenile recruitment and a viable population. Many of the documented extirpations of this species have been in impounded systems where some of these habitat types may have been lost downstream of dams, where hydrologic regimes and sediment transport mechanisms no longer function as they had historically, inevitably
changing the natural depths and flows that many species need to complete their life history.

Studies of other riverine species support this concept of changing EFH through successive ontogenetic stages. Pacific salmon (*Oncorhynchus nerka*), brown trout, (*Salmo trutta*), and alewife (*Alosa pseudoharengus*), all require a suite of habitats to support the ontogenetic changes occurring in the first year of life (Crowder and Magnuson 1982; Rimmer et al. 1983; Maki-Petays et al. 1997). Many factors influence these shifts, including diet, water quality requirements, and predation. As the ontogenetic changes occur with recruitment, a suite of different habitat types and physicochemical gradients may be crucial for these species within their natal systems.

Overall, the findings suggest that a broad-based management approach may not be effective for this species. While some aspects of the species biology are consistent across drainages (e.g., ontogenetic shifts in habitat use, Figure 1.3), others are either different or fundamental differences in the drainages result in other variables being identified as more important. Further, the mechanisms driving the importance of individual variables is likely unique for each drainage. Conductivity may be influential in the Suwannee River for Alabama shad presence but not important in the Pascagoula or Apalachicola rivers. Similarly, because the Suwannee River has inherently lower temperatures than the other two rivers sampled, temperature may not appear to influence the presence of Alabama shad within that particular system. However, if overall temperatures in the system were to increase dramatically, then temperature may become an important factor for discriminating among sites with presence versus absence.

It is important to point out that all of the data shown here involve Gulf of Mexico Coastal Plain rivers. A population genetics study of Alabama shad revealed
differentiation between inland and coastal populations (Bowen 2005). Thus, it is likely that inland populations reproduce and recruit in different habitat, and a similar modeling approach would identify those differences. For example, Bowen (2005) collected Alabama shad from the Gasconade River, an Ozark river from the interior highlands region with larger substrate, and clearer and cooler water than the three systems studied here. Attempts were made to include these drainages in this study, but no fish were captured in repeated sampling trips over several years targeting the same localities. The health and stability of those unique populations is clearly an immediate conservation concern.

Restoring natural flow regimes to systems that have Alabama shad populations may be important to the life history of this species. The natural flows would provide the cues needed for the adults in relation to timing of reproduction. These flows would also allow water quality parameters to remain similar to what the Alabama shad has evolved with. Natural flows will create and maintain the three habitat types that all these systems possess to support the ontogenetic shifts seen with the juvenile Alabama shad. Any type of refugia needed for the Alabama shad in relation to physicochemical parameters must be present and accessible for these juveniles. Altering flows and habitats within these systems may eliminate the necessary refugia needed for the Alabama shad to successfully complete its lifecycle.
Literature Cited

pp 152, 171-175.

effects of temperature, hypoxia and exercise for diadromous fishes. Fish
Physiology, Toxicology, and Water Quality. p 207.

Southern Mississippi, Hattiesburg.

Buchanan, T. M. 1999. Occurrence and distribution of juvenile Alabama shad, Alosa
alabamae, in the Ouachita and Little Missouri Rivers of Arkansas in 1999. Pages
12. Final Report to US Forest Service, Ouachita National Forest, Hot Springs,
AR.

of Alabama shad In Rivers Tributary to The Gulf Of Mexico. Report to USFWS.

practical information-theoretical approach, 2nd edition. Springer-Verlag, New
York, USA.

Claramunt, R. M., and D. H. Whal. 2000. The effects of abiotic and biotic factors in
determining larval fish growth rates: A comparison across species and reservoirs.

Coker, R. E. 1930. Studies of common fishes of the Mississippi River at Keokuk. Bureau
Crowder, L. B., and J.J. Magnuson. 1982. Thermal habitat shifts by fishes at the
thermocline in Lake Michigan. Canadian Journal of Fish and Aquatic Science

in the northern third of the world Science 266:753-762.

Evermann B. W. 1902. Description of a new species of shad (Alosa ohiensis) with notes
on other food fishes of the Ohio River. Report of the Commissioner of the U.S.

riverscapes: bridging the gap between research and conservation of stream fishes.

Grenouillet. 2006. Population dynamics of mottled sculpin (Pisces) in a variable
234.

pages 3-4.

Hatch, J.T. 1985. Distribution, habitat, and status of the gilt darter (Percina evides) in

of the western North Atlantic, part three. Sears Foundation for Marine Research,
Yale University, New Haven, Connecticut.
Huntsman, G. R. 1994. Endangered marine finfish: neglected resources or beasts of

communities. Journal of the American Water Resources Association. 23(6) 1047-
1055.

Kemp, S. J. 2008. Autecological effects of habitat alteration: trophic changes in
mangrove marsh fish as a consequence of marsh impoundment. Marine Ecology

Laurence, G. C., and R. W., Yerger. 1967. Life history studies of the Alabama shad,
Alosa alabamae, in the Apalachicola River, Florida. Proceedings of the Annual
Conference Southeastern Association of Game and Fish Commissioners

Legget, W. C., and R. R., Whitney. 1972. Water temperature and the migrations of

Limburg, K. E. 2001. Through the gauntlet again: Demographic restructuring of
American Shad by migration. Ecology 82:1584-1596.

Limburg, K. E., and J. R. Waldman, editors. 2003. Biodiversity, status and conservation
of the world’s shads. American Fisheries Society, Symposium 35, Bethesda,
Maryland.

changes in habitat use and preference by juvenile brown trout, Salmo trutta, in a
northern boreal river. Canadian Journal of Fish and Aquatic Science. 54(3) 520-
530.


INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE
NOTICE OF COMMITTEE ACTION

The proposal noted below was reviewed and approved by The University of Southern Mississippi Institutional Animal Care and Use Committee (IACUC) in accordance with regulations by the United States Department of Agriculture and the Public Health Service Office of Laboratory Animal Welfare. The project expiration date is noted below. If for some reason the project is not completed by the end of the three year approval period, your protocol must be reactivated (a new protocol must be submitted and approved) before further work involving the use of animals can be done.

Any significant changes (see attached!) should be brought to the attention of the committee at the earliest possible time. If you should have any questions, please contact me.

PROTOCOL NUMBER: 07103101
PROJECT TITLE: Alabama Shad
PROPOSED PROJECT DATES: 08/01/2007 to 05/31/2010
PROJECT TYPE: Renewal
PRINCIPAL INVESTIGATOR(S): Jake Schaefer
COLLEGE/DIVISION: College of Science & Technology
DEPARTMENT: Biological Sciences
FUNDING AGENCY/SPONSOR: NOAA
IACUC COMMITTEE ACTION: Designated Reviewer Approval
PROTOCOL EXPIRATION DATE: 09/30/2010

[Signature]
Robert C. Rateman, Jr., Ph.D.
IACUC Chair

[Signature]
11-8-2007
Date
Table 1.1 Locations and number of samples and habitats within the drainages sampled. The Pascagoula River was sampled 2004-2007, the Apalachicola and Suwannee Rivers were sampled 2007-2008. Samples collected during June and October of each year at each site with exception of Fowler’s Bluff which was visited only once in October of 2008. The number of Alabama shad collected in each habitat is in parentheses.

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Bar</th>
<th>Channel</th>
<th>Bank</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pascagoula (2004-07)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>112</td>
</tr>
<tr>
<td>1. McLain</td>
<td>N31°06’30.57”</td>
<td>W-88°48’29.10”</td>
<td>12(59)</td>
<td>10(17)</td>
<td>10(25)</td>
<td>32</td>
</tr>
<tr>
<td>2. Lower Chickasawhay</td>
<td>N31°59’25.30”</td>
<td>W-88°43’22.30”</td>
<td>8(0)</td>
<td>7(0)</td>
<td>6(1)</td>
<td>21</td>
</tr>
<tr>
<td>3. Merrill</td>
<td>N30°58’04.71”</td>
<td>W-88°44’09.96”</td>
<td>8(12)</td>
<td>7(21)</td>
<td>7(33)</td>
<td>22</td>
</tr>
<tr>
<td>4. Wade</td>
<td>N30°36’29.21”</td>
<td>W-88°38’21.20”</td>
<td>14(18)</td>
<td>11(12)</td>
<td>12(7)</td>
<td>37</td>
</tr>
<tr>
<td><strong>Apalachicola (2007-08)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>56</td>
</tr>
<tr>
<td>5. Woodruff</td>
<td>N30°41’49.03”</td>
<td>W-84°51’28.87”</td>
<td>6(12)</td>
<td>6(27)</td>
<td>5(12)</td>
<td>17</td>
</tr>
<tr>
<td>7. Blountstown</td>
<td>N30°26’11.17”</td>
<td>W-85°00’09.05”</td>
<td>7(14)</td>
<td>7(25)</td>
<td>6(28)</td>
<td>20</td>
</tr>
<tr>
<td>8. Wewahitchka</td>
<td>N30°14’56.56”</td>
<td>W-85°00’09.05”</td>
<td>6(16)</td>
<td>7(28)</td>
<td>6(25)</td>
<td>19</td>
</tr>
<tr>
<td><strong>Suwannee (2007-08)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>22</td>
</tr>
<tr>
<td>9. Withlachoochee</td>
<td>N30°23’09.41”</td>
<td>W-83°10’18.36”</td>
<td>4(0)</td>
<td>2(0)</td>
<td>3(0)</td>
<td>9</td>
</tr>
<tr>
<td>10. Perry</td>
<td>N30°15’07.38”</td>
<td>W-83°15’08.90”</td>
<td>4(0)</td>
<td>3(0)</td>
<td>4(6)</td>
<td>11</td>
</tr>
<tr>
<td>11. Fowler’s Bluff</td>
<td>N29°23’51.17”</td>
<td>W-83°01’24.88”</td>
<td>0(0)</td>
<td>1(0)</td>
<td>1(0)</td>
<td>2</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td></td>
<td></td>
<td>69</td>
<td>61</td>
<td>60</td>
<td>190</td>
</tr>
</tbody>
</table>
Table 1.2 Candidate models used in AICc model selection for presence/absence response variables. $K$ indicates the number of model parameters. Models compared including physicochemical PC scores and categorical variables (Season, River, and Habitat).

<table>
<thead>
<tr>
<th>Model</th>
<th>Number</th>
<th>Variables</th>
<th>$K$</th>
<th>Hypotheses that are best explained by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Null</td>
<td>1</td>
<td>None</td>
<td>2</td>
<td>None of the measured variables</td>
</tr>
<tr>
<td>Temporal</td>
<td>2</td>
<td>Season</td>
<td>4</td>
<td>Differences on a temporal scale region wide (June, October)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Season*River</td>
<td>4</td>
<td>Differences on a temporal scale between drainages</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Season*Habitat</td>
<td>4</td>
<td>Differences on a temporal scale between habitats</td>
</tr>
<tr>
<td>Spatial</td>
<td>5</td>
<td>Habitat</td>
<td>4</td>
<td>Differences at the fine scale (channel, bank, sand bar habitat)</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>River</td>
<td>4</td>
<td>Large spatial scale (Pascagoula, Apalachicola, Suwannee rivers)</td>
</tr>
<tr>
<td>Physicochm.</td>
<td>7</td>
<td>Habitat*River</td>
<td>9</td>
<td>Combination of both</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>PC1</td>
<td>3</td>
<td>Sample differences in physicochemical variables</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>PC2</td>
<td>3</td>
<td>Sample differences in physicochemical variables</td>
</tr>
<tr>
<td>Spatial +</td>
<td>10</td>
<td>PC1*PC2</td>
<td>5</td>
<td>Combination of both</td>
</tr>
<tr>
<td>Physicochm.</td>
<td>11</td>
<td>Habitat*PC1</td>
<td>7</td>
<td>Fine spatial scale and first physicochemical axis</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Habitat*PC2</td>
<td>7</td>
<td>Fine spatial scale and second physicochemical axis</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>River*PC1</td>
<td>7</td>
<td>Large spatial scale and first physicochemical axis</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>River*PC2</td>
<td>7</td>
<td>Large spatial scale and second physicochemical axis</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>Habitat<em>PC1</em>PC2</td>
<td>11</td>
<td>Fine spatial scale and both physicochemical axes.</td>
</tr>
<tr>
<td>Global</td>
<td>16</td>
<td>River<em>PC1</em>PC2</td>
<td>11</td>
<td>Large spatial scale and both physicochemical axes.</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>All</td>
<td>28</td>
<td>Combination of all spatial and physicochemical variables.</td>
</tr>
</tbody>
</table>
Table 1.3 Mean water physicochemical values with standard deviation and principal components analysis loadings for each drainage. PCA Axis 1 and 2 explain 48% and 33% of variance in all physicochemical data, respectively.

| Variable       | Pascagoula | Apalachicola | Suwannee | PCA  \\
|----------------|------------|--------------|----------|-------|
|                | Mean  | SD   | Mean  | SD   | Mean  | SD   | Loadings  \\
| Depth (m)      | 1.50   | 0.33 | 1.50  | 0.42 | 2.20  | 0.30 | 0.41       | 0.83 |
| Flow Upper (m/s) | 1.54  | 0.84 | 2.13  | 0.62 | 1.11  | 0.37 | -0.61      | 0.56 |
| Flow Lower (m/s) | 1.38  | 1.00 | 2.09  | 0.65 | 1.05  | 0.14 | -0.64      | 0.56 |
| Secchi (m)     | 0.41   | 0.19 | 0.49  | 0.15 | 1.48  | 0.52 | 0.66       | 0.11 |
| Temperature (°C) | 26.64 | 1.73 | 26.21 | 1.07 | 24.03 | 2.54 | -0.25      | -0.04 |
| Diss.Oxygen (g/ml) | 5.71  | 0.49 | 5.99  | 0.58 | 6.77  | 0.77 | 0.36       | 0.73 |
| Cond. (µS/cm)  | 87.73  | 37.91| 82.27 | 18.12| 148.53|36.70| 0.63       | 0.27 |
| pH             | 6.83   | 0.32 | 6.87  | 0.19 | 7.01  | 0.02 | 0.32       | 0.57 |
Table 1.4 Candidate models used in AICc model selection for presence/absence response variables. Physicochemical variables compared within each river along with the spatial variable of Habitat. K indicates the number of model parameters.

<table>
<thead>
<tr>
<th>Model</th>
<th>Number</th>
<th>Variables</th>
<th>K</th>
<th>Hypotheses that are best explained by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physicochm.</td>
<td>1</td>
<td>Dissolved Oxygen</td>
<td>4</td>
<td>Differences in pres/abs related to dissolved oxygen</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Secchi</td>
<td>4</td>
<td>Differences in pres/abs related to water clarity</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Depth</td>
<td>4</td>
<td>Differences in pres/abs related to depth</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Temperature</td>
<td>4</td>
<td>Differences in pres/abs related to temperature</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Flow Lower</td>
<td>9</td>
<td>Differences in pres/abs related to flow velocity at the downstream end of the site</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Flow Upper</td>
<td>3</td>
<td>Differences in pres/abs related to flow velocity at the upstream end of the site</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Conductivity</td>
<td>3</td>
<td>Differences in pres/abs related to conductivity</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>pH</td>
<td>5</td>
<td>Differences in pres/abs related to pH</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Habitat*dissolved oxygen</td>
<td>7</td>
<td>Differences in pres/abs related to dissolved oxygen among habitats</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Habitat*depth</td>
<td>7</td>
<td>Differences in pres/abs related to depth among Habitats</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Habitat*temperature</td>
<td>7</td>
<td>Differences in pres/abs related to temperature among habitats</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Habitat*flow lower</td>
<td>7</td>
<td>Differences in pres/abs related to flow at the upper part of the site among habitats</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>Habitat*flow upper</td>
<td>11</td>
<td>Differences in pres/abs related to flow at the lower part of the site among habitats</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>Habitat*conductivity</td>
<td>11</td>
<td>Differences in pres/abs related to conductivity among habitats</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>Habitat*pH</td>
<td>28</td>
<td>Differences in pres/abs related to pH among the habitats</td>
</tr>
</tbody>
</table>
Table 1.5 AIC<sub>c</sub> statistics and weights (Wi) for the response variable of presence of Alabama shad. Model numbers match list in Table 2. Models with weights below 5% were excluded from the table.

<table>
<thead>
<tr>
<th>Model</th>
<th>Number</th>
<th>Variables</th>
<th>K</th>
<th>AICC</th>
<th>Wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Null</td>
<td>1</td>
<td>None</td>
<td>2</td>
<td>31.6</td>
<td></td>
</tr>
<tr>
<td>Temporal</td>
<td>2</td>
<td>Season</td>
<td>4</td>
<td>32.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Season*River</td>
<td>4</td>
<td>14.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Season*Habitat</td>
<td>4</td>
<td>23.8</td>
<td></td>
</tr>
<tr>
<td>Spatial</td>
<td>5</td>
<td>Habitat</td>
<td>4</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Habitat*River</td>
<td>9</td>
<td>33.3</td>
<td>0.078</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>River</td>
<td>4</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>Physicochm.</td>
<td>8</td>
<td>PC1</td>
<td>3</td>
<td>23.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>PC2</td>
<td>3</td>
<td>23.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>PC1*PC2</td>
<td>5</td>
<td>25.6</td>
<td></td>
</tr>
<tr>
<td>Spatial + physicochm.</td>
<td>11</td>
<td>Habitat*PC1</td>
<td>7</td>
<td>21.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Habitat*PC2</td>
<td>7</td>
<td>5.3</td>
<td>0.054</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>River*PC1</td>
<td>7</td>
<td>0.4</td>
<td>0.393</td>
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<td></td>
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<td>River*PC2</td>
<td>7</td>
<td>22.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>Habitat<em>PC1</em>PC2</td>
<td>11</td>
<td>11.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>River<em>PC1</em>PC2</td>
<td>11</td>
<td>0.0</td>
<td>0.489</td>
</tr>
<tr>
<td>Global</td>
<td>17</td>
<td>All</td>
<td>28</td>
<td>38.3</td>
<td></td>
</tr>
</tbody>
</table>
Table 1.6 Interpretable models, AIC<sub>c</sub> statistics and weights for physicochemical variables. Models with weights below 5% were excluded from table. Abbreviation: D.O. = dissolved oxygen; Temp. = water temperature; Cond. = conductivity. K indicates the number of model parameters.

<table>
<thead>
<tr>
<th></th>
<th>Rivers</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pascagoula</td>
<td>AIC&lt;sub&gt;c&lt;/sub&gt;</td>
<td>W&lt;sub&gt;i&lt;/sub&gt;</td>
<td>AIC&lt;sub&gt;c&lt;/sub&gt;</td>
<td>W&lt;sub&gt;i&lt;/sub&gt;</td>
<td>AIC&lt;sub&gt;c&lt;/sub&gt;</td>
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Figure 1.1 Map of the three drainages sampled for Alabama shad from 2004-2008. A-Pascagoula River, B-Apalachicola River, C-Suwannee River. Sites: 1-McLain, 2-Lower Chickasawhay, 3-Merrill, 4-Wade, 5-Woodruff, 6-Wewahitchka, 7-Blountstown, 8-Withlachoochee, 9-Perry, 10-Fowler’s Bluff.
Figure 1.2 Principal Components Analysis outputs of each site between rivers (A) and habitats (B). 46% of the variance accounted for in axis 1 and 25% in axis 2.
Figure 1.3 Catch Per Unit Effort (CPUE) between habitats and rivers over the different seasons. June = Summer, October = Fall. All sites combined within each drainage and CPUE computed from number of fish collected divided by total sampling effort (electrofishing seconds) combined.
Figure 1.4 Mean temperature differences (with SD) in relation to presence and absence of Alabama shad. All sites and seasons combined within each habitat type. The error bars represent standard deviations and significant differences between temperature within a habitat are indicated by * based on Bonferroni-corrected pairwise test.
Figure 1.5 Mean velocity differences (with SD) in relation to presence and absence of Alabama shad. Sites and seasons combined within each habitat type. The error bars represent standard deviations (* indicates significant difference).
Figure 1.6 Mean conductivity differences (with SD) in relation to presence and absence of Alabama shad. Sites and seasons combined within each habitat type. The error bars represent standard deviations (* indicates significant difference)
CHAPTER II
TROPHIC ECOLOGY OF ALABAMA SHAD (ALOSA ALABAMAE) IN NORTHERN GULF OF MEXICO DRAINAGES

Abstract

In recent years, understanding food web ecology has been shown to be valuable in conservation by linking interactions of multiple species together. Alabama shad, *Alosa alabamae*, reproduce in Gulf of Mexico rivers and influence the food webs of these systems. The goals of this project were to determine if diet changes as Alabama shad mature, determine if diet for Alabama shad differs between drainages, identify diet similarities with a sister species the skipjack herring (*Alosa chrysochloris*), and determine if piscivorous fishes are actively feeding on Alabama shad. I used a Non-Parametric Multi Variate Analysis of Variance or NP-MANOVA to determine diet differences of size groups as well as drainages for Alabama shad. Shannon-Weiner diversity indices were used to compare diet diversity of different age classes of Alabama shad and a closely related species, skipjack herring, *Alosa chrysochloris*. Juvenile Alabama shad had highly diverse diets during the first year of life. Many groups of aquatic and terrestrial insects were found in the stomachs of this species. Skipjack herring were only collected as adults and were predominantly piscivorous. Diets of Alabama shad smaller than 50mm standard length (SL) consisted primarily of detritus. Larger Alabama shad, >50mm SL, fed almost exclusively on insects. Alabama shad diets also differed among drainages. Interspecific differences in diet were seen between adult skipjack herring and large, juvenile Alabama shad. Stomach contents of predators that were collected in areas with Alabama shad indicate Alabama shad may be important prey items for other
predatory species. Diet and trophic placement of Alabama shad may allow managers to understand the importance of this fish within its natal rivers.

Introduction

Within the last forty years, the disciplines of community and ecosystem ecology have become more intertwined in an attempt to better understand the role individual species and habitat heterogeneity have in regulating ecosystem emergent properties (Lawton 1996; Johnson et al. 2005). Each link in a food web serves a functional role and allows the systems to sustain a level of stability in a variable environment (Payne 1980; McCann et al. 1998). The relative importance among many species to maintaining ecosystem properties is variable. Keystone species are often defined as those whose importance to the ecosystem is disproportionately large compared to their biomass (Mills et al. 1993; Davic 2003). While the importance of keystone species is clear, debate continues over the importance of other species to ecosystem function. The rivet hypothesis (Ehrlich and Ehrlich 1981) posits that all species play potentially vital roles and removal of any one could result in dramatic ecosystem change (Ehrlich and Walker 1998; Peterson et al. 1998). At the other extreme, some hypothesize that species are redundant and removal of any one will have no impact on ecosystem function (Walker 1992). In most instances, when a species is removed, the effects are unknown beforehand, although the outcome has the potential to affect overall ecosystem function and equilibrium (Pimm 1984; Lyons and Schwartz 2001). As anthropogenic impacts on ecosystems have increased, more sensitive species are declining and showing patterns of local extirpations. Conservation and management of natural resources requires an understanding of what role these species play in ecosystem function and maintenance of ecosystem services.
Riverine food webs have been studied in many different ecosystems and the importance of energy flow in these systems is documented (Power 1992). Power et al. (1996) found large scale change to food web structure and ecosystem function downstream of impoundments. Without natural variations in flow, communities and trophic exchanges were transformed and ultimately altered the functionality of the system (Power et al. 1996).

The Alabama shad, *Alosa alabamae*, is potentially an important species to riverine food web ecology. Other shad species have been shown to influence plankton populations and overall condition of predators (Michaletz 1997; Shauss and Vanni 2000). It is possible that predator and prey species in the ecosystem may be directly influenced by the presence of Alabama shad. However, studies of the diet and predation on Alabama shad are lacking. Alabama shad is an anadromous species, reproducing in northern Gulf of Mexico river drainages during the spring months, and spending their first summer and fall in rivers before moving into the Gulf of Mexico (Mettee and O’Neil 2003). As age 0 Alabama shad grow, they tend to shift from sand bar to open channel and steep bank habitats (Mickle et al. 2010). One might expect shifts in diet to coincide with the observed habitat use and juvenile size.

Currently, the Alabama shad is listed as endangered by the International Union for the Conservation of Nature (IUCN) and threatened by the American Fisheries Society. Many states list the Alabama shad as a species of greatest conservation need including: AL, AR, FL, GA, KY, LA, MS, and MO (Meadows et al. 2006).

Much of the basic biology for Alabama shad has been inferred from work done on the American shad in northern Atlantic basins. Studies addressing fecundity, spawning, feeding behavior, and even restoration of American shad have been conducted (Olney
The trophic ecology of Alabama shad is not well understood but is important to consider when developing a management plan. To assess the potential for resource competition (or species redundancy), the diet of an ecologically and morphological similar species found in similar habitats was also studied. The skipjack herring (*Alosa chrysochloris*) is a congener of the Alabama shad and both reproduce at similar times (Bowen et al. 2009). Very little is known about the diet of the skipjack herring (Coker 1930), and there is the potential for competitive interactions negatively impacting Alabama shad survival and growth. If these two species eat similar prey, information regarding any spatial or temporal resource partitioning would be valuable to managers in relation to the conservation of the Alabama shad.

The purpose of this study was to compare diets of skipjack herring and Alabama shad collected in two northern Gulf of Mexico river systems. Diets of two size groups of juvenile Alabama shad were compared to identify ontogenetic diet shifts that may accompany habitat shifts. Diets of adult skipjack herring were compared to those of large juvenile Alabama shad to help determine if there are potential species interactions due to overlapping resource use. Finally, stomachs of numerically dominant, large-bodied predators were examined for the presence of both Alabama shad and skipjack herring. The specific objectives were to determine if:

1. Juvenile Alabama shad diets change as they mature,
2. Alabama shad diets differ between drainages,
3. Large, juvenile Alabama shad and adult skipjack herring diet compositions differ, and if
4. Piscivorous fishes feed on Alabama shad.
Study Systems

The Pascagoula River is located in southeastern Mississippi. The mean daily discharge in the Pascagoula River is 1586 m³/s, and it is the only large river in the contiguous United States that is not impounded (Nilsson et al. 2005). Two large tributaries, the Leaf and Chickasawhay rivers, join to form the Pascagoula River (Figure 2.1). The drainage lies entirely within the Gulf Coastal Plain province, and its large rivers are characterized by sinuous channels dominated by large sand bar, open channel, and steep bank habitats, the latter typically containing large woody debris. Land use within the drainage consists of forestry and agriculture, with limited industrial and urban development (USGS 2001). The lower five miles of the east mouth of the Pascagoula River is periodically dredged.

The Apalachicola River has over twice the discharge of the Pascagoula River with a mean discharge of 3588 m³/s and has the largest remaining population of Alabama shad (Mettee and O’Neil 2003). The river has a large impoundment at the confluence of its two major tributaries, the Flint and Chattahoochee rivers. The river is located in the central panhandle of Florida and its tributaries extend into eastern Alabama and western Georgia. The Apalachicola River is a major commercial waterway with periodic dredging along its entire length. Fish habitat types and seasonal discharges are similar to those in the Pascagoula River. Land use within the Apalachicola basin is primarily forestry (USGS 2001).

Materials and Methods

Sampling was conducted during June and October of 2007 and 2008 in both rivers. Alabama shad, skipjack herring, and piscivorous fishes were all collected within
the same sampling sites and times. All fish were collected with a Smith-Root™ SR-14EB electrofishing boat at 5,000 watts and 16 amps. Pulses-per-second varied from 7.5-120. We typically electrofished for 400 seconds within each habitat type, at each site. On some of the larger sand bars we electrofished an additional 50 - 75 s. Skipjack herring were also collected by hook and line (using rooster tailed spinner baits) after the schools were detected via electrofishing. Alabama shad and skipjack herring were weighed (wet weight, to the nearest 0.01 g) and measured (standard length [SL], to the nearest mm) in the field before being individually tagged and placed in 95% ethanol.

During low water periods, some sites (typically shallow sandbars) were not accessible by the electrofishing boat. Because Alabama shad go through ontogenetic shifts in habitat use (Mickle et al. 2010), these sites were seined and occasionally cast netted to ensure individuals of all ages were sampled throughout the sampling period. Cast nets ranged from 1.52-2.43 m diameter and all had a bar mesh of 1.59 cm. Seines were 3.0-3.7 m wide by 1.8-2.4 m deep with a 0.3 cm mesh.

In the lab both skipjack herring and Alabama shad stomachs and lower intestines were excised and food items were then preserved in 10% formalin. Stomach contents from all Alabama shad and skipjack herring were initially identified as plankton, nekton, detritus, insect, or fish using a Heerbrugg Switzerland Wild M38 dissecting microscope at 16x power. Insect and fish items were then identified to order or appropriate lower taxonomic level and counted. Fifteen percent of the items were validated by personnel in the University of Florida Entomology department (F. Macky and A. Williams) and the University of Southern Mississippi Biology department (J. Watkins and A. Wilberdink).

Stomach contents of putative predators (large centrarchid and ictalurid species > 200 mm) with gape sizes capable of ingesting Alabama shad or skipjack herring were
examined to assess potential predation. Predators were collected during the same
electrofishing surveys described above, and stomach items were non-lethally removed by
gastric lavage (Light et al. 1983). Predators were then released and prey items visually
identified and counted.

Analysis

Nonmetric multidimensional scaling (NMDS) of a Bray-Curtis similarity matrix
was used to reduce the dimensionality of the diet data. Two nonparametric multivariate
analyses of variance (NP-MANOVA; Anderson 2001) with 10,000 iterations were then
used to test for differences in Alabama shad diets between drainages and size groups (<70
mm and >70 mm). These size groups were determined from the size at which ontogenetic
shifts in habitat were previously documented (Mickle et al. 2010). The NP-MANOVA
was also used to test for diet differences between skipjack herring and Alabama shad
(10,000 iterations).

To quantify diet diversity in each fish stomach, I used the Shannon-Weiner index
$$H' = -\sum_{i=1}^{S}(p_i \ln p_i)$$
calculated from untransformed abundance of diet items. I then
compared diet diversity between Alabama shad size categories, drainages, and species
with analysis of variance (ANOVA).

Indicator species analysis (ISA, Dufrene and Legendre 1997) was used to identify
taxa that were indicative of Alabama shad diet for each drainage and size group.
Indicator species analysis produces an indicator value based on the relative abundance
and the occurrence rate of species among groups of samples. Indicator values range from
0.0 to 1.0. A value of 1.0 represents a perfect indicator that is present in all samples of
one particular group and in no samples of other groups. Thus, in this application, a diet
item that is a perfect indicator for one group would be found in all stomachs of that particular group exclusively. The significance of indicator values was tested through Monte Carlo 5000 permutations. All analyses were performed on R statistical software (R Development Core Team, 2005).

Results

In total, 211 juvenile Alabama shad and 139 skipjack herring were collected; 115 Alabama shad from the Pascagoula River and 96 from the Apalachicola River. Stomach contents from Alabama shad < 50mm SL (n=47) were primarily detritus (Table 2.1). The detritus was composed of semi-decomposed algae and various other materials that were not identified further. These fish were not included in the analyses. Of the remaining 303 fish > 50 mm, 76 Alabama shad (46 %) and 90 skipjack herring (65%) had stomach contents that were identifiable. Dominant diet items within Alabama shad stomachs included the orders Ephemeroptera (aquatic larvae), Lepidoptera (terrestrial), and Hymenoptera (terrestrial) (Table 2.2). Although sampling was conducted in the large tributaries as well as the main river in the Pascagoula basin, diets did not differ between tributary and mainstem sites (e.g., NP-MANOVA, R=.091, p-value=0.19, df=50), so samples were pooled.

Skipjack herring diets were composed almost entirely of fish, with small amounts of detritus. In most cases, fish in stomachs were decomposed to the point that identification could only be done to family.

A total of 43 stomachs were examined from four predator species. Predator diets consisted primarily of fish (13 species identified) and mussels (Table 2.3). The stomachs of spotted and largemouth bass (*Micropterus punctulatus* and *Micropterus salmoides*) contained primarily highfin carpsucker, *Carpiodes velifer*, and blacktail shiner,
Cyprinella venusta. Stomachs of the blue catfish (Ictalurus furcatus) and flathead catfish (Pylodictis olivaris) contained mostly mussels (without shells, could not be identified further) and some carpsuckers (Carpiodes spp.). One Alabama shad was found in the stomach of a spotted bass collected in an area where I also collected Alabama shad.

Although there was overlap between groups in NMDS ordination space (Figure 2.2), Alabama shad less than 70mm SL had significantly different diet composition than Alabama shad larger than 70mm SL (Table 2.4). The diet of small Alabama shad showed a high frequency of Hymenoptera as well as a broad range of other orders. Indicator species analysis identified the orders Hymenoptera and Lepidoptera as significant indicators of small Alabama shad diet and Ephemeroptera as indicators for large (>70mm) Alabama shad diets. Diets of Alabama shad in the different drainages also differed, with Ephemeroptera versus Hymenoptera dominating stomachs of fish from the Pascagoula and Apalachicola rivers, respectively (Table 2.4, Figure 2.3). Indicator species analysis identified the orders Lepidoptera and Hymenoptera as significant indicators in the Apalachicola River, whereas Ephemeroptera was the lone significant indicator in the Pascagoula River (Table 2.2). Diet differences between adult skipjack herring (mean SL of 215 mm) and large, juvenile Alabama shad (mean SL of 100 mm) were highly significant, with the Alabama shad being primarily insectivorous and the skipjack herring piscivorous.

There was no significant difference in Shannon-Weiner diversity indices of diet items between Alabama shad size groups (Table 2.5). Diversity levels were different between the two drainages. Diets of Alabama shad from the Pascagoula River displayed higher diversity and richness compared to those from the Apalachicola River. Shannon-Weiner diversity indices differed between the two shad species, with the insectivorous
diets of the Alabama shad being more diverse than the piscivorous diets of the skipjack herring (Table 2.5).

Discussion

Aside from one Alabama shad with a single sand darter (*Ammocrypta beani*) in its stomach, there was no diet overlap with the morphologically-similar skipjack herring that were exclusively piscivorous in this study. Piscivory in *Alosa* is not novel; it has been previously reported in the twaite shad, *Alosa fallax*, and the blue back herring, *Alosa aestivalis* (Assis et al. 1992; Wheeler and Loftis 2003). Studies on the diet of skipjack herring are rare, though Cocker (1930) reported the species preyed on a variety of insects and fishes as they matured. While the data presented here suggests virtually no chance for resource competition between these two species, there is the potential for a predator-prey relationship. Both species can reach over 500 mm SL (Ross 2001), but skipjack herring are not considered anadromous, so large piscivorous adults may be co-occurring with age 0 Alabama shad. It is also important to note that I did not collect smaller skipjack herring (smallest was 179mm SL) that may be insectivorous and potential competitors with Alabama shad. The fact that no juvenile skipjack herring were collected in habitats that Alabama shad were collected may be a result of two outcomes: 1) juvenile skipjack herring do not co-occur with juvenile Alabama shad, so regardless of what the former eat, there is spatial–temporal resource partitioning or 2) juvenile skipjack herring do co-occur but are not susceptible to the gear. It is not likely that the skipjack herring are avoiding the gear as the morphology of the skipjack are similar to the Alabama shad and the juvenile Alabama shad are highly susceptible to the electrofishing gear in all habitats sampled.
Although small and large juvenile Alabama shad eat different insects, the variability within the two diets was comparable, suggesting they are generalist insect feeders. The larger Alabama shad had an Ephemeroptera dominated diet. This order possesses almost exclusively aquatic juvenile larvae that emerge in open water where the large Alabama shad were collected (Merritt and Cummins 1983). The habitat shift seen in age 0 Alabama shad may be attributed to a generalist diet strategy. Similar findings were shown with the Bayou darter in which the diet shifted to match changes in food availability (Knight and Ross 1994).

With the exception of gar (primarily *Lepisosteus* spp.), the group of large bodied piscivorous species sampled is representative of potential predator species known to occur with juvenile Alabama shad in fresh waters. Gar species were collected, but the gastric lavage technique was not effective in recovering stomach contents. Although only one Alabama shad was recovered from a predator’s stomach, this represented 1.3% of all the individual fish recovered from predator stomachs. The two most abundant prey species in predator stomachs were *Cyprinella venusta* and *Carpiodes velifer* that together made up 68% of the prey. These two species are typically very abundant in Pascagoula River samples (Schaefer et al. 2006) while Alabama shad are not (typically far less than 1.3% of individuals sampled). Thus, it is plausible that predation pressure on juvenile Alabama shad may be substantial. In addition, on numerous occasions I observed piscivorous fishes feeding on schools of Alabama shad near the water’s surface. Many shad species, such as gizzard shad (*Dorosoma cepedianum*), threadfin shad (*Dorosoma petenense*) and blueback shad (*Alosa aestivalis*), are important prey items to a variety of large bodied riverine predators (Matthews et al. 1988; Stahl and Stein 1994).
Food webs within Northern Gulf of Mexico drainages are complex and highly variable in relation to season and flow. Optimal foraging theory predicts that animals should select the most profitable prey items and only specialize if the types of prey items differ markedly in overall profitability (energetic gain minus search, capture and handling costs) (Futuyma and Moreno 1988). If prey items are all of similar profitability, the theory predicts an animal to forage in a manner minimizing search time by consuming whatever is encountered. In that case, variability in the abundance or distribution of prey items will be most influential in determining diet and may result in a broad based diet (Futuyma and Moreno 1988). Many stream fish that are insectivorous feed on a wide variety of insects but may specifically key in on the most abundant items at the present time. The variability is present as a whole but during small temporal cycles the strategy may be closer to a specialist. Within variable systems such as Gulf Coastal Plain rivers, a generalist strategy as a whole may be more advantageous for first year growth. The findings within this diet project are consistent with a generalist strategy. One would expect specialist strategies to be seen in very stable systems where competition is intense (niche compression: Holling 1973; Stahl and Stein 1994). These rivers may not be stable enough and can be quite stochastic which is expected to reduce competitive interactions that would favor more of a specialist strategy.

To properly conserve this rare species, the food webs of their rivers must be protected as well. These variable systems must have multiple food items from different sources that fish species can utilize. Anthropogenic affects such as pollution and flow alteration can alter insect communities (Batzer 1996). To properly conserve Alabama shad, managers must monitor the habitats, water quality, and resources that this fish is utilizing during the first year of life.


Michelitz, P. H. 1997. Influence of abundance and size of age-0 gizzard shad on predator...


Power, M. E. 1992. Top-down and bottom-up forces in food webs: Do plants have


INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE
NOTICE OF COMMITTEE ACTION

The proposal noted below was reviewed and approved by The University of Southern Mississippi Institutional Animal Care and Use Committee (IACUC) in accordance with regulations by the United States Department of Agriculture and the Public Health Service Office of Laboratory Animal Welfare. The project expiration date is noted below. If for some reason the project is not completed by the end of the three year approval period, your protocol must be reactivated (a new protocol must be submitted and approved) before further work involving the use of animals can be done.

Any significant changes (see attached) should be brought to the attention of the committee at the earliest possible time. If you should have any questions, please contact me.

PROTOCOL NUMBER: 07103101
PROJECT TITLE: Alabama Shad
PROPOSED PROJECT DATES: 08/01/2007 to 05/31/2010
PROJECT TYPE: Renewal
PRINCIPAL INVESTIGATOR(S): Jake Schaefer
COLLEGE/DIVISION: College of Science & Technology
DEPARTMENT: Biological Sciences
FUNDING AGENCY/SPONSOR: NOAA
IACUC COMMITTEE ACTION: Designated Reviewer Approval
PROTOCOL EXPIRATION DATE: 09/30/2010

Robert C. Bateman, Jr., Ph.D.
IACUC Chair

11-8-2007
Date
Table 2.1 Number of Alabama shad, skipjack herring and predators collected within the two studied drainages.

<table>
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<th>Species/Size</th>
<th>Pascagoula</th>
<th>Apalachicola</th>
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<td>Alabama shad &lt;50mm</td>
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<tr>
<td>Alabama shad 50-70mm</td>
<td>67</td>
<td>32</td>
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<tr>
<td>Alabama shad &gt;70</td>
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<td>64</td>
</tr>
<tr>
<td>Skipjack herring</td>
<td>64</td>
<td>75</td>
</tr>
<tr>
<td>Predators</td>
<td>74</td>
<td>1 (Largemouth bass)</td>
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</table>
Table 2.2 Alabama shad and skipjack herring stomach items collected. Numbers represent the total number of items collected within each category. Indicator species values are noted below total counts. Significant indicator values are in bold ($\alpha \leq 0.05$).

<table>
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<th>Diet Item</th>
<th>Alabama Shad &lt;70mm</th>
<th>Alabama Shad &gt;70mm</th>
<th>Skipjack Herring (both rivers) (Alabama shad collected)</th>
<th>Apalachicola River (Alabama shad collected)</th>
<th>Total</th>
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<td><strong>0.23</strong></td>
<td>0.02</td>
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<tr>
<td></td>
<td>Ind. Value</td>
<td>0.05</td>
<td>0.18</td>
<td>0.17</td>
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<tr>
<td></td>
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<tr>
<td></td>
<td>Ind. Value</td>
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<td>0.11</td>
<td>0.09</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
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<td>Number</td>
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<td>5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Ind. Value</td>
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<td>0.00</td>
<td>0.03</td>
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<td>Actinopterygii</td>
<td>Cypriniformes</td>
<td>Number</td>
<td>0</td>
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<td>128</td>
</tr>
<tr>
<td></td>
<td>Ind. Value</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Perciformes</td>
<td>Number</td>
<td>0</td>
<td>0</td>
<td>35</td>
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<tr>
<td></td>
<td>Ind. Value</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Table 2.3 Predators stomach items that were identified.

<table>
<thead>
<tr>
<th>Family</th>
<th>Species of prey</th>
<th>Micropterus punctulatus n=18</th>
<th>Micropterus salmoides n=7</th>
<th>Ictalurus furcatus n=13</th>
<th>Pylodictis olivaris n=5</th>
<th>Total n=43</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clupeidae</td>
<td>Alosa alabamae</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Dorosoma cepedianum</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Dorosoma petenense</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
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<td>Hiodontidae</td>
<td>Hiodon tergisus</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Cyprinidae</td>
<td>Carpiodes velifer</td>
<td>6</td>
<td>11</td>
<td>1</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Cyprinella venusta</td>
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<td>19</td>
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<td>0</td>
<td>32</td>
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<tr>
<td></td>
<td>Hybognathus nuchalis</td>
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<td>3</td>
<td>0</td>
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<td>4</td>
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<tr>
<td></td>
<td>Macrhybopsis storriana</td>
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<td>2</td>
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<td></td>
<td>Notropis longirostris</td>
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<td>1</td>
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<td></td>
<td>Notropis winchelli</td>
<td>6</td>
<td>3</td>
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<td>0</td>
<td>9</td>
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<td>Fundulidae</td>
<td>Fundulus olivaceus</td>
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<td>0</td>
<td>0</td>
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<td>1</td>
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<tr>
<td>Centrarchidae</td>
<td>Lepomis microlophus</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Percidae</td>
<td>Ammocrypta beani</td>
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<td>0</td>
<td>0</td>
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<td>1</td>
</tr>
<tr>
<td></td>
<td>Unidentified mussels</td>
<td>0</td>
<td>0</td>
<td>34</td>
<td>23</td>
<td>57</td>
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</table>
Table 2.4 Non-Parametric MANOVA of diet items between size classes (1) and river (2), Non-Parametric MANOVA of diet items between size classes with river as a covariate (3), and a Non-Parametric MANOVA of diet items between Alabama shad and skipjack herring (4). Significant P-values (< 0.05) are identified by (*).

<table>
<thead>
<tr>
<th>Number</th>
<th>Comparison</th>
<th>Df</th>
<th>Sums Of Sqs</th>
<th>Mean Sqs</th>
<th>F. Model</th>
<th>R²</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Size</td>
<td>1</td>
<td>0.51</td>
<td>0.51</td>
<td>3.11</td>
<td>0.03</td>
<td>0.031*</td>
</tr>
<tr>
<td>2</td>
<td>River</td>
<td>1</td>
<td>8.82</td>
<td>8.82</td>
<td>29.71</td>
<td>0.24</td>
<td>0.001*</td>
</tr>
<tr>
<td>3</td>
<td>Size vs. River</td>
<td>1</td>
<td>0.77</td>
<td>0.77</td>
<td>2.28</td>
<td>0.01</td>
<td>0.023*</td>
</tr>
<tr>
<td></td>
<td>Residuals</td>
<td>75</td>
<td>25.52</td>
<td>25.52</td>
<td></td>
<td>0.72</td>
<td></td>
</tr>
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<td></td>
<td>Total</td>
<td>76</td>
<td>35.62</td>
<td></td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Species</td>
<td>1</td>
<td>31.69</td>
<td>31.69</td>
<td>181.16</td>
<td>0.32</td>
<td>0.001*</td>
</tr>
<tr>
<td></td>
<td>Residuals</td>
<td>118</td>
<td>22.11</td>
<td>22.11</td>
<td></td>
<td>0.68</td>
<td>0.601</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>119</td>
<td>63.89</td>
<td></td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2.5 Shannon-Weiner Index values compared by ANOVA between rivers, size classes, and species. Significant P-values (< 0.05) are identified by (*).

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Mean diversity levels</th>
<th>Df</th>
<th>Sums Of Sq</th>
<th>Mean Sq</th>
<th>F Model</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apalachicola to Pascagoula</td>
<td>0.087 0.311</td>
<td>1, 72</td>
<td>65.230</td>
<td>0.906</td>
<td>24.306</td>
<td>&lt; 0.05*</td>
</tr>
<tr>
<td>&lt;70mm vs. &gt;70 mm</td>
<td>0.095 0.199</td>
<td>1, 72</td>
<td>24.672</td>
<td>6.233</td>
<td>11.231</td>
<td>0.112</td>
</tr>
<tr>
<td>Alabama shad to Skipjack herring</td>
<td>0.020 0.005</td>
<td>1, 161</td>
<td>84.350</td>
<td>0.524</td>
<td>12.935</td>
<td>&lt; 0.05*</td>
</tr>
</tbody>
</table>
Figure 2.1 Map of the two drainages sampled for Alabama shad and skipjack herring from 2007-2008. A- Pascagoula River, Mississippi; B-Apalachicola River, Florida. Sites: 1-Eastabuchie, 2-Petal, 3-New Augusta, 4-McLain, 5-Enterprise, 6-Shubuta, 7-Leakesville, 8-Lower Chickasawhay, 9-Merrill, 10-Wade, 11-Woodruff, 12-Blountstown, 13-Wewahitchka.
Figure 2.2 Non Metric Dimensional Scaling ordination (stress value = 13.17) of diet items from small (< 70mm) and large (> 70mm) juvenile Alabama shad in both rivers.
Figure 2.3 Non Metric Dimensional Scaling ordination (stress value = 13.17) of juvenile Alabama shad diet items from the Apalachicola and Pascagoula rivers.
CHAPTER III
HATCH WINDOW AND FIRST YEAR GROWTH COMPARISONS OF JUVENILE ALABAMA SHAD (ALOSA ALABAMAE) IN NORTHERN GULF OF MEXICO DRAINAGES

Abstract

In recent years, the Alabama shad has experienced dramatic declines and extirpations from drainages. Habitat degradation and barriers to migration are considered contributing factors to range contraction. Successful hatch windows were identified within two Northern Gulf of Mexico drainages. Timing and length of successful hatch windows differed between drainages. Age and condition (mass/SL$^3$) comparisons of Alabama shad between the two rivers suggested that river conditions, particularly flow and temperature, during spawning have large impacts on recruitment success. Differences in condition and growth of early-versus late-hatched fish were also seen, suggesting that river condition variability may also influence survival of age zero Alabama shad. Documenting and understanding the river conditions during successful reproduction may be important for river management of this threatened species.

Introduction

Migratory species invest significant amounts of resources in moving through a variety of disparate habitats to reach spawning habitats (Roff 1988; Gross 1987). For fishes, these costs can be substantial (i.e., osmoregulation, movement, exposure to predators and disease), and spawning migrations coincide with energetic demands associated with gonad maturation (Leggett 1977; Hodgson and Quinn 2002). These costs are also inextricably linked to a number of species life history traits (i.e., body size,
fecundity, age of maturation) that have coevolved with migration to maximize individual fitness (Gross 1987; Kinnison et al. 2001). Despite the evolution of complex behaviors, physiology and morphology associated with migration, many migratory species show substantial flexibility in the timing and migratory routes taken (Berthold 2001; Alerstam et al. 2003). Extreme examples of this include coexisting migratory and non-migratory populations of Artic char (Salvelinus alpinus) and brown trout (Salmo trutta) (Jonsson 1985).

There are also examples of species that have shown rapid secondary loss of migratory behavior when changes in the environment made it maladaptive (Berthold et al. 1992; Able and Belthoff 1998). In those cases, migratory capabilities were not completely lost. Thus, it is clear that migratory species maintain substantial flexibility in many aspects of migratory biology. For migratory species that are of conservation concern, understanding this flexibility, the environmental cues that trigger spawning runs (beginning the ascent up a drainage) and actual spawning, and population variability in the temporal scope of spawning are keys to proper management.

For migratory riverine species, migratory cues and spawn timing may be vital to successful recruitment. Most anadromous fishes initiate spawning migrations and spawn during seasonal shifts. In both temperate and tropical regions, these seasonal changes usually coincide with substantial changes in water temperature, rainfall or a variety of other factors (Malh et al. 1999). The environmental conditions during, and soon after spawning, can also be crucial for both hatching success and early juvenile survival. Thus, timing of reproduction in rivers may be important in allowing fish to use the potentially small successful hatch windows in rivers with variable conditions (Hodgson and Quinn 2002). Therefore, one might expect the ability to identify the proper environmental cues
to be under strong selection. Conversely, a less specialized strategy that allows for broad
temporal coverage of spawn times may be adaptive in highly variable systems (e.g., bet-
hedging strategy; Futuyma and Moreno 1988).

River conditions that are likely to be cues for migration include discharge, flow
velocity, temperature, suspended sediment, pH, conductivity, and dissolved oxygen.
These parameters also are susceptible to rapid changes during spring rains when river
discharge increases dramatically. Many of these parameters, including discharge and
temperature, also influence recruitment success in a variety of species (Secor and Haude
1995; Freeman et al. 2001). Flows and temperature are correlated with oxygen levels,
egg development time, and ultimately hatch success (Mann 1996). After hatching,
temperature and nutrient level variability is also expected to influence growth and
survivorship. Thus, individuals spawned early versus late in a season may have different
growth rates and mortality linked to the timing of spawning (Limburg 1996).

Fish otoliths (earbones) provide a detailed history of an individual’s daily and
annual growth and can provide a useful tool for retrospective assessment of early juvenile
growth rates. As fish grow, they produce daily rings on otoliths consisting of alternating
calcium and protein-rich layers (Armstrong et al. 2004). Strong diel feeding cycles lead
to variable growth, resulting in two distinct otolith rings in each twenty-four hour period.
Unlike other skeletal elements, otoliths do not undergo bone remodeling that would
potentially resorb layers (Simkiss 1974). Thus, otolith daily rings provide a method for
determining age in days of bony fishes. Validation of otolith age rings has been studied
extensively with American shad in northern drainages (shad between 50-300 days old)
(Limburg 1996). An age validation study by Lorson and Mudrak (1987) on American
shad found that 82% of the fish showed detectable daily rings through 152 days.
Immediately following hatch, American shad consumed yolk continuously for 5-10 days, resulting in a lack of daily rings during that period (Lorson and Mudrak 1987).

Alabama shad is an anadromous fish currently listed as endangered by the International Union for the Conservation of Nature (IUCN) and threatened by the American Fisheries Society. Many states list the Alabama shad as a species of greatest conservation need including: AL, AR, FL, GA, KY, LA, MS, and MO (Meadows et al. 2006). The Alabama shad ascend northern Gulf of Mexico rivers to spawn during the spring of each year. The Pascagoula River contains the only remaining population of Alabama shad in Mississippi, and the Apalachicola River in Florida has the largest known population. Population genetic data suggests that site fidelity is at least moderately strong within some populations of Alabama shad. As a result, differences in spawn timing and recruitment due to drift or local adaptation are possible (Bowen 2005).

Until recently, much of the basic biology for Alabama shad, *Alosa alabamae*, has been inferred from work done on the American shad in northern Atlantic basins. American shad are fairly well studied, with published work addressing fecundity, spawning, feeding behavior, and even restoration (Olney and McBride 2003; Walter and Olney 2003). Much less is known about the ecology of the Alabama shad. For example, no studies have addressed the species’ spawning ecology. The goal of this study was to improve understanding of Alabama shad spawning and early juvenile life history.

The objectives of this study were to determine if:

1. There are differences in the timing (both start time and duration) of hatching between rivers,
2. There are differences in river temperatures and discharge during hatch,
3. Age 0 condition and growth differ between years, and if
4. There are differences in growth and condition between early and late-
spawned fish.

Materials and Methods

To investigate drainage-level differences in reproductive timing and river
condition cues, juveniles were collected from the Pascagoula River in Mississippi from
2005-2008 and the Apalachicola River in Florida from 2007-2008 and aged by counting
daily otolith rings (Figure 3.1). Samples were taken in June and October in the
Apalachicola River and June through October in the(80,467),(917,994)
sampling period, 2007 was the only year to be categorized as a severe drought year by the
Palmer drought severity index for the region (Drought Monitor 2010). The other years
(2005, 2006, and 2008) were characterized as low water years but not identified as
drought.

Fish were collected with a Smith-Root™ SR-14EB electrofishing boat at 5,000
watts and 16 amps with pulses-per-second ranging from 7.5-120. Electrofishing effort
was typically 1200 s at each site. Alabama shad were weighed (wet weight, to the nearest
0.01 g) and measured (standard length [SL], to the nearest mm) in the field before being
individually tagged and placed in 95% ethanol.

During low water periods, some sites (typically shallow sand bars) were not
accessible by the electrofishing boat. Because Alabama shad go through ontogenetic
shifts in habitat use (Mickle et al. 2010), these sites were seined and occasionally cast
netted to ensure individuals of all ages were sampled throughout the sampling period.
Cast nets ranged from 1.52-2.43 m and all have a bar mesh of 1.59 cm. Seines were 3.0-3.7 m wide by 1.8-2.4 m deep with a 0.3 cm mesh.

Daily age was estimated by counting daily rings on the sagittal otoliths (Hendricks et al. 1991). One otolith per individual was removed and mounted on a slide using Primox™ resin. The otoliths were mounted with the primordia facing down and sanded by hand with sequential grits, as necessary, to expose the rings (Figure 3.2). Daily ring increments were counted with the aid of a high-powered Wild Heerbrugg (Gais, Switzerland) compound microscope. Magnification ranged from 290X to 1080X depending on the diameter (0.25-0.50 mm) of the otolith. Images of the otoliths were taken by a Spot Insight Color Digital Camera (Sterling Heights, Michigan) using Spot Advance Software and enhanced by Image Pro Express version 4.0.1 (North Reading, Massachusetts).

Age rings on each otolith were counted three times by the same person during separate sessions, and counts were averaged over the three observations. The otoliths of older fish (>250 days) became thick, making accurate reading of daily rings difficult. These older fish were removed from the analysis. As suggested by Lorson and Mudrak (1987), fish age was determined by adding ten days to each daily ring count to compensate for the post-hatching yolk stage that precedes daily ring formation. The hatch date for each individual was determined by counting back the fish’s age from its catch date. The successful hatch window for each drainage and year was defined as the period between the earliest and latest hatch date for all Alabama shad younger than 250 days captured within a drainage in a given year.

Standard length (SL) and mass data were used to calculate Fulton’s index ($K = \frac{W}{L^3} \times 100$) as a measure of fish condition. The calculation of $K$ assumes isometric
growth as shown in multiple species (Weber et al. 2003). Growth rates were compared by fitting von Bertalanffy growth curves for each drainage (pooling data for all years) to standard length and age data allowing the curve values to be compared. The von Bertalanffy growth function is used for length-based analyses of growth (von Bertalanffy 1942). Curves were fit to existing data and the growth constant ($k$) used to express growth rate. Mean daily river flows and temperatures during spawn times were recorded at the east mouth of the Pascagoula River by USGS flow gauge number 02480285 at HW 90. Mean daily flows and temperatures were recorded at Woodruff Dam on the Apalachicola River and obtained from Florida Wildlife Conservation Commission (Figure 3.1).

**Analysis**

I used analysis of variance (ANOVA) to test for differences in hatch dates (Julian date of individual fish hatching) between drainages and years. Once successful hatch windows were determined, mean, maximum and minimum river temperature and discharge within each hatch window were compared by ANOVA. Minimum and maximum discharges were transformed to relative measures by dividing by the mean discharge for that hatch window.

Differences in growth were compared by analysis of covariance (ANCOVA). I used ANCOVA to compare SL (with age as a covariate) between rivers and between late- versus early- hatched (last half vs. first half of each hatch window) fish within each river. Lastly, Fulton’s condition index of fish was compared between rivers and between early and late spawned fish within river by separate ANOVAs. Fish condition analyses were also separated by when fish were sampled (June vs. October) to avoid a size bias (fish
collected in October were typically larger than those collected in June). All analyses were performed on R statistical software (R Development Core Team, 2005).

Results

A total of 366 juvenile Alabama shad were collected over the four years; 270 from the Pascagoula River (85, 79, 49, 57 from 2005-2008, respectively) and 96 from the Apalachicola River (52 and 44 from 2007 and 2008, respectively). Daily ring counts were completed on 173 Alabama shad from the Pascagoula River and 53 from the Apalachicola River. Variability between repeated ring counts for individuals was low. Repeated counts typically yielded a difference of zero to four rings with a maximum disparity in one otolith of 18. In all otoliths, the interior rings (around the primordium) remained clear. Many fish collected in October had otoliths that were too thick to be aged accurately. These fish were removed from all analyses.

Within the Pascagoula River, successful hatch windows began on Julian days 32, 38, 38, and 32 in 2005-2008, respectively. The end of the hatch windows for those years were Julian days 58, 73, 65, and 79 (Figures 3.3, 3.4, and 3.5). For the Apalachicola River, the successful hatch windows began on days 6 and 9 in 2007-2008 and ended on days 64 and 67 for 2007-2008 (Figures 3.4 and 3.5). Median hatch day in the Apalachicola River was day 43 and 35 for 2007-2008 compared to day 48, 50, 55 and 57 in the Pascagoula River for 2005-2008. Successful hatch window length was longer in the Apalachicola River (Table 3.1) with an average window length of 58 (SD 0.0) days compared to 33.75 (SD 9.7) days in the Pascagoula River (Figures 3.3, 3.4, and 3.5). The distribution of hatch dates within the successful hatch window was similar between years and rivers (Figure 3.6).
River discharges and temperatures during hatch windows were variable but not significantly different between drainages (Table 3.1). Both drainages experienced warming periods within the hatch windows with increasing spring flows (Figures 3.3, 3.4, and 3.5). Averaging across years and rivers, mean temperature during initial hatch was 14.48 °C with an average discharge of 5217 m³/s.

Mean Fulton’s condition index (K) in both June and October was lower for fish collected in the Apalachicola River (1.33 in June, 1.24 in October) than in the Pascagoula River (1.69 in June, 1.46 in October) (Table 3.2). There were also differences in condition between early and late hatched fish in the Apalachicola River but not in the Pascagoula River (Table 3.2, Figure 3.7). Fish hatching later in the season in the Apalachicola River had significantly lower condition values than those hatching earlier (mean early=1.45 and late =1.36).

Growth rates of Alabama shad were also different between rivers (Table 3.3) and higher overall in the Apalachicola River ($k=58.29 +/- 6.4$ SE) than in the Pascagoula River ($k=47.42 +/- 3.5$ SE; Figure 3.8). The modeled growth curves indicated larger size differences in younger fish (Apalachicola River fish generally 10-15 mm longer at age 150 d) compared to older fish (largest individuals sampled were 118 and 120 mm in the Pascagoula and Apalachicola Rivers, respectively). The ANCOVA of SL, with age as a covariate, showed significant differences between rivers and between early and late hatched fish within each river (Table 3.3). The Alabama shad in the Apalachicola River were longer (both early and late hatch with age as a covariate) than those in the Pascagoula River (Table 3.3).

Discussion
Alabama shad hatch windows were significantly longer and earlier in the Apalachicola River than the Pascagoula River despite river conditions (temperature and discharge) being generally similar. Three possible explanations are: (1) the cues used to trigger spawning runs and cues used to trigger spawning differ between the rivers, (2) spawning times are similar, but the two populations differ in timing of successful hatching, and (3) spawning and successful hatch times are similar, but in the years sampled, differences in recruit survival gave the appearance of significantly different hatch windows. Earlier population genetic work on this species was consistent with some drainage level fidelity that would allow for population variability in the timing of spawning runs (Bowen et al. 2009). While temperature and discharge did not differ significantly between rivers, the river condition analyses suffered from low sample sizes. It is also possible that some other unmeasured (and variable between drainages) extraneous variable(s) play key roles as migration cues.

In general, hatch windows coincided with spring floods and increasing river temperatures. Migration of the Alabama shad sister species, the American shad, has been linked to river temperature (Leggett and Whitney 1972; Quinn and Adams 1996). It is possible that the discharge and temperature data used in this study (from a single gauging station in the Pascagoula and at an impoundment in the Apalachicola) are not on a fine enough spatial scale to detect ecologically meaningful differences. It is also worth noting that the Apalachicola River is impounded and that could have a buffering effect on temperature, flow and other potential cues. The buffering of these cues would be expected to prolong spawning windows by diluting otherwise strong signals induced by changes in temperature or discharge. Finally, I cannot rule out the possibility that spawning occurs over longer periods, and the drainages differ in time of successful
recruitment. There is always a possibility that other cohorts of Alabama shad were not collected or present in the analysis.

The information obtained regarding differences in hatch windows provides valuable information but does not allow for definitive conclusions on the mechanisms at work. Additional data are needed (both spatially and temporally) to elucidate these mechanisms. Tracking adults ascending and descending the river systems during these spawning runs would be valuable information. Adult sampling was attempted in the Pascagoula River, but only one adult was captured over a two year period. Unfortunately, this is a species in decline and sample sizes are likely to be too small or populations judged too imperiled to allow intensive adult sampling (e.g., Mobile Basin).

The initial experimental design included comparing samples from inland drainages in Arkansas and Missouri where spring increases in temperature would lag behind Gulf of Mexico drainages. However, three years of August sampling in these systems (at sites where fish had been collected earlier) yielded no fish.

The observed patterns in length and condition index could be attributed to plastic morphological changes in response to discharge. Current velocities during the growing season of the Alabama shad (June-October) are much higher in the Apalachicola River. Average surface flow velocity on the Apalachicola River taken during sampling between June and October of 2007 and 2008 was 44% higher than that of surface flow velocities at the confluence of the tributaries of the Pascagoula River (0.64 m/s vs. 0.44 m/s, respectively) (USGS 2010). Fish body shape is known to be quite plastic in response to water velocities encountered during development (Langerhans 2008). Brown trout (*Salmo trutta*) living in high flow velocities displayed a less robust body shape than fish in slower velocities (Pakkasmaa and Piironen 2001). The Alabama shad are an open
water, high velocity specialist. If Alabama shad are sufficiently plastic in body shape, drainage differences in flow velocity might be responsible for differences in shape, yielding differences in condition indices. Further, differences in shape induced by plastic responses to flow would result in non-isometric growth patterns, violating an assumption made when making comparisons using Fulton’s index. Alternative measures of fitness (i.e., using whole body shape or full body lipid composition) would help address this question but are not possible with fish preserved in ethanol. Ethanol preservation was necessary for otolith analyses but tends to alter both shape (specimen dehydration) and lipid composition.

A second possible explanation for the interdrainage difference in condition index is that resource levels differ between the drainages, or the larger population in the Apalachicola River creates more intra-specific competition. Low resource levels or increased competition would select for faster growth to utilize other resources that are not available to smaller, gape limited fish. This was seen in the pumpkinseed sunfish (*Lepomis gibbosus*) in which growth rates increased while condition suffered to utilize other resources (Arendt and Wilson 1997). The Apalachicola River with a higher population density of Alabama shad may similarly select for faster growth.

Within impounded systems, flow regimes may be managed through water release to mimic natural cues and allow populations to complete the spawning runs. Castro-Santos and Letcher (2010) found that flow-regulated systems altered migration timing of American shad. This resulted in decreased migration success in adults as well as reduced fecundity. Other riverine species have also been adversely impacted by altered flow regimes. Manipulated flows physically altered habitats resulting in decreased diversity of fish species (Freeman et al. 2001). Altering systems in which Alabama shad reproduce
may add stressors to the migration event and counter the evolutionary advantage of anadromy. As human populations grow along the drainages of Alabama shad populations, the balance of migration cost and reproductive success may be disrupted and cause the species to experience further extirpations.


Lorson, R. D. and V. A. Mudrak. 1987. Use of tetracycline to mark otoliths of


Mann, R. F. H. 1996. Environmental requirements of European non-salmonid fish

Meadows, D. W., S. B. Adams, and J. F. Schaefer. 2006. Threatened fishes of the
world: Alosa abalamae (Jordan and Evermann, 1896) (Clupeidae). Environmental

in Gulf of Mexico drainages. Page 157-170 in Limburg K., Waldman J., editors
Biodiversity, status, and conservation of the world’s shads. American Fisheries
Society Symposium 35, Bethesda, Maryland.

Alabama shad in the Pascagoula River drainage, USA. Journal of Ecology of
Freshwater Fish 19:107-115.

of American shad: revisiting the paradigm of reciprocal latitudinal trends in
reproductive traits. Pages 185-192 inK. E. Limburg and J. R. Waldman, editors.
Biodiversity, status, and conservation of the world’s shads. American Fisheries
Society Symposium 35.

Evolutionary Ecology. 14(8) 721-730.


INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE
NOTICE OF COMMITTEE ACTION

The proposal noted below was reviewed and approved by The University of Southern Mississippi institutional Animal Care and Use Committee (IACUC) in accordance with regulations by the United States Department of Agriculture and the Public Health Service Office of Laboratory Animal Welfare. The project expiration date is noted below. If for some reason the project is not completed by the end of the three year approval period, your protocol must be reactivated (a new protocol must be submitted and approved) before further work involving the use of animals can be done.

Any significant changes (see attached!) should be brought to the attention of the committee at the earliest possible time. If you should have any questions, please contact me.

PROTOCOL NUMBER: 07103101
PROJECT TITLE: Alabama Shad
PROPOSED PROJECT DATES: 08/01/2007 to 03/31/2010
PROJECT TYPE: Renewal
PRINCIPAL INVESTIGATOR(S): Jake Schaefer
COLLEGE/DIVISION: College of Science & Technology
DEPARTMENT: Biological Sciences
FUNDING AGENCY/SPONSOR: NOAA
IACUC COMMITTEE ACTION: Designated Reviewer Approval
PROTOCOL EXPIRATION DATE: 09/30/2010

[Signature]
Robert C. Bateman, Jr., Ph.D.
IACUC Chair

[Signature]
11-8-2007
Date
Table 3.1 ANOVAs comparing Julian day of hatch (1), and river condition (2) with temperature and discharge (separate ANOVAs) between the Apalachicola and Pascagoula rivers. Significant P values less than 0.05 are identified by (*).

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Mean Square</th>
<th>F value</th>
<th>N</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Days of hatch</td>
<td>4516.88</td>
<td>24.76</td>
<td>226</td>
<td>&lt; 0.05*</td>
</tr>
<tr>
<td>2. River Condition</td>
<td>Temp 4.53</td>
<td>17.79</td>
<td>6</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>Flow 103.33</td>
<td>18.31</td>
<td>6</td>
<td>0.09</td>
</tr>
</tbody>
</table>
Table 3.2 ANOVAs of Fulton’s condition index values (K) between rivers, early versus late hatch in Apalachicola River, and early versus late hatch in Pascagoula River (years combined). Significant P values less than 0.05 are identified by (*).

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Collection month</th>
<th>Df</th>
<th>Mean Square</th>
<th>F value</th>
<th>N</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apalachicola vs. Pascagoula</td>
<td>June</td>
<td>1,135</td>
<td>4.33</td>
<td>6.87</td>
<td>136</td>
<td>&lt; 0.05*</td>
</tr>
<tr>
<td>Apalachicola vs. Pascagoula</td>
<td>October</td>
<td>1,89</td>
<td>2.46</td>
<td>2.02</td>
<td>90</td>
<td>&lt; 0.05*</td>
</tr>
<tr>
<td>Apalachicola early vs. late</td>
<td>June</td>
<td>1,30</td>
<td>0.49</td>
<td>6.58</td>
<td>31</td>
<td>0.81</td>
</tr>
<tr>
<td>Apalachicola early vs. late</td>
<td>October</td>
<td>1,21</td>
<td>0.26</td>
<td>2.83</td>
<td>22</td>
<td>0.78</td>
</tr>
<tr>
<td>Pascagoula early vs. late</td>
<td>June</td>
<td>1,107</td>
<td>3.68</td>
<td>4.13</td>
<td>108</td>
<td>0.06</td>
</tr>
<tr>
<td>Pascagoula early vs. late</td>
<td>October</td>
<td>1,64</td>
<td>0.96</td>
<td>1.02</td>
<td>65</td>
<td>0.52</td>
</tr>
</tbody>
</table>
Table 3.3 The ANCOVAs of standard length with age as a covariate, between rivers, early versus late hatch in Apalachicola, and early versus late hatch in Pascagoula River (years combined). Significant P values less than 0.05 are identified by (*).

<table>
<thead>
<tr>
<th>Comparison (growth)</th>
<th>Mean (SL/Age)</th>
<th>Std. Dev.</th>
<th>Df</th>
<th>Mean Square</th>
<th>F value</th>
<th>N</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apalachicola vs. Pascagoula</td>
<td>87.2/173.6</td>
<td>24.9/41.4</td>
<td>1,225</td>
<td>4471.38</td>
<td>97.33</td>
<td>220</td>
<td>&lt; 0.05*</td>
</tr>
<tr>
<td>Apalachicola early vs. late</td>
<td>85.8/173.6</td>
<td>23.5/45.4</td>
<td>1,52</td>
<td>1039.93</td>
<td>8.68</td>
<td>53</td>
<td>&lt; 0.05*</td>
</tr>
<tr>
<td>Pascagoula early vs. late</td>
<td>74.4/173.1</td>
<td>18.6/34.9</td>
<td>1,172</td>
<td>822.16</td>
<td>6.19</td>
<td>159</td>
<td>&lt; 0.05*</td>
</tr>
<tr>
<td>Pascagoula early vs. late</td>
<td>55.3/154.1</td>
<td>20.4/49.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 3.1 Map of the two drainages sampled for Alabama shad and skipjack herring from 2007-2008. A- Pascagoula River, B-Apalachicola River. Sites: 1-Eastabuchie, 2-Petal, 3-New Augusta, 4-McLain, 5-Enterprise, 6-Shubuta, 7-Leaksville, 8-Lower Chickasawhay, 9-Merrill, 10-Wade, 11-Woodruff, 12-Wewahitchka, 13- Blountstown.
Figure 3.2 Image of a sagittal otolith from an Alabama shad at 200x magnification. Daily rings used for age estimation are visible.
Figure 3.3 Alabama shad successful hatch window for the Pascagoula River 2005 (A) and 2006 (B).
Figure 3.4 Alabama shad successful hatch window for the (A) Apalachicola River and (B) Pascagoula River 2007.
Figure 3.5 Alabama shad successful hatch window for the (A) Apalachicola River and (B) Pascagoula River 2008.
Figure 3.6 Distribution of successful hatch dates of Alabama shad within the Pascagoula River 2005-2008 and Apalachicola River 2007-2008. X-axis is the Julian day of hatch and the Y-axis is the number of fish in each set of days.
Figure 3.7 Von Bertalanffy growth curves of juvenile Alabama shad from each river.
**Figure 3.8** Differences in Fulton’s condition of Alabama shad from the Apalachicola and Pascagoula rivers between first and second half hatch windows.