Comparing the Hickory Shad (*Alosa mediocris*) and American Shad (*Alosa sapidissima)* Sport Fishery Using Age and Spawning Composition and Social Media.

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Abstract

The goal of this study was to compare aspects of Hickory Shad (*Alosa mediocris*) (Mitchell 1814) and American Shad (*Alosa sapidissima*) (Wilson 1811) life history while also providing supplemental information on their age and spawning composition, recreational catch and effort, and geographical distribution for future stock assessments. Hickory and American shads are anadromous fish species native to the East Coast of North America that ascend freshwater watersheds to spawn in the spring. Exactly how similar these two species are in life history is unknown, but the two species are co-managed federally by the Atlantic States Marine Fisheries Commission. Based on the 2020 stock assessment, American Shad are in a state of decline in multiple watershed along the spawning range, but it is unknown whether Hickory

Shad are experiencing the same decline because the lack of scientific literature makes a benchmark coastwide stock assessment impossible to complete.

The first objective of this study was to compare the age and spawning composition of Hickory Shad captured from different river systems across the range. Since aging protocols for Hickory Shad scales and sagittal otoliths were never published in the primary literature, the Massachusetts Division of Marine Fisheries American Shad Ageing Protocol was used in its place. A subsample of transversely sectioned otoliths was aged, coupled with otolith microchemistry, and compared to whole otolith ages. The results determined that Hickory Shad otoliths should be aged slightly differently than American Shad, an aspect of its life history that disagrees with the current co-management. Otoliths were the more precise aging structure, so a sex-specific age-length key for North Carolina was created from 240 Hickory Shad otoliths aged from the Rulifson Lab. The keys were then used to assign ages to length data provided by the North Carolina Wildlife Resources Commission (NCWRC) and North Carolina Division of Marine Fisheries (NCDMF) to create a length-at-age distribution. Fish used in this study were primarily grab samples from agency spring monitoring and so results may not accurately extrapolate to the entire spawning population; however, with the exception of Georgia the results here suggest a latitudinal repeat spawning gradient of increased iteroparity from south to north, a trend also observed for the American Shad.

Both species comprise important recreational fisheries throughout their ranges, so much so that a Facebook group named "NC-Shad" was created in 2013 by shad anglers to post about their fishing trips, successful or otherwise. From 2013-2020, a total of 1,790 posts were analyzed to determine angler demographics, lure characteristics, and catch information. From all posts, 78% (n=1,398) included location information, so Geographic Information Systems (GIS) was employed to examine spatiotemporal patterns in fishing location and Hickory Shad and American Shad Catch Per Post (CPP). Catch Per Post(or per interview in the case of a creel survey) was used in place of Catch Per Unit Effort (CPUE) because not every post indicated the number of anglers present, so effort could not be assessed based on this data collection method. Although significant spatiotemporal trends were not found based on both Hickory and American shad CPP, an overall positive trend in Hickory Shad CPP and negative trend in American Shad CPP are apparent throughout the study period. These opposing CPP trends suggests that something, whether it is anthropogenic or naturally occurring, is affecting American Shad more drastically than Hickory Shad. The "NC-Shad" CPP was also compared to the CSMA anadromous creel survey CPP obtained annually by the NCWRC, and multiple years within multiple watersheds were found to have significant differences in CPP for both Hickory and American shads. One caveat in this comparison is that creel surveys do not collect information from bank anglers, but many posts from "NC-Shad" were from bank anglers, which may explain some of the CPP differences. Results of my social media study demonstrated that social media is a technological adaption with potential to form a recreational angler citizen science network based on Local Ecological Knowledge (LEK). Social media data mining could be a cost-effective alternative to obtain supplementary information on recreationally important fish species, and viable technique for the future of fisheries management.

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TABLE OF CONTENTS

LIST OF TABLES xiii

LIST OF FIGURES xviii

CHAPTER 1: INTRODUCTION, OBJECTIVES, AND LITERATURE REVIEW 1

Diadromy 1

Hickory Shad *(Alosa mediocris)* and American Shad *(Alosa sapidissima)* 2

Management 6

Commercial and Recreational Fishery 8

The Role of Social Media in Management 10

Goals and Objectives 11

Literature Cited 16

CHAPTER 2: AGEING AND SPAWNING MARKS OF HICKORY SHAD 26

Abstract 26

Introduction 27

Methods 29

Sample Collection and Processing 29

Ageing Scales and Otoliths 31

Spawning Marks 35

Length-at-age Distribution 36

Results 37

Ageing Scales and Otoliths 37

Spawning Marks 39

Length-at-age Distribution 42

Discussion 44

Ageing Scales and Otoliths 44

Spawning Marks 49

Length-at-age Distribution 53

Literature Cited 56

CHAPTER 3: SOCIAL MEDIA AS A MANAGEMENT TOOL:ANGLER TRENDS AND SPECIES DISTRIBUTION USING HICKORY AND AMERICAN SHADS AS MODELS 96

Abstract 96

Introduction 98

Methods 104

Social Structure 104

Catch Per Post.. 107

Geographic Information Systems 108

Creel Survey Comparison 112

Results 114

Social Structure 114

Species Reported 114

Days of the Week 115

Number of Individuals Reporting 115

Gender and Age 116

Lure and Bait Type 117

Lure Color 117

Catch Per Post 118

CPP by Year 118

CPP by River 119

CPP Comparisons by River and Year 119

Geographic Information Systems 122

Creel Survey Comparison 126

Survey Overview 126

Descriptive Statistics 127

CPP/CPI Comparison 128

Discussion 130

Social Structure 130

Catch Per Post.. 135

Geographic Information Systems 138

Creel Survey Comparison 145

Literature Cited.. 149

CHAPTER 4: CONCLUSIONS AND RECOMMENDATIONS 175

Conclusions 175

Literature Cited.. 184

LIST OF TABLES

2-1. Number of paired Hickory Shad otoliths and scales by sex completed by three readers. Rivers ordered from north to south 63

2-2. Precision of age estimates of paired Hickory Shad otoliths and scales examined by three readers... 63

2-3. Absolute difference of Hickory Shad scale and otolith age estimates between three readers (n=240) 64

2-4. The precision and absolute difference of age estimates obtained between Hickory Shad otoliths and scales 64

2-5. GLM results of ageing Hickory Shad based on sex, method (scales vs otoliths), and reader. 65

2-6. Coastwide summary of age frequency (%) by year class of Hickory Shad collected from 10 locations in 2016, 2017, and 2018 (n=240) 65

2-7. Coastwide summary of repeat spawning (%) by age class of Hickory Shad collected from 10 locations in 2016, 2017, and 2018 (n=240) 66

2-8. Repeat spawning (% of total) of Hickory shad estimated from scales of adults collected from 11 watersheds (n=240).. 66

2-9. Repeat spawning of Hickory Shad summarized by state from scales of adults collected from 10 locations (n=220).. 67

2-10. Repeat spawning of Hickory Shad by river estimated from spawning marks on scales of adult fish collected from 10 watersheds (n=220) 67

2-11. Wilcoxon Rank Sum Test for Hickory Shad spawning and repeat spawning by state (n=220) 68

2-12. Wilcoxon Rank Sum Test for Hickory Shad spawning and repeat spawning by river (n=220) 68

2-13. North Carolina Hickory Shad length-at-age distribution summary statistics. 69

2-14. Summary contingency table for the North Carolina female Hickory Shad age-length key. 70

2-15. Summary contingency table for the North Carolina male Hickory Shad age-length key. 71

2-16. Mean age and total length for North Carolina male and female Hickory Shad 72

2-17. Mean age and total length for female Hickory Shad by river and capture year 73

2-18. Results of Wilcoxon Rank Sum Test for female Hickory Shad based on mean age, total length, and capture year for Contentnea Creek, a tributary of the Neuse River 74

2-19. Results of Wilcoxon Rank Sum Test for female Hickory Shad based on mean age, total length, and capture year for Pitchkettle Creek, a tributary of the Neuse River 74

2-20. Results of Wilcoxon Rank Sum Test for female Hickory Shad based on mean age, total length, and capture year for the Middle Neuse River 74

2-21. Mean age and total length for male Hickory Shad by river and capture year 75

2-22. Results of Wilcoxon Rank Sum Test for male Hickory Shad based on mean age, total length, and capture year for Contentnea Creek, a tributary of the Neuse River 76

2-23. Results of Wilcoxon Rank Sum Test for male Hickory Shad based on mean age, total length, and capture year for Pitchkettle Creek, a tributary of the Neuse River. 76

2-24. Results of Wilcoxon Rank Sum Test for male Hickory Shad based on mean total length and capture year per river. 77

2-25. Results of Wilcoxon Rank Sum Test for male Hickory Shad based on mean age, total length, and capture year for the Middle Neuse River. 77

3-1. Hickory Shad Catch Per Post (CPP) per year with all rivers combined (n=1786 posts). 155

3-2. Number of members who provided the percentage of total posts per year. 155

3-3. Hickory Shad Catch Per Post (CPP) per river with all years combined................. 156

3-4. Number of members who provided the percentage of total posts per year 156

3-5. Hickory Shad and American Shad Catch Per Post (CPP) per parent river per year. 157

3-6. Tukey HSD Post Hoc results based on Hickory Shad CPP per year for the Cape Fear River (n=61). 158

3-7. Captured Hickory Shad and American Shad by year at locations above removed dams 159

3-8. CSMA creel survey and "NC-Shad" Hickory Shad data comparison 160

3-9. CSMA creel survey and "NC-Shad" American Shad data comparison. 161

LIST OF FIGURES

1-1. Map displaying relative location of river spawning grounds, transitional zones, and overall collection sites of Hickory Shad during the 2016, 2017, and 2018 spawning runs used for age and spawning analyses 24

1-2. Example post from the Facebook group "NC-Shad". 25

2-1. CSMA creel survey and "NC-Shad" American Shad data comparison. 78

2-2. Photograph of an age-4 adult female Hickory Shad otolith displaying the translucent (fall/winter[F/W]) and opaque(spring/summer[S/S]) bands. 79

2-3. Photograph of a regenerated adult Hickory Shad scale not suitable for ageing 80

2-4. Photograph of a crystallized adult Hickory Shad otolith not suitable for ageing..... 80

2-5. Hickory Shad whole otolith transverse section indicating the opaque and translucent zones on the ventral side of the section. 81

2-6. Photograph of an adult Hickory Shad scale indicating repeat spawning marks. 82

2-7. Age-bias plot for Hickory Shad otolith age estimates between Readers 1 and 3..... 83

2-8. Column (A): Mean (points) and 95% confidence intervals of Hickory Shad otolith age estimates between readers.. 84

2-9. Age-bias plot for Hickory Shad age estimates between otoliths and scales 85

2-10. Number of individuals by each scale and otolith age estimate combination for Hickory Shad. 86

2-11. Photograph of an age-5 Hickory Shad scale indicating repeat and skip spawning. . 87

2-12. Age-bias plot for Hickory Shad spawning mark estimates between Reader 1 and 4. 88

2-13. Number of individuals by Reader 1 and Reader 4 spawning mark estimates for Hickory Shad (n=60). 89

2-14. ECU Rulifson Lab final estimated otolith ages used for the age-length key (n=160). 90

2-15. Length frequency plot for North Carolina female Hickory Shad 91

2-16. Length frequency plot for North Carolina male Hickory Shad. 91

2-17. Density Plot for North Carolina female Hickory Shad.. 92

2-18. Density Plot for North Carolina male Hickory Shad. 92

2-19. Age-7 females from the ECU Rulifson Lab, the NCDMF Creel Survey, the NCWRC Creel Survey, and the NCWRC Electrofishing Survey (n=113). 93

2-20. Age-6 males from the ECU Rulifson Lab, the NCDMF Creel Survey, the NCWRC Creel Survey, and the NCWRC Electrofishing Survey (n=135) 93

2-21. A) Mean age per capture year and B) mean total length per capture year for female Hickory Shad separated by river. 94

2-22. A) Mean age per capture year and B) mean total length per capture year for male Hickory Shad separated by river. 95

3-1. Total number of posts versus day of the week for all rivers and all years combined (n=1786) 161

3-2. Number of posts made based on calendar day for all years and rivers combined (n=1786). 162

3-3. Angler age class distribution that were reported to catch one or more Hickory Shad and/or American Shad (n=1837) 162

3-4. Lure types that reported to catch one or more A. Hickory Shad (n= number of posts containing lure type, n=426) and B. American Shad (n=49). 163

3-5. Lure colors that reported to catch one or more A. Hickory Shad (n= number of posts containing lure color, n=401) and B. American Shad (n=47). 163

3-6. Average Hickory Shad and American Shad CPP obtained from "NC-Shad" per year with all rivers combined (n=1786 posts)... 164

3-7. Average Hickory Shad and American Shad CPP obtained from "NC-Shad" per river with all years combined (n=1550 posts). 165

3-8. Average Hickory Shad CPP per year per river (n=1786 posts)............................. 166

3-9. Average American Shad CPP per year per river (n=1786 posts). 166

3-10. North Carolina fishing locations (n=83) reported from "NC-Shad" posts(n=1398). 167

3-11. Locations where at least one Hickory Shad and/or American Shad were captured and reported from "NC-Shad" posts (n=1398) along with current and removed locks and dams... 168

3-12. Emerging Hot Spot Analysis indicating significant hot spot trends based on fishing location from 2013-2020.. 169

3-13. Emerging Hot Spot Analysis indicating significant hot spot trends based on Hickory Shad CPP from 2013-2020 170

3-14. Emerging Hot Spot Analysis indicating significant hot spot trends based on American Shad CPP from 2013-2020... 171

3-15. Flow chart grouping recreational anglers based on participation within the "NC-Shad" Facebook group.. 172

3-16. Boxplot of Hickory Shad CPP calculated from the CSMA creel survey (n=437) and the "NC-Shad" Facebook group (n=728) per year per river.. 173

3-17. Boxplot of American Shad CPP calculated from the CSMA creel survey (n=437) and the "NC-Shad" Facebook group (n=728) per year per river.. 174

CHAPTER 1

INTRODUCTION, OBJECTIVES, AND LITERATURE REVIEW

Diadromy

Understanding the basic life history and distribution of a fish species is the basis for effective management. Some species exhibit complex migrations, either because of their broad ranges or because of their specific life histories (McDowall 2001). Diadromy, first described by Myers (1949), could be considered one of those complexities. Diadromous migrations are evolutionarily driven with a physiological cost between two environments -- freshwater and saltwater -- and occur at predictable times during specific life phases (McDowall 1997).

Anadromy, one form of diadromy, is when fish are hatched in freshwater, spend most of their lives in marine waters to feed, grow, and mature, then migrate from marine waters to continental freshwater watersheds to reproduce (McDowall 1987; 1997). The ability to move between different habitats allows anadromous fish to utilize high ocean productivity for growth, and coastal and inland nursery habitats and breeding grounds for a higher chance at successful reproduction and recruitment (Waldman et al. 2016). Although anadromy could have evolved due to improve access to food resources and reduce predation, this life history characteristic comes with osmoregulatory and energetic costs when moving from one environment to the other (Gross 1987; McDowall 1987; Limburg and Waldman 2009). Although this reproductive strategy is used by relatively few fish taxa, those species play important ecological roles in the environment (Meyers 1949). Spawning migrations made by anadromous fish bring marine-derived nutrients and energy into freshwater habitats, thus enhancing productivity and increasing nutrient availability within river systems (Samways et al. 2017).

Migratory movements of anadromous fish are very complex, mainly because they ascend hundreds of miles inland and are influenced by anthropogenic factors (Rulifson 1994; ASMFC 2010). Migration and growth patterns help delineate spawning populations, and those spawning populations may be clumped into stocks, or discrete management units. The definition of stock continues to evolve with management requirements and technological advances; thus, stock identification can be improved by a holistic approach based on morphometric, life history and genetic data (Begg and Waldman 1999). Like most life history parameters, age, growth, and distribution are influenced by environmental factors (Serchuk et al. 1994) but differentiating the effects of these factors may be difficult when the species in question is underrepresented in published literature.

Hickory Shad *(Alosa mediocris)* and American Shad *(Alosa sapidissima)*

The Hickory Shad, *Alosa mediocris (Mitchill 1814),* is a member of the family Clupeidae and was first described by Columbia University professor Samuel L. Mitchill as the Staten-Island Herring, *Clupea mediocris*, *Mitchill 1814* (Bean 1903). The American Shad, *Alosa sapidissima (Wilson 1811),* also a member of the family Clupeidae, was first described as *Clupea sapidissima*, *Wilson 1811* (Bean 1903). Both Hickory and American shad are anadromous alosines that have a native range spanning the Atlantic coastal ocean. Hickory Shad range from the Bay of Fundy, Canada to St. Johns River, Florida, with the spawning populations found between Pennsylvania and Northern Florida (Rulifson 1994; Smith 2018; Rulifson unpublished data). Waters south of Cape Canaveral, Florida are uninhabitable by Hickory Shad because of the tropical water temperatures (Williams et al. 1975). Similarly, the American Shad native range is from the St. Lawrence River in Canada to St. Johns River, Florida, but they were introduced to rivers on the Pacific coast in the 1800s and now range from Cook Inlet, Alaska, to Todos Santos Bay, Baja California (Howe 1981). Although American Shad have an obligate anadromous nature, one landlocked population exists in a reservoir in San Joaquin River on the Pacific coast (Zydlewski and McCormick 1997). My study will only focus on the native Atlantic American Shad stocks.

There are three known offshore aggregation locations for American Shad to overwinter: the Scotian Shelf/ Bay of Fundy, the Mid-Atlantic Bight, and off the Florida coast (Dadswell et al. 1987). Based on the same tagging study, three offshore summer aggregation locations were also found: Bay of Fundy/ Gulf of Maine, St. Lawrence estuary, and off the coast of Newfoundland and Labrador (Dadswell et al. 1987). Offshore survey data from the early 1980s indicated that Hickory Shad were present in continental shelf waters starting in November between Cape Lookout and Cape Charles, Virginia, and this is the first indication of a possible oceanic overwintering location (Rulifson et al. 2020). Hickory Shad have been found in the coastal sounds of North Carolina as early as October (Rulifson et al. 2020), but it is unknown how long adults remain in freshwater after they have spawned. The American Shad spring spawning migration begins in the south and continues north as water temperatures increase, and the spawning run lasts two or three months (Limburg et al. 2003), a fairly short time for these species to immigrate, spawn, and emigrate back to the ocean. North Carolina watersheds are utilized by alosines for spawning runs; the Neuse River, for example, contains migratory passages that are important for Hickory and American Shad life histories (Rock et al. 2018). Spawning of both species has been documented in the Roanoke (Harris and Hightower 2011), Tar (Smith and Rulifson 2015), both the mainstem Neuse and its branching tributaries (Burdick and Hightower 2006), and Cape Fear (Fischer 1980) rivers. The 2020 American Shad Stock

Assessment reported that the Cape Fear River is presumed to support the largest North Carolina American Shad spawning population (ASMFC 2020).

Hickory Shad, like many other alosines, initiates its spawning run based on temperature (Harris et al. 2007). There are few reported temperature ranges for Hickory Shad, but published literature indicates that Neuse River spawning occurs in water temperatures of 10-23^{o}C and in the Tar River between 11.9-25.1^{o}C; peak spawning occurs between 12-16^{o}C (Burdick and Hightower 2006; Harris and Hightower 2011; Smith and Rulifson 2015). Similarly, for American Shad water temperature is the primary factor that triggers spawning, but photoperiod, water flow, and turbidity also play a role (Leggett and Whitney 1972). Population-level responses to climate change vary, especially with species that rely on multiple habitats throughout the life span (Lynch et al. 2016). One study noted that North Carolina spawning runs have commenced earlier compared to studies done in the 1970s, which suggests that the gradual warming offshore temperatures may be causing these spawning runs to occur at the same temperatures, but earlier in the season (Smith and Rulifson 2015; Rulifson et al. 2020).

The age distribution of mature adult Hickory Shad ranges from two to eight years old (Rulifson et al. 1982), with the oldest fish estimated at nine years old (MDDNR 2016). American Shad generally complete their first spawning run between two and five years old (Dadswell et al. 1987), and the oldest fish was documented at 13 years old (Government of Canada 2016). Age and length-based life history parameters receive a lot of attention in stock identification studies because they are vital parameters used in yield and productivity calculations, which in turn provide the basis for stock assessment and management (Casselman et al. 1981). Scales and otoliths, or the fish ear bone, are the most common structures used to estimate Hickory and American shad ages, and an American Shad ageing protocol is included in the most recent coastwide stock assessment based primarily on the Massachusetts Division of Marine Fisheries published ageing protocol (ASMFC 2020). Scale ageing usually underestimates older fish and overestimates younger fish, which is why otoliths have become increasingly important in achieving accuracy (ASMFC 2020). One study found otoliths to be more precise between readers and ageing structures for American Shad (Elzey et al. 2015), but the use of otoliths to estimate age means sacrificing the specimen. Contrastingly, scales can be taken non-lethally, and they are also used to document spawning marks and repeat spawning (ASMFC 2020).

Hickory Shad are known to be iteroparous (spawn multiple years throughout a lifetime) throughout their range and spawn an average of three to five times before dying (Schaeffer 1976). American Shad have been found to spawn up to seven times before they die (Government of Canada 2016), but they also exhibit a latitudinal gradient of increased iteroparity from south to north (Leggett and Carscadden 1978) split into three regions: northern iteroparous (north of the Hudson River, New York), southern iteroparous (Hudson River, New York to north of the Cape Fear River, North Carolina), and semelparous (spawn once and die) stocks (Cape Fear River, North Carolina to St. Johns River, Florida; ASMFC 2020). This adaption may be a result of more consistent, predictable climates in the south, and more variable, erratic climates in the north (Roff 1992). There is no documented evidence of Hickory Shad exhibiting this same latitudinal spawning gradient (Greene et al. 2009). Iteroparous stocks of American Shad also exhibit philopatry (returning to their natal river) to spawn (Carscadden and Leggett 1975; Hendricks et al. 2002), with a degree of wandering (Melvin et al. 1985). Rulifson et al. (2020) utilized four different techniques (meristics and morphometrics, geometric morphometrics, otolith shape, and otolith chemistry) and found all methods suggested that Hickory Shad also home to natal watersheds with a degree of wandering.

Klauda et al. (1991) indicated that the lack of studies conducted on Hickory Shad is partially due to the lack of interest in the species compared to other alosines. Since Hickory Shad life history, migration, and stock status are understudied, fisheries agencies make assumptions about these aspects and believe they like that for the American Shad (*Alosa sapidissima*). If this is true, then the Hickory Shad could be managed the same way as American Shad, as is the current management strategy. However, the American Shad is in a state of decline throughout its range, and populations are threatened in multiple watersheds (ASMFC 2017, ASMCF 2020). On the other hand, the National Marine Fisheries Service estimated 5.6 metric tons of Hickory Shad landed in 1990, and by 1999, landings exhibited an exponential increase to 61.9 metric tons (Waldman and Limburg 2003). Therefore, one must conclude that there are differences between the two species causing the Hickory Shad to thrive while the American Shad continues to decline (Harris et al. 2007; Murauskas and Rulifson 2011). Recent fisheries management strategies are focusing more on an ecosystem-based approach -- encompassing many habitats and species -- so understanding linkages between environmental factors and species interactions have the utmost importance for successful ecosystem management (Kraus et al. 2015).

Management

It is challenging for fisheries managers to implement effective management strategies, especially for highly migratory species that travel between interjurisdictional management borders. Currently American Shad and Hickory Shad are managed together by the 1985 Interstate Fishery Management Plan (IFMP) for Shad and River Herring (ASFMC 1985), but the many aspects of American Shad life history applied to Hickory Shad have not been supported in the published literature. The 2007 American Shad stock assessment by the Atlantic States Marine

Fisheries Commission (ASMFC) focused on individual river stocks and reported that stocks were at all-time lows and were not recovering because of loss of habitat access and habitat degradation (ASMFC 2010, ASMFC 2017, ASMFC 2020). The ASMFC recently completed a benchmark stock assessment for American Shad in 2020 and assessed both coastwide and river-specific data, but because the species is considered a low priority and is highly migratory, data limitations make proper assessment difficult (ASMFC 2020). The 2020 American Shad Stock Assessment found that adult mortality for the Albemarle Sound and Neuse River is sustainable, but this can only be maintained if juvenile mortality is also sustainable, a parameter that is currently not collected for any river system coastwide. The abundance status for American Shad was found to be "not depleted" in the Albemarle Sound system, but the coastwide metapopulation was found to be depleted based on a dramatic decrease in landings since the 1950s (ASMFC 2020). American Shad are not the only anadromous species exhibiting major declines in abundance; multiple factors including overfishing, habitat degradation, migration restrictions due to dam construction, predation, and pollution are most likely responsible for the declines (ASMFC 2020). A coastwide stock assessment has been completed five times now for American Shad, whereas a coastwide assessment of Hickory Shad stock status has never been attempted (ASFMC 2020). Although Hickory Shad populations have not been adequately assessed, available information indicates that some stocks are healthy (Batsavage and Rulifson 1998; ASMFC 1999).

American Shad research has been extensive in the past but now is limited due to its precarious stock status; active stocking programs have offered some success in stock restoration efforts (Rulifson and Laney 1999). In 1998, the NCWRC began stocking American Shad fry in the Roanoke River at Weldon, North Carolina to restore a viable, self-sustaining population to the tributary (ASMFC 2020). American Shad fry were also stocked above the Kerr, Gaston, and Roanoke Rapids dams to evaluate downstream dam passage and whether trap and transport is a feasible option to enhance population abundance (ASMFC 2020). The Neuse River American Shad stocking program began in 2012 to supplement the wild population (ASMFC 2020). Amendment 3 to the Interstate Fishery Management Plan (IFMP) for Shad and River Herring states that one of the research needs is understanding Hickory Shad migratory behavior because this may explain why their populations continue to rise while other alosines, like the American Shad, Alewife (*A. pseudoharengus)*, and Blueback Herring (*A. aestivalis)*, continue to decline.

Commercial and Recreational Fishery

The American Shad was historically one of the top commercially fished species in the United States, with the total catch of 22,954 metric tons in 1896 -- considered an off year compared to previous years (Stevenson 1899). Between 2007 and 2017, coastwide commercial harvests averaged 224 metric tons, one-hundred-fold lower than harvests in the 19th century (ASMFC 2020). Commercial and recreational harvest in North Carolina are regulated by the North Carolina Division of Marine Fisheries (NCDMF) in coastal waters, and recreational harvest in inland waters by the North Carolina Wildlife Resource Commission (NCWRC) (ASMFC 2020). The North Carolina ocean commercial fishery for American Shad was closed in 2005, and today commercial seasons are set annually for the Albemarle Sound/Roanoke River, Tar/Pamlico River, Neuse River, and Cape Fear River (ASMFC 2020). During the early pre-spawning season, Hickory Shad comprise a major component of commercial shad harvest, and they are marketed together as “shad” for crab bait and in the local seafood markets, but Hickory Shad have a minor role in human consumption because of their bony nature (Whitehead 1985).

Beginning in 1989, a Hickory Shad population surge in the Albemarle Sound supported commercial fishing in the sound and a growing sport fishery in the Roanoke River (Greene et al. 2009). Hickory Shad and American Shad are still recreationally harvested for their roe, where it is usually flash-fried, but some consider Hickory Shad roe to be the most delectable of the other alosines (Nichols 1959).

In North Carolina, Hickory and American shads support a multi-million dollar recreational sport fishery in coastal rivers during the spawning runs, as documented by the NCDMF Central Southern Management Area (CSMA) spring creel survey data (NCWRC 2016). Since the late 1990s, the NCWRC has listed Hickory Shad and American Shad on the annual creel survey, a survey that collects catch, effort, and socioeconomic information from recreational anglers (ASMFC 2020). The North Carolina comprehensive recreational creel restrictions were implemented in 2012 and represents an overall 10-fish aggregate creel limit for both Hickory Shad and American Shad combined (ASMFC 2020). Each river system is different and creel limits have changed from 2012 to present day. Initial creel limits of the Albemarle Sound, Tar-Pamlico, coastal and joint waters of the Neuse, and Cape Fear allowed 10 fish with any combination of Hickory or American Shad. Only one creel limit remains the same today, and that is for the Tar-Pamlico. The Cape Fear allows only five of the 10-fish limit to be American Shad, the Roanoke and Neuse rivers only one of the 10-fish limit to be American Shad, and the Albemarle Sound has been split into inland waters, where 10 fish of any combination can be caught, and coastal and joint waters where only one American Shad is allowed with the 10-fish limit (ASMFC 2020). All CSMA creel surveys completed in North Carolina are non-uniform probability-based access point creel surveys, and one caveat for this survey is the misrepresentation of bank anglers: the CSMA creel survey only interviews boat anglers (ASMFC

2020). Considering the vulnerability of multiple American Shad stocks coastwide, it is critical that we gain a better understanding of both recreational boat and bank anglers. Social media may be a novel tool that allows management to obtain supplemental recreational data.

The Role of Social Media in Management

Inadequately understanding fisher behavior has resulted in unsuccessful fisheries management worldwide (Hilborn 2007). Socioeconomics is a huge driver of commercial and recreational fishery success. Fisher behavior is influenced by technological, ecological, and economic factors such as species distribution, market value, and catchability (Turner et al. 2014). The knowledge of a local fisher through traditional (TEK) or local (LEK) ecological knowledge can be an individual or social asset (Turner et al. 2014) depending on whether they share their ecological knowledge with the public, for example through social media platforms.

A section of this study used posts and comments from social media, specifically the Facebook group “NC-Shad”, to assess spatiotemporal trends for Hickory and American shads during their spawning ascension into watersheds along the North Carolina coast. At the individual level, fishers accumulate local ecological knowledge over time because of their experience throughout the fishing grounds (Turner et al. 2014). Hickory Shad are known to strike flies, small spoons, and other artificial lures (NCWRC 2010); a previous study looked at 61 adult migratory Hickory Shad stomachs from the St. Johns River, Florida and found 36.1% with animal or plant material present, suggesting that they feed during the spawning migration (Harris et al. 2007). Another study identified the gut contents of 212 fish from the Roanoke River and Albemarle Sound in North Carolina and found that an average of 27% contained fish, seeds, wood, and plastic (Rulifson and Batsavage 2014). Each fisher will have distinct individual knowledge because of differing experience, which expands the available fishing opportunities and fishing success (Branch et al. 2006).

Social relationships and sharing knowledge are important factors in acquiring information on when and where to fish (Gezelius 2007; Venturelli 2017), which in turn increases fishing efficiency and decreases time spent searching for productive fishing grounds (Rudd 2003). Science relies on observation and sharing information. Incorporating social media as a tool for supplementary information used in management shows the public that technology, social or otherwise, is an important tool for science inquiry. Utilizing social network platforms will help explore how information sharing influences fishing success (Turner et al. 2014). My study investigates whether public postings can be incorporated into scientific literature, and something as localized as a Facebook group post can help scientists and managers gather supplemental information for at-risk fish species.

Goals and Objectives

The overall goal of this study was to compare aspects of Hickory and American shad life histories while also providing supplemental information on age and spawning composition, recreational catch and effort, and geographical distribution for future stock assessments. The current chapter (Chapter 1) is devoted to a general literature review based on the goals and objectives presented. Chapter 2 evaluated Hickory Shad age and repeat spawning and assessed whether age could be estimated with the same methods used for American Shad. Two structures – scales and sagittal otoliths – were estimated for age from 240 Hickory Shad, and scales from the same individuals were examined for evidence of repeat spawning. The following was the first tested hypothesis of Chapter 2:

H_O: American Shad otolith and scale ageing methods = Hickory Shad otolith and scale ageing methods

H_A: American Shad otolith and scale ageing methods ≠ Hickory Shad otolith and scale ageing methods

Accepting the null hypothesis suggests that another commonality exists between the two life histories of these alosines and provides evidence that continued co-management may be sufficient. Rejecting the null hypothesis suggests that separate management should be considered, and a proper Hickory Shad ageing protocol must be established based on known-age fish, an aspect this study was unable to attain.

Age and spawning trends were compared between all North Carolina watersheds, two watersheds north of North Carolina, and two watersheds south of North Carolina (Figure 1.1). The second hypothesis tested in Chapter 2 is as follows:

H_O: scale age = otolith age

H_A: scale age ≠ otolith age

Accepting the null hypothesis indicates that both ageing structures accurately estimate Hickory Shad age, so either could be used in a future stock assessment. Rejecting the null hypothesis indicates that one structure is more accurate and precise compared to the other. The ages from the most precise and accurate structure were used to create an age-length key for North Carolina based on total length (TL) and age, which allowed me to estimate ages for Hickory Shad collected during NCWRC and NCDMF surveys.

The last objective of the Chapter 2 determined if repeat spawning differed along the Hickory Shad spawning range. American Shad are known to exhibit a latitudinal gradient of iteroparity; semelparous populations are abundant in the south, and an increase in iteroparity is apparent as you move north. It is known that Hickory Shad are iteroparous, so the final hypothesis is as follows:

> Hickory Shad will exhibit a latitudinal spawning gradient, with increased iteroparity from south to north.

If the hypothesis is accepted, another aspect of Hickory and American shad life history supports their continued co-management. If the hypothesis is rejected, biotic and abiotic factors presumably influence the two species differently which causes the differences in iteroparity.

The goal of Chapter 3 was to use social media, specifically the Facebook group "NC-Shad," to obtain information on Hickory and American shad distribution and recreational angler trends that may supplement future stock assessment and fisheries management plans. From 2013-2020, a total of 1,790 posts and comments from "NC-Shad" were used to assess member and angler demographics, fishing location, catch information, Hickory and American shad geographical distribution, lure characteristics, and Catch Per Post (CPP, Figure 1.2). Catch Per Post was used in place of Catch Per Unit Effort (CPUE) because not every post indicated the number of anglers present, so effort could not be assessed based the data collection method in this study. It is important to note that the anglers from "NC-Shad" were assumed to be targeting Hickory Shad and/or American Shad.

The Geographic Information Systems (GIS) Emerging Hot Spots Analysis tool mapped latitude and longitude waypoints obtained from the social media posts and identified spatiotemporal trends for fishing location, where a hot spot is considered higher than average number of posts for a fishing location compared to neighboring locations, and a cold spot is lower than average number of posts for a fishing location compared to neighboring locations. The first hypothesis for Chapter 3 states:

> The Emerging Hot Spot Analysis will indicate a significant spatiotemporal trend for fishing location.

An accepted hypothesis suggests that members of "NC-Shad" targeted Hickory Shad and/or American Shad at specific locations more often than others over time. This would also suggest a higher probability of intersecting anglers for annual creel surveys at specific locations, thus obtaining information in a more cost-effective manner. If the hypothesis is rejected, then there is no difference in fishing pressure between all reported locations over time.

The same tool was employed to assess significant spatiotemporal changes in mean Hickory Shad and American Shad CPP per month, where a hot spot is considered statistically significantly higher than average CPP in that month compared to neighboring locations, and a cold spot is statistically significantly lower than average CPP in that month compared to neighboring locations. CPP was calculated where one post = one unit of effort. Because the species were analyzed separately, the two hypotheses were as follows:

1. The Emerging Hot Spot Analysis will indicate a significant spatiotemporal trend for Hickory Shad CPP.
2. The Emerging Hot Spot Analysis will indicate a significant spatiotemporal trend for American Shad CPP.

An accepted hypothesis indicates a significantly higher or lower CPP over time, supporting the idea of an increase or decrease in the species abundance at certain locations. If either hypothesis is rejected, that suggests no significant changes in abundance have caused one location to have higher capture success compared to another.

The last objective of Chapter 3 was to compare the CPP calculated from posts from "NC-Shad" and compare them to the calculated CPI from the annual CSMA anadromous creel survey for the 2013-2019 period. One caveat was that not all interviews from the creel survey could be included, only those where the angler was targeting Hickory and/or American shads. The species were analyzed separately, and the hypotheses are as follows:

1. The annual Hickory Shad CPP calculated from "NC-Shad" is not significantly different from the annual Hickory Shad CPI calculated from CSMA anadromous creel survey data per year for the Tar and Neuse rivers.
2. The annual American Shad CPP calculated from "NC-Shad" is not significantly different from the annual American Shad CPI calculated from CSMA anadromous creel survey data per year for the Tar, Neuse, and Cape Fear rivers.

Accepting the hypothesis suggests that using posts from social media could be a cost-effective method to obtain a viable metric for catch and effort data comparable to what is used in stock assessments today. Rejecting the hypothesis implies that CPP calculated from social media cannot be accurately compared to the CSMA creel survey. One important difference between the collection methods is the anglers that are interviewed; the creel survey only interviews anglers at Boat Access Areas (BAAs), whereas the posts from "NC-Shad" include both boat and bank anglers.

Lastly, Chapter 4 combined the results from previous chapters to point out key findings and provide recommendations for future studies and implications for management.

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Figures

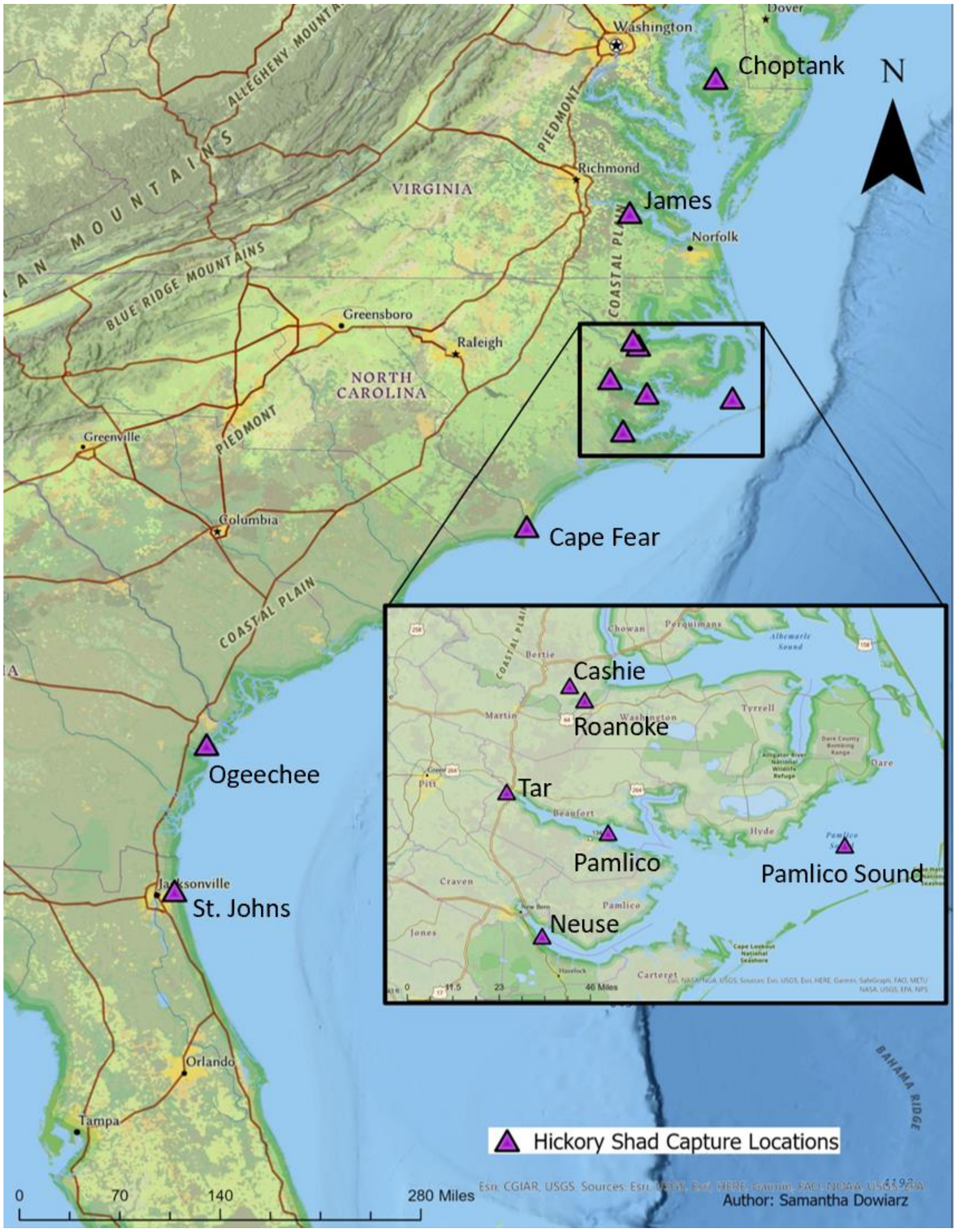

Figure 1.1. Map displaying relative location of river spawning grounds, transitional zones, and overall collection sites of Hickory Shad during the 2016, 2017, and 2018 spawning runs used for age and spawning analyses. Tributaries Contentnea Creek, Pitchkettle Creek, Swift Creek (Neuse), and Swift Creek (Tar) not shown.

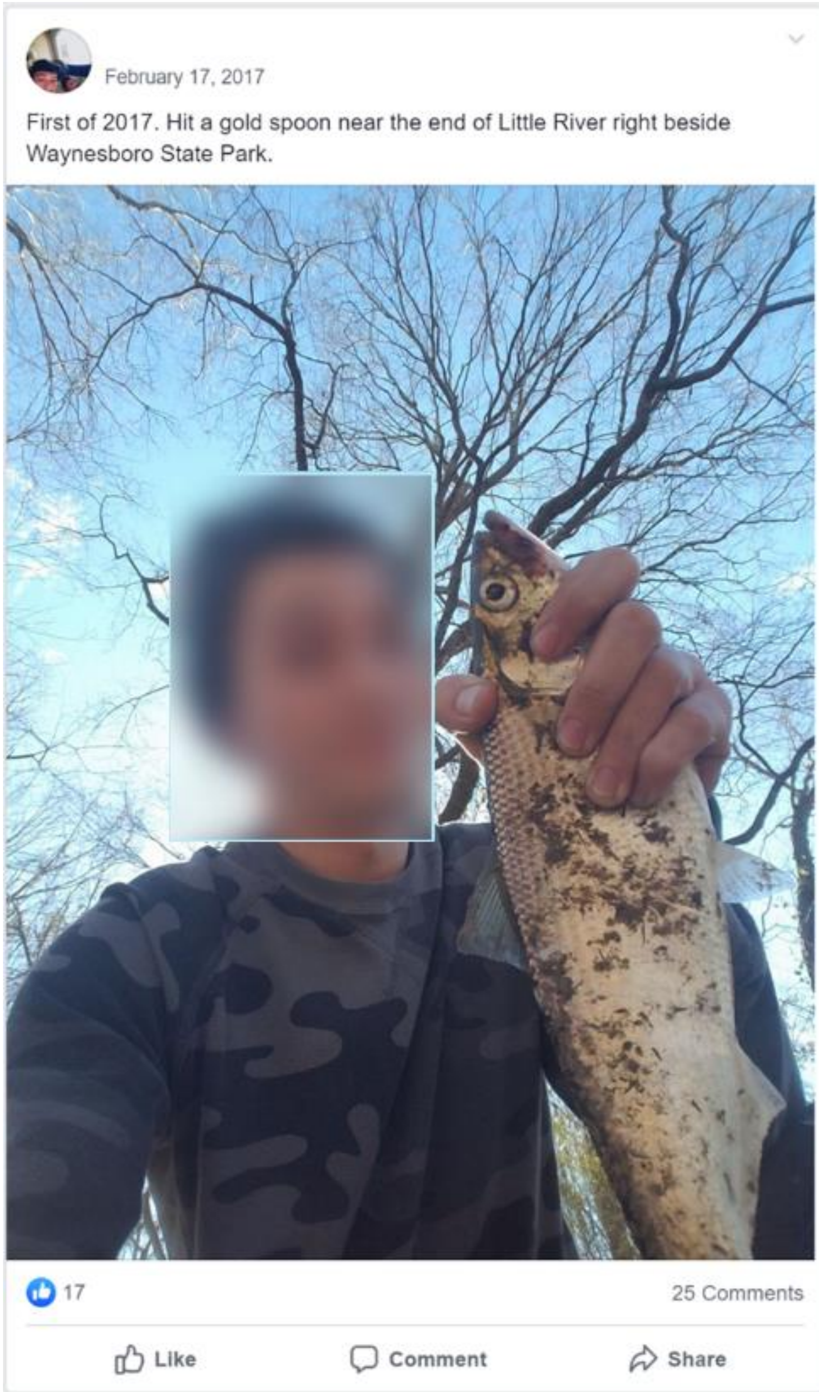

Figure 1.2. Example post from the Facebook group "NC-Shad." The date, location, angler demographics, catch, lure type, and lure color were reported and could be used for analyses in this study.

CHAPTER 2: AGEING AND SPAWNING MARKS OF HICKORY SHAD

Abstract

Two structures were used to estimate Hickory Shad (*Alosa mediocris*) age: sagittal otoliths and scales. Repeat spawning was estimated by examining the spawning marks from scales. In order to obtain information from watersheds within and outside North Carolina, about 20 individuals (10 males and 10 females if sample sizes allowed) were aged using both structures from the Roanoke, Cashie, Tar-Pamlico, and Cape Fear rivers in North Carolina. Because of the strong Hickory Shad spawning runs in three tributaries of the Neuse River, North Carolina, about 40 individuals were aged from that river. Outgroups were aged from the Choptank River on the northeast side of the Chesapeake Bay in Maryland, the James River on the southwest side of the Chesapeake Bay in Virginia, the Ogeechee River in Georgia, and the St. Johns River in Florida. Readable pairs of ageing structures -- otoliths and scales -- were obtained from 240 Hickory Shad (110 females, 130 males). Scale age estimates ranged from 2-5 years, and otolith age estimates ranged from 2-7 years old. A sex-specific age-length key was created for North Carolina based on the total length (TL) and otolith age, and the length data provided by the North Carolina Wildlife Resources Commission (NCWRC) and North Carolina Division of Marine Fisheries (NCDMF) were included to create a length-at-age distribution. Multiple tributaries of the Neuse River exhibited an apparent drop in both average age and total length over sampling years for both sexes. The same 240 individuals were examined for spawning marks. Skip-spawning was observed for multiple individuals from watersheds from every state. The number of spawning events ranged from 0-4 (i.e., a virgin spawner up to four previous spawning events) for females, and 0-3 for males. Fish from the Ogeechee River, Georgia, had the highest mean number of spawning marks (2.00) with the

Choptank River, Maryland coming in a close second at 1.95. The lowest average (1.25) was from the St. Johns River at the end of the species range. Fish used in this study were primarily grab samples from agency spring monitoring and so results may not accurately extrapolate to the entire spawning population; however, with the exception of Georgia the results here suggest a latitudinal repeat spawning gradient also observed for the American Shad.

Introduction

Fisheries assessments often rely on age composition data to infer information about growth, mortality, strong year classes and the outcome of current management policies (Coggins 2013). Age and length-based life history parameters receive a lot of attention in stock identification studies because they are the vital parameters used in calculations of yield and productivity, which in turn provide the basis for a stock assessment (Casselman et al. 1981). The word "stock" in this study is a discrete management unit self-sustained through reproduction, has similar growth and mortality parameters, and resides within a specific geographical area (Ludwig et al. 1993). Fisheries management relies on detailed information on life history parameters, but species with expansive ranges and/or migratory behaviors can make obtaining this information complex. The Hickory Shad (*Alosa mediocris*) is an example of a species with both life history complexities.

Hickory Shad range from the Delaware River in Pennsylvania to the St. Johns River in Florida, deeming them a multi-jurisdictional species. They are currently managed under Amendment 3 of the Atlantic States Marine Fisheries Commission (ASMFC) Interstate Fishery Management Plan (IFMP) for Shad and River Herring, but large areas of Hickory Shad life history information, such as age and spawning mark composition, are missing, so they are assumed to mirror those of American Shad. The IFMP for Shad and River Herring stated that research on within-species variation in reproductive and ecological characteristics may explain their intraspecific latitudinal differences (ASMFC 2010). Apparent increases in fishing effort in some rivers (Rulifson and Batsavage 2014) and ongoing environmental and anthropogenic changes within systems indicate that a greater understanding of migration, natal fidelity, and age composition would aid in the proper management of Hickory Shad.

The age distribution for mature Hickory Shad ranges from two to eight years (Rulifson et al. 1982), with a maximum age estimated at nine years old (MDDNR 2016), and females mature at least one year later than males (Rulifson and Batsavage 2014). A latitudinal trend exists for Hickory Shad, where a higher proportion of age two fish are mature in the south compared to populations in the north (Street and Adams 1969; Schaeffer 1976). American Shad populations along the Atlantic coast show a high rate of philopatry, or natal fidelity, with 97% of individuals spawning in their natal rivers (Melvin et al. 1992; Hendricks et al. 2002), but there is no documented evidence whether Hickory Shad exhibit the same trend (Rulifson and Batsavage 2014). On the other hand, Hickory Shad are iteroparous, or have multiple spawning cycles throughout a lifetime (Schaeffer 1976), and similarly an American Shad latitudinal gradient exists where increased iteroparity occurs from south to north (Leggett and Whitney 1972). Northern American Shad, however, have lower total fecundity compared to southern populations because of the higher prevalence of repeat spawning (Leggett and Carscadden 1978). In order to explain American Shad iteroparity, a study by Judy (1961) validated the Cating (1953) scale aging method for three age classes, ages four through six, for both virgin and previously spawned American Shad indicating that repeat spawning can be detected on scales (Judy 1961). In recent years, multiple state agencies, such as The Connecticut Department of Energy and

Environmental Protection, Delaware River Basin Fish and Wildlife Management Cooperative, Delaware Division of Fish and Wildlife, Pennsylvania Fish and Boat Commission, use scale samples to estimate repeat spawning (ASMFC 2020). It is important to note that the percentage of repeat spawners may fluctuate over time within the same river due to habitat destruction, fishing pressure, and other biotic and abiotic factors (Limburg et al. 2003).

In the current study, two methods were used to determine Hickory Shad age: otoliths and scales. Hickory Shad are iteroparous, or have multiple spawning cycles throughout a lifetime, and the only method to determine iteroparity is from estimating spawning marks from scales (Schaeffer 1976). Nowadays, otoliths are considered the most accurate method for ageing fish; however, using otoliths requires sacrificing the specimen and spawning marks are not visible. Development of age-length keys helps reduce the costs of direct-ageing all fish collected for a study (Coggins 2013). Using the estimated ages, the age-length key summarizes the relationship between age and length by taking a random subsample of aged fish and applying the key to the entire unaged sample. Hickory Shad lack proper management, and age-class structure and spawning trends are vital components of an effective management plan.

Methods

Sample Collection and Processing

A total of 1,081 Hickory Shad individuals were collected during the 2016, 2017 and 2018 spring spawning runs from 23 different rivers and seven of their tributaries. From north to south, they are the Susquehanna, Patapsco, Choptank, and Patuxent rivers, Maryland; the Potomac River, District of Columbia; the Nanticoke River, Delaware; the Rappahannock, Appomattox, and James rivers, Virginia; the Chowan River and three of its headwater tributaries, Meherrin, Nottoway, and Blackwater, also in Virginia; the Roanoke, Cashie, Pungo, Pamlico, New, and Cape Fear rivers, the Tar River and one of its tributaries, Swift Creek (Tar), and the Neuse River and three of its tributaries, Swift Creek (Neuse), Pitchkettle Creek, and Contentnea Creek, North Carolina; the Waccamaw and Santee rivers, South Carolina; the Altamaha and Ogeechee rivers, Georgia, and the St. Johns River, Florida. Hickory Shad collected in North Carolina away from the spawning grounds included these Pamlico Sound locations: Uncle Jimmy's Landing, Spencer Bay, Old New Inlet, Juniper Bay, Hatteras, Ocracoke, Clarks Reef, Caffee Bay, near the villages of Waves and Rodanthe, and by Brooks Creek; and a few specimens (n=5) were obtained from the Atlantic Ocean off Wrightsville Beach, all within North Carolina waters. All specimens were collected by rod and reel, gillnet, or electrofishing. Specimens from all states were collected and donated by the respective state or federal agencies. Additional specimens were collected in North Carolina by the Rulifson Lab with rod and reel and electrofishing (Scientific Collection Permit Number 17-SFC00133; AUP #D330). North Carolina fish came from the North Carolina Wildlife Resources Commission (NCWRC) or the North Carolina Division of Marine Fisheries (NCDMF).

After collection, all specimens were frozen in water to minimize freezer burn, transferred to the Rulifson Lab at East Carolina University, thawed and blotted dry, weighed to the nearest 0.01g, bagged individually without water, assigned unique identification numbers, and kept frozen (-20^{o} C) until examination. Before examination each sample was taken out of the freezer and fully thawed. Morphological characters were measured for morphometric analysis or counted for meristic analysis (Smith 2018). Gonads were weighed (nearest 0.01 g), gill rakers from the first arch of each side were counted and measured, and a dorsal fin clip was taken, placed in 95% ethanol (EtOH), and stored in a freezer (-80^{o} C) for genetic analysis.

Ageing Scales and Otoliths

Approximately 20 scales were collected from the left side of each fish from underneath the pectoral fin because often the scales below the dorsal fin were either severely disturbed or missing, perhaps from capture or from the freezing process. Obtaining scales from underneath the pectoral fin was the most reliable and productive location to obtain samples. Scales were dried and stored in individual manila coin envelopes containing a unique fish identification code. Scales were soaked in warm soapy water to remove any tissue or mucus, and a fine-bristled paintbrush was used to remove any residual dirt and mucus. Depending on the sizes of the scales, four to ten scales were mounted between two microscope slides. Once completely dry, whole-scale photographs were taken of three to four suitable scales for ageing using an Olympus SZX16 stereo microscope (0.5X lens and 2.0X magnification, transmitted light) and the CellSens Standard software package, Version 2.3.

The largest of the three otoliths – the sagitta – is used for ageing American Shad (*Alosa sapidissima*) and river herring, so they were removed for the Smith (2018) and Meyer (2019) studies and were employed in this study. After removal, the left and right otoliths were placed dry into plastic 1.5-mL microcentrifuge tubes labeled with the fish identifier code and otolith position (left or right). The otolith was first cleaned in distilled water using a fine-bristled paintbrush, dried, and placed sulcus side down in a drop of mineral oil on a petri dish. Photographs were taken of whole otoliths against a black background using an Olympus SZX16 stereo microscope (0.5X lens and 5.0X magnification), a 115-volt fiber optic reflected light, and CellSens Standard software package, Version 2.3. For consistency, the rostrum and anti-rostrum of the otolith faced left in each photograph. After capturing a photo, the otolith was rinsed with distilled water to remove any mineral oil residue, dried using a Kimwipe, and placed back in its respective 1.5-mL microcentrifuge tube.

A total of 240 fish from across the species range were used to determine age and spawning marks. About 20 individuals (10 males and 10 females if sample sizes allowed) were aged using both scales and otoliths from the Cape Fear, Cashie, Pamlico, Pamlico Sound, Roanoke, and Tar rivers in North Carolina, the Choptank River on the northeast side of the Chesapeake Bay in Maryland and the James River on the southwest side of the Chesapeake Bay in Virginia, the Ogeechee River in Georgia, and the St. Johns River in Florida. Because of the strong Hickory Shad spawning runs in three tributaries of the Neuse River, North Carolina, about 40 individuals were aged from that river. Since the Pamlico Sound is a passageway that leads to multiple rivers and individuals collected there cannot be accurately placed in a river, the sampled fish were included in descriptive statistics but removed from all inferential analyses.

Since there are no published methods for ageing Hickory Shad, we randomly selected 50 pairs of scales and otoliths as an instructional data set for training readers; this training set was not used in the subsequent ageing analysis. We used a method described in a MS thesis by Murauskas (2006). Briefly, one photograph for each specimen was aged independently a single time by three readers, and the two readers with the highest precision between both structures have their ages incorporated in analyses. If reader agreement was inadequate for a sample, the readers came to an agreed consensus age for that sample. All structures of a particular type were viewed together, and all estimations were completed before the viewing of a different structure one river at a time. Readers were not provided with information on fish length, sex, or date of capture. Once training was completed, the photographs of both structures were shared using the internet due to the severe COVID-19 restrictions not allowing the trained personnel to be in the laboratory during spring, summer and fall of 2020.

Otolith and scale ageing criteria for American Shad have been developed by the Massachusetts Division of Marine Fisheries (MADMF 2015) and were used as a guideline for this study. For scales, the annuli were counted from the center outwards on a 45^{o} plane parallel to the radii, and true annuli continued past the baseline, with the edge counted as the last annulus because the specimens were caught during the spring spawning run (Figure 2-1). Otolith annuli were counted from the center outward on the pararostrum, with one opaque and one translucent band equaling one annulus. The opaque bands equate to fast growth and are laid in the spring and summer, whereas translucent zones are laid down in the fall and winter when growth is slowest (Campana and Neilson 1985, Figure 2-2). Scales were considered suitable for ageing if they were not regenerated and were symmetrical and not irregularly shaped (Figure 2-3). Only suitable otoliths were aged, so any crystalized otoliths were removed (Figure 2-4).

Ages from whole otolith samples were compared to ages from a random subsample of otoliths transversely sectioned (Figure 2-5). These transversely cut otoliths had been embedded in an epoxy resin block and were initially used for otolith microchemistry. From each block a 0.5-mm thin section from the transverse midplane was cut with an Isomet low-speed saw (series 15HC diamond blade). Each cut was photographed using the Olympus BX41 microscope (4.0X, 10.0X, and 20.0X magnification, transmitted light) and the CellSens Standard software package, Version 2.3. The sectioning methods were those used by the Campana Lab at the University of Iceland. This procedure helped determine where the first annulus began and ended, which is the most apparent difference to that of ageing American Shad and river herring (MADMF 2015).

The precision of scale and otolith ages was determined with percent agreement (PA), a measure of agreement between ageing results from both structures from the same fish. PA was calculated with the following formula

$$\text{PA} = 100 \ * \ A/n,$$

where *A* is the number of fish where paired ages for scales and otoliths agreed, and *n* is the total number of fish aged (McBride 2015). The index of average percent error (APE), using the mean age as the divisor, was calculated as the degree of variation between readers and ageing structures (Beamish and Fourneir 1981; Libby 1985; Watkinson 2003). The APE index is calculated with the following formula:

$$\text{APE}_j = \frac{1}{N}\sum_{j=1}^{N}\left[\frac{1}{R}\sum_{i=1}^{R}\frac{|X_{ij}-\overline{X_j}|}{X_j}\right] * 100\%,$$

Where N fish are aged, and R is the number of times each is aged. X_{ij} is the *i*th age determination of the *j*th fish and X_j is the average age calculated for the *j*th fish (Beamish and Fourneir 1981). A lower APE index equates to greater precision, whether it be between readers or between ageing structures. The APE index was included in the analysis because percent agreement is a poor measure of precision when only a few year classes are present within a population (Beamish and Fournier 1981). Systematic bias can occur between readers or between ages for different structures. Because neither of the previous tests can detect bias or separate bias from imprecision, Bowker's unpooled test of symmetry was selected for these analyses (McBride 2015). Age-bias plots (Campana et al. 1995) were created to detect linear and non-linear biases in ageing. These plots look at each distinct age and can compare readers or ageing structures. All analyses described above were completed using R Studio Software (Version 3.5.2) under the guidelines of Dr. Derek Ogle and the fishR Vignette-Age-Precision and

Accuracy in Ages found at

http://derekogle.com/fishR/examples/oldFishRVignettes/AgeComparisons.pdf (Ogle 2018). The ageBias function uses one-sample t-tests corrected for multiple comparisons to test for differences in mean age estimates between readers or ageing structures (Koch et al. 2019).

Spawning Marks

Although previous studies have found scale age estimates to be less precise among readers compared to otoliths, scales still hold valuable information about spawning checks and iteroparity. Scales are the only structure known to contain spawning marks from adults that successfully spawn and migrate back to their marine habitats, information critical to management for fecundity estimates. Cating (1953) was the first to describe American Shad spawning marks as scar-like rings on scale margins in place of true annuli, but unlike the annuli they do not fully extend into the exposed, or posterior, portion of the scale. These marks form through erosion, absorption, or inhibition of growth when the fish undertake the spawning run (Cating 1953).

For consistency, the same 240 individuals estimated for ages were also used to examine spawning marks. Spawning marks were not easily distinguishable from annuli based on the photographs, so a microfiche reader was used to detect spawning marks and determine if repeat spawning exists for all watersheds (Figure 2-6). Cating's description pertains to Hickory Shad with a few caveats; the infolding spawning mark is clearest on the dorsal and ventral portions of the scale and usually becomes lost in the anterior portion between circuli, and the spawning mark disrupts and disconnects the circuli, forming a clearer "scar" compared to a normal annulus. Figure 2-6 highlights an example, but the photograph makes it difficult to detect such fine detail.

Spawning marks were counted from the center outwards on a 25° plane parallel to the radii, with the edge counted as the last spawning mark because the specimens were caught during the spawning run. The same three readers began estimating spawning marks, but the COVID-19 pandemic hindered access to the lab for two readers. Because of this, an experienced reader (10+ years for scales and spawning marks) estimated a random subsample (n=60) of scales for spawning marks. This reader will be considered Reader 4 for the remainder of the report.

Length-at-age Distribution

Each fish was measured to the nearest millimeter for standard length (SL), fork length (FL), and total length (TL). Samples that had a missing SL, TL, and FL were removed from analyses. Ageing protocols based on scales and otoliths are outlined above. Because Hickory Shad exhibit sexual dimorphism related to shape (Smith 2018), a sex-specific age-length key was created for North Carolina based on the TL and otolith age, and the length data from the annual NCWRC Electrofishing Survey. A regression line between TL and FL was used to manually compute TL for samples where the value was missing.

An age-length key summarizes the relationship between age and length by taking a random subsample of fish and applying the key to the entire unaged sample. For this study, a random subsample of fish from each river was aged from each 10-mm length interval. The construction and application of the age-length key followed Isermann and Knight (2005) and was created using R Software (Version 3.5.2) under the guidelines of Dr. Derek Ogle and the fishR Vignette-Age-Length Keys to Assign Age from Lengths found at http://derekogle.com/fishR/examples/oldFishRVignettes/AgeLengthKey.pdf (Ogle 2018). The age-length key was created using only fish aged by the ECU Rulifson Lab from North Carolina rivers. The semi-random method of assigning ages to individual fish was used, which states that the exact expected number of fish with a given length interval of a given age will be assigned that age, with the exception of fractionality (Isermann and Knight 2005). In the case of an odd number of unaged individuals in a length interval, fractionality is handled by assigning the fish to an age-group based on the probability it belongs to that group while also depending on the proportion of fish in each age (Ogle 2018).

Results

Ageing Scales and Otoliths

Readable pairs of ageing structures -- otoliths and scales -- were obtained from 240 Hickory Shad (110 females, 130 males), which were included in the statistical analyses (Table 2-1). Scale age estimates ranged from 2-5 years, and otolith age estimates ranged from 2-7 years. Because of the small sample size, otolith and scale samples with reader agreement of less than two were then mutually agreed upon by all three readers. Initial precision was measured between the three readers with a total percent agreement (PA) of 12.5% (30 of 240 scale samples with three reader agreement) and 13.75% (33 of 240 otolith samples with three reader agreement), respectively. The random sample of transversely sectioned otoliths had 70% agreement (21 of 30 otolith sections that agreed). The index of average percent error (APE) between all three readers was 15.02% for scales and 14.16% for otoliths.

Based on reviewed literature, many ageing studies can be carried out with an APE of less than 5.5% depending on the longevity of the species (Campana 2001). The lowest APE score in our study was between Readers 1 and 3 for otoliths (5.79%), indicating that otoliths provided more precise age estimates for Hickory Shad (Table 2-2). Reader 1 was considered the reference reader for all future tests because of the highest PA and lowest APE between readers (Table 2-2). The absolute differences between Readers 1 and 3 indicated 100% agreement ±3 years for both scales and otoliths (Table 2-3). Bowker's unpooled test of symmetry for estimated otolith ages between Readers 1 and 3 (χ^2=25.02, df=9, P<0.0001) indicated a random distribution among age classes between the two readers. Based on the age-bias plot between readers, Reader 3 slightly overestimated the younger ages (age 2 and 3) and underestimated the older ages ($\geq$ age 4) compared to Reader 1 (Figure 2-7). The corresponding otolith age estimates between pairs of readers follows the same pattern in varying degrees (Figure 2-8).

Precision was measured between structures (otoliths and scales) with a PA of 43.75% (105 of 240 estimated the same age). The APE index between structures indicated moderate agreement at 9.46%, with 43.75% complete agreement across both structures, and 43.33%, 11.67%, and 1.25% either above or below one, two, or three years for all fish, respectively (Table 2-4). With the truncated age classes (ages 2-7) due to the short-lived nature of Hickory Shad, Bowker's unpooled test of symmetry (χ^2=12.17, df=8, P=0.139) failed to reject the null hypothesis of random distribution among age class, and supported asymmetrical distribution of age estimates for each structure. Otoliths yielded the most precise ages, so they were used as the standard against scales for the age-bias plot. The Hickory Shad year classes ranged from 2010-2016, with females dominating ages 5 through 7, and males dominating ages $\leq$4 (Table 2-6). Based on the age-bias plot between structures, scales overestimated the younger ages (age-2 and age-3 individuals) and underestimated the older ages (starting at age-4 individuals) compared to otoliths (Figure 2-9). By age for both scale and otolith agreements 2, 51, 48, and 4 individuals perfectly agreed for ages 2, 3, 4 and 5, respectively, but only otolith estimates were available for age-6 and age-7 Hickory Shad (Figure 2-10).

Otolith and scale ages were reported for a subset of Hickory Shad from the NCWRC Neuse River boat Electrofishing survey. Using a Generalized Linear Model (GLM), we compared those ages and the respective total length measurements to those Neuse River samples that had been aged by ECU. The first GLM model was

$$TL = Age + Sex + Method + Reader,$$

where age ranged from ages 2-6, sex was male or female, ageing method was scales or otoliths, and reader was either NCWRC or ECU. Results of this full model indicated that all variables were significant at $P<0.0001$ (Table 2-4). The only age not showing significant contribution to the full model was age-5 (L-R $X^2 = 3.19$, $P=0.0742$). The model was then modified to use sex, method, and reader as the dependent variables by age class. The full model was not significantly different for age-2 fish but was for ages 3 through 6 (Table 2-5). Differences in ageing by sex were always highly significant. Method -- scales or otoliths -- was only significant for age-4 fish. Differences by reader were significant in age-3 and age-5 fish (Table 2-5).

Spawning Marks

Reader 1 evaluated spawning marks for 240 individuals (110 females, 130 males; Table 2-7). Although two of the three readers were not able to complete their spawning mark estimates due to COVID-19, an experienced reader (Reader 4) was able to examine 60 random individuals. Precision was measured between Readers 1 and 4 with a total PA of 78.33% (47 of 60 estimated the same number of spawning events). The APE index results indicated relatively high agreement between the two readers at 5.03%, with 78.33% exact agreement and 21.67% within one year. With the truncated number of repeat spawners (0-4 estimated spawning events) due to the short-lived nature of Hickory Shad, Bowker's unpooled test of symmetry (χ^2=3.29, df=3, *P*=0.349) failed to reject the null hypothesis of random distribution among age classes and supported asymmetrical distribution of age estimates for each structure. Based on the age-bias plot between Reader 1 and Reader 4, there was little systematic difference in the number of spawning mark estimates (Figure 2-12). Figure 2-13 compares the number of spawning marks estimated by Reader 4 and Reader 1. Since an APE of 5.5% is a threshold used by many ageing laboratories (Campana 2001), all further spawning mark analyses were completed with only one reader.

The number of spawning events ranged from 0-4 (i.e., a virgin spawner up to four previous spawning events) for females and 0-3 for males. A large portion of males were virgin spawners (45.4%), and the individuals with 1, 2, and 3 spawning marks made up 43.1%, 7.7%, and 0.8% of the sample, respectively (Table 2-7). A large portion of females spawned once previously (46.4%), and the individuals with 0, 2, 3, and 4 spawning marks made up 43.6%, 10%, 1.8%, and 1.8% of the sample, respectively (Table 2-7). Age-3 females were more often virgin spawners compared to age-4, where they were more likely to have completed a previous spawning event. This trend is also valid for males, but males showed a lower frequency of repeat spawning marks after two previous spawning events (Table 2-7). The Neuse and Tar rivers of North Carolina were the only rivers with individuals estimated with four previous spawning events (Table 2-8). Proportionally, the Pamlico River of North Carolina held the most female virgin spawners, whereas the St. Johns River of Florida had the highest number of male virgin spawners; overall both river samples were comprised of about 50% virgin spawners (Table 2-8).

Skip spawning is a rare occurrence. Out of the 240 individuals evaluated, a total of six individuals -- one male and five females -- were identified as skip spawners. The six Hickory Shad reported came from the Cashie (1 fish, 5%), Neuse (1, 5%), and Cape Fear (1, 5%) rivers in North Carolina, and the Ogeechee River, Georgia (3, or 15% of Ogeechee samples). Five individuals were age-4 and skipped spawning at 3 years old. The last individual was age-7 and skipped spawning at 4 years old. Although this species is short lived, a trend indicates Hickory Shad skip earlier in life compared to older ages, with five out of the six skipping at 3 years old.

The next tests examined whether the number of spawning events within the subsamples varied significantly by sex, state, or river. Because of the way samples were collected by agency staff, these results may not accurately represent the entire spawning population. Hickory Shad caught in the Pamlico Sound were removed from river analyses because they were not collected in a particular watershed. The highest mean number of spawning events (2.0 spawning events) came from the Ogeechee River, the only river sampled in Georgia, which also explains why it holds the highest average number of spawning marks for the states (Tables 2-9, 2-10). The lowest average number of spawning events (1.25 spawning events) came from the St. Johns River, again the only river sampled in Florida, which also explains its lowest mean value for the state (Tables 2-9, 2-10). Because the data failed to pass normality for sex (Shapiro Wilk Test = 0.81, $P<0.001$), state (Shapiro Wilk Test = 0.87, $P<0.001$), and river (Shapiro Wilk Test = 0.91, $P<0.001$), non-parametric Kruskal-Wallis rank sum tests were performed. Sex showed no significant differences (Kruskal-Wallis $\chi^2=0.86$, df=1, $P=0.353$), but both state (Kruskal-Wallis $\chi^2=19.85$, df=4, $P=0.0005$), and river (Kruskal-Wallis $\chi^2=25.98$, df=9, $P=0.002$) had significant differences. The Wilcoxon Rank Sum Test indicated which states and rivers were significantly different from one another based on the number of spawning events (Tables 2-10, 2-11). North

Carolina was significantly different from Maryland (*P*=0.054) and Georgia (*P*=0.019), and Florida was significantly different from Maryland (*P*=0.005), Virginia (*P*=0.019), North Carolina (*P*=0.043) and Georgia (*P*=0.001, Table 2-11). As for rivers, the Ogeechee River was significantly different from the Pamlico (*P*=0.028), Roanoke (*P*=0.035), and St. Johns (*P*=0.005) rivers, and the St. Johns River was significant different from the Cashie (*P*=0.023), Choptank (*P*=0.021), and James (*P*=0.046) rivers (Table 2-12).

Length-at-age Distribution

The North Carolina age data from the ECU Rulifson lab was used to create a sex-specific age-length key. From the ECU Rulifson Lab data, the NCDMF Creel Survey, the NCWRC Creel Survey, and the NCWRC Electrofishing Survey, total length ranged from 284-554 mm with a mean of 413.17 mm for females, and from 230-492 mm with a mean of 373.98 mm TL for males (Table 2-13). Age-4 fish dominated for females, and age-3 fish dominated for males based on the length frequency table (Table 2-13). Otoliths were found to be the preferred structure for ageing in this study (APE=5.79% between two readers), so otolith ages based on Reader 1 and Reader 3 age estimates were used for the construction of the age-length key. Figure 2-14 displays those ages against total length for each watershed. The three readers had no prior ageing experience, so that paired with the lack of known-age fish in this study is the reason why the age estimates between the two most precise readers were chosen to be used in the age-length keys. The random subsample of fish from each North Carolina river aged by the ECU Rulifson Lab did not span all NCWRC and NCDMR specimen length intervals, so fish outside of the age-length key length intervals were not given an estimated age (Tables 2-14, 2-15).

Estimated ages of the North Carolina subsampled fish varied significantly by river. Hickory Shad caught in the Pamlico Sound were removed from analyses because they were not assigned to a particular watershed. The highest average age for females (4.5 years old) was in Contentnea Creek, the mouth of Contentnea Creek, and Pitchkettle Creek, all tributaries of the Neuse River; the highest average age for males (4.1 years old) was in the mouth of Contentnea Creek (Table 2-16). The lowest average age for females (3.5 years old) and males (3.2 years old) came from the Tar River (Table 2-16). Throughout all sampled North Carolina rivers, the majority of females were age 4 and the majority of males were age 3 (Figures 2-15, 2-16). Based on the female density plot, age-6 or age-7 individuals may have been mis-aged because of the staggered appearance; alternative explanations could be high exploitation pressure on the largest females, or different growth rates between watersheds (Figure 2-18). If differences in growth do exist, this would most likely be attributed to genetics, especially because the majority of growth is suggested to occur in the ocean. Because the ocean distribution for Hickory Shad is unknown, it is assumed that they all intermix, thus reducing the chances of environmental factors influencing growth differences. The male density plot shows very wide distributions of younger fish, with lower variation in total length as fish get older (Figure 2-18).

Because the data failed to pass normality for river and female age (Shapiro Wilk Test = 0.902, $P<0.001$) and river and male age (Shapiro Wilk Test = 0.906, $P<0.001$), a non-parametric Kruskal-Wallis rank sum test was performed. Mean female age (Kruskal-Wallis $\chi^2=75.782$, df=12, $P<0.001$) and mean male age (Kruskal-Wallis $\chi^2=34.4$, df=12, $P=0.001$) and river were significantly different. An apparent bimodal distribution for age-6 males and age-7 females can be seen in their respective density plots (Figures 2-17, 2-18).

Final analyses compared the mean age and total length by capture year for rivers in North Carolina. Per river, any capture year with less than 10 individuals was removed from analyses. Capture year ranged from 2005-2019 for females and males (Tables 2-16, 2-20). Visually, four of the six rivers for female mean age, mean TL, and capture year had a negative slope (Figure 2-21), while a majority of the male mean ages and mean TL by capture year had a positive slope (Figure 2-22). Because each river failed to pass normality for female and male mean age, mean TL, and capture year, a non-parametric Kruskal-Wallis rank sum test was performed. All rivers with a significant *P*-value from the Kruskal-Wallis rank sum test for both males and females are presented in Tables 2-16 and 2-20. The Wilcoxon Rank Sum Test indicated for females that Contentnea Creek of the Neuse River had a significantly different mean age and TL between 2006 and 2018 (Table 2-18). Pitchkettle Creek of the Neuse River also had significant differences in mean age and TL by capture year between 2007 and 2018 (Table 2-19). As small as a two-year difference between sampling seasons showed significant difference between mean TL for females of the Middle Neuse (Table 2-20). Males also experienced a similar situation, but one-year differences were found for some rivers (Tables 2-22, 2-23, 2-24, 2-25).

Discussion

Ageing Scales and Otoliths

Understanding the age, growth, and distribution of a fish species is the basis for effective management, but Hickory Shad have no scale or otolith ageing protocol published in the literature. Cating (1953) aged American Shad by counting the number of transverse grooves and suggested this method could be used for similar species, so Street and Adams (1969) and Pate (1972) used this method for Hickory Shad. Pate (1972) used a now obsolete validation method, and Street and Adams (1969) failed to validate ageing in their study. A later publication found the transverse groove validation method inconsistent for all American Shad populations because transverse grooves function to improve scale flexibility relative to scale size and not be indicative of age (Duffy et al. 2011); therefore, the technique was disregarded in my study. Harris et al. (2007) aged Hickory Shad from the St. Johns River, Florida, Watkinson (2003) used aged Hickory Shad from the James River in her thesis, and both Batsavage (2013) and Murauskas (2013) aged adult Hickory Shad for their North Carolina studies, but again no details of the methodology were included in these studies. The database for electrofishing monitoring conducted annually by the NCWRC had scale or otolith ages for a portion of the data but the ageing protocol was undocumented, so they were not included in the analyses. Therefore, we went with the protocol developed by the Massachusetts Division of Marine Fisheries for American Shad (MADMF 2015).

In my study, researchers aged pairs of otoliths and scales for 240 Hickory Shad (110 males and 130 females) and compared the ages for each one of the pairs; otoliths appeared to produce the most reliable age estimate, which is a result of most studies comparing the two structures (Duffy et al. 2012; Elzey et al. 2015). The discrepancy in scale and otolith age accuracy and precision meant the null hypothesis was rejected (H_O: scale age = otolith age) and the alternative hypothesis was accepted (H_A: scale age ≠ otolith age). Murauskas and Rulifson (2011) remarked that the use of otolith microchemistry in ageing Hickory Shad may help confirm which structures represent annular rings, and which may represent habitat switching between freshwater and saltwater habitats especially within the first year of life. Hill (2020) contains detailed information about Hickory Shad otolith microchemistry, and a random subsample of transversely sectioned otoliths were compared to the final whole otolith ages. The 70% agreement between the whole and sectioned ages is high considering the low subsample size, but these were only used to support the whole otolith estimates and were not used in the analyses.

Earlier studies reported that the age distribution for mature Hickory Shad ranges from two to eight years (Rulifson et al. 1982, MDDNR 2015), and this still holds true using our protocol. Both male and female adult Hickory Shad ranged from 2-7 years old. Hawkins (1980) reported that age-3 and age-4 males were the dominant year classes, values similar to the mean ages in our study for the upper, middle, and lower Neuse River (Table 2-16). Fisher (1980) reported that males from the Cape Fear River had a mean age of 3.6, a value essentially the same as the mean age of 3.8 years found in our study.

Although there is a lack of known age fish to validate the accuracy of the age estimates, improving the understanding of possible Hickory Shad age variability associated with both scales and otoliths will lend corroboratory evidence as to which ageing method is preferred and produces higher precision and lower bias. Total percent agreement between all three readers was low for both scales and otoliths. Agreement between Reader 1 and Reader 3, however, was higher, which indicates that those readers were more successful at following the ageing protocol compared to Reader 2, especially because all readers had no previous ageing experience. The age-bias plot indicated Reader 3 overestimated younger fish ($\leq$3 years) and underestimated the older fish, a trend seen between the readers in this study and in a study of American Shad otoliths (Elzey et al. 2015). The asymmetrical distribution of age estimates between readers could be due to the low sample sizes for older individuals.

Previous comparisons of ageing structures from American Shad have shown otoliths to be the most accurate for known-age fish (Elzey et al. 2015), and although this current study lacks known-age fish, otoliths were found to be more precise and less biased than scales. The results from between-structure analyses found 43.75% PA between otolith and scale ages and an APE of 9.46%, indicating imprecision of age estimates from the two structures. Imprecision of otoliths and scale ages (57% exact agreement) was also reported in a study of Hickory Shad from the St. Johns River, Florida (Harris et al. 2007). Most disagreements were within one year, a trend also found in Elzey et al. (2015) for American Shad ageing structures. Otoliths tend to provide better precision and a larger range in ages compared to scales, and this theory has been found in other anadromous species such as Striped Bass (*Morone saxatilis)* in the Chesapeake Bay (Secor et al. 1995). The tests of symmetry between structures failed to reject the null hypothesis, again indicating an asymmetrical distribution of ages; however, scale ages of the most common age classes (ages 3 and 4) were most often within one year of the estimated otolith age (Figure 2-10). The lack of scale ages older than 5 years could indicate inability to discern annuli on scales of older fish likely due to erosion caused by multiple spawning events.

The comparison between the NCWRC and ECU readers determined that sex, method, and reader were significant for specific ages. Sex was significantly different for almost all ages because Hickory Shad exhibit sexual dimorphism, so the total length-at-age will vary for each sex. Method may not have been significant for all ages because the variability above and below the estimated ages was similar. For those ages that had a significant difference in method, readers were either consistently lower or higher in one method compared to the other so precision across all ages should be the same and all ages can be used for analyses. Reader was significant for age-3 and age-5 fish, which could be due to differences in the ageing protocol. ECU ages also were based on three readers, with two reader agreement, whereas NCWRC ages were based only on one reader, which may be one reason for the differences. Established Hickory Shad ageing techniques were not available prior to this study, and the assumption that

American Shad ageing protocols apply to Hickory Shad may have introduced unknown variability.

One distinction between the Hickory Shad and American Shad ageing was the discovery of the start of the first annulus, thus allowing us to reject the null hypothesis (H_O: American Shad otolith and scale ageing methods = Hickory Shad otolith and scale ageing methods) and accept the alternative hypothesis (H_A: American Shad otolith and scale ageing methods ≠ Hickory Shad otolith and scale ageing methods). Figure 2-5 details how the translucent and opaque bands match the otolith microchemistry, specifically when determining the first annulus. The inverse relationship between strontium and barium (high barium in freshwater) can be detected in Hickory Shad otoliths. The transition between environments in the first year of life is obvious with the steady drop in barium and increase in strontium, indicative of the fish transitioning from freshwater through brackish into marine waters (Figure 2-5). Slight peaks in barium and dips in strontium are seen near the other annuli, specifically at the outermost edge of the year-2 translucent zone, but nothing compared to the initial levels (Figure 2-5). This uncertainty makes validation tricky, which is why Hill (2020) urged that reasons for this unexpected pattern in barium should be explored in detail. A tag-recapture study with cultured and parentage-based tagged (PBT) larvae, similar to what is done for the stocked American Shad fry in the Neuse and Roanoke rivers (ASMFC 2020), would be needed for age validation. After validation, a reference collection of otoliths and scales should be compiled for each state or watershed. This collection would be a valuable tool for developing a Hickory Shad ageing protocol and training readers.

Spawning Marks

Ageing scales and estimating spawning marks uncovers the trends for spawning migration age and the rate of repeat spawning. Most populations of Hickory Shad and American Shad are thought to be iteroparous, meaning they have multiple spawning cycles throughout a lifetime (Schaeffer 1976). In order to explain American Shad iteroparity, a study by Judy (1961) validated the Cating (1953) scale ageing method for ages 4–6 for both virgin and previously spawned American Shad and indicated that repeat spawning can be detected on scales. A watershed with multiple reproductive age classes helps stabilize populations, and multiple spawning year-classes may increase the survival rate of juveniles in variable environmental conditions (Hsieh et al. 2010). To my knowledge, no published literature compares multiple watersheds along the east coast of the United States to determine if iteroparity occurs for Hickory Shad.

Although two of the three readers were not able to complete their spawning mark estimates due to COVID-19, an experienced reader (Reader 4) was able to examine scales from 60 random individuals, and 240 individuals (110 females, 130 males) were estimated for spawning marks by Reader 1 (Table 2-7). A portion of this study determined that iteroparity can be validated from scales for this species. Like other clupeids, skip-spawning was also observed for 6 individuals from the Cashie, Cape Fear, and Neuse rivers of North Carolina, and the Ogeechee River in Georgia. The small sample sizes from each river indicated that evidence of skip spawning was low; however, presence of skip spawning in this species should be examined in future studies with larger sample sizes over multiple age classes.

When fish forego spawning for a season due to low levels of stored energy or unfavorable environmental conditions, skip spawning could occur in any of the three forms:

retaining, resorbing, and resting (Rideout et al. 2005). Retaining is when a mature fish produces gametes that are never released, resorbing is when oocytes form but are resorbed via follicular atresia, or the breakdown of the follicle in the ovary, and resting is when secondary growth oocytes are absent and only primary growth oocytes are present throughout the year (Rideout and Tomkiewicz 2011). It is impossible to know which of the three forms caused skip spawning without histological analysis of the gonads, which is an important aspect to consider in future studies. Skip spawning was found for one male and five females, with the majority skipping spawning at 3 years old. Figure 2-11 indicates an age-5 Hickory Shad from the Cashie River that skipped spawning during Year 3. A previous study indicated an annulus formed between two spawning marks on individual Hickory Shad from the St. Johns River, Florida (Harris et al. 2007), but no other publications mention this phenomenon for other locations. One study found that almost 59% of American Shad in the St. Lawrence River, Canada did not spawn every year following the onset of maturation, skipping one or more seasons (Provost 1987). Secor and Piccoli (2007) used ^{87}Sr:^{86}Sr and Sr:Ca ratios in the otoliths of anadromous striped bass and concluded that a small proportion of individuals in the annual spawning run demonstrated skipped spawning. Results from Pate (1972) indicated that the reproductive potential of Hickory Shad increased with age, so future research should focus on Hickory Shad fecundity from each watershed or region. This may also lead to more in-depth explanation of the skip spawning phenomenon.

Based on ages from otoliths, mature Hickory Shad ranged from 2 to 7 years old, and most spawning individuals were age 3 or 4, which aligns with the Harris et al. (2007) study. It is apparent that both male and female Hickory Shad survive the stresses of spawning, with females completing up to five spawning events, and males four (Table 2-7). This is similar to the findings from Pate (1972), who reported that males from the Neuse River completed up to five spawning events. Fischer (1980) also found male and female repeat spawners in the Cape Fear River. Based on the Wilcoxon Rank Sum Test comparing states, Florida was significantly different from every state in terms of repeat spawning, with the St. Johns River holding the lowest average occurrence of repeated spawning compared to any other watershed (Tables 2-9 and 2-10). Conversely, North Carolina was significantly different from both Maryland and Georgia, but not the neighboring state of Virginia. In this study, North Carolina held the bulk of the samples (n=120) compared to any other state (n=20), which could have skewed the data.

The Wilcoxon Rank Sum Test comparing watersheds uncovered the specifics of the differences between states. The Ogeechee River, Georgia was significantly different from the Pamlico and Roanoke rivers of North Carolina and the St. Johns River, Florida (Table 2-12). It is no surprise that the St. Johns River is different, but the Roanoke River branches off Albemarle Sound, and the Pamlico River branches off the Pamlico Sound, two large estuaries that connect many other North Carolina Rivers in this study. The spawning conditions of both estuaries are likely similar enough not to influence the occurrence of repeat spawning for North Carolina Hickory Shad since watershed means are within 0.4 of each other (Table 2-10). This result might be indicative of wandering between adjacent watersheds, since fish sampled from the Ogeechee and St. Johns rivers had significant differences in iteroparity. Street and Adams (1969) reported that both male and female Hickory Shad from Georgia had up to five spawning events, whereas our study found a maximum of three spawning events for each sex (Table 2-8). Harris et al. (2007) found that more than half of the Hickory Shad caught in the St. Johns River, Florida were virgin spawners, a similar trend in this study (Table 2-8). As for the Neuse River, Pate (1972) suggested that female Hickory Shad usually make three spawning migrations; this study found females may participate in up to five spawning events which, along with the Tar River, was the most for any location (Table 2-8). It is unknown where Hickory Shad aggregate in the ocean after the spawning season, so future studies should examine the rate of post-spawn mixing in ocean habitats throughout the year to further elucidate these regional and watershed differences.

For American Shad, increased iteroparity follows a latitudinal gradient from south to north (Leggett and Whitney 1972). With the exception of the Georgia samples, this gradient of increased iteroparity from south to north is also apparent for Hickory Shad based on the mean number of spawning events, thus accepting the hypothesis that a latitudinal trend exists (Table 2-5). Future studies on differences in latitudinal fecundity between spawning populations of northern and southern Hickory Shad may show similarities in fecundity trends between the two shad species; northern American Shad have lower annual fecundity compared to southern populations attributed to the higher prevalence of repeat spawning of northern populations (Leggett and Carscadden 1978).

Ageing scales and estimating spawning marks uncovers the trends for spawning migration age and the rate of repeat spawning. Although scales can provide data regarding repeat spawning behavior, erosion that forms spawning marks can hinder the use of scales for accurate age estimates (Elzey et al. 2015). Otoliths were shown to be more precise than scales in this study; therefore, otoliths are recommended for Hickory Shad ageing. Understanding spawning stock age composition can help managers evaluate performance of management actions and inform future management decisions (Ailloud and Heonig 2019).

Length-at-age Distribution

An age-length key is vital in understanding demographic variations in recruitment, reproductive potential, and mortality (Ailloud and Heonig 2019). Assessing the ages for many fish could be very time consuming, which is why an age-length key is attractive. Changes in age composition through time can also provide insight on how a population is responding to exploitation and what capacity it must withstand and recover from overfishing and anthropogenic disturbance (Ailloud and Heonig 2019). The age-length key in our study was created by the ECU Rulifson Lab based on ages from the two most precise readers. It was important to minimize uncertainty, so the third reader's age estimates were thrown out for the age-length keys. Based on the otolith ages estimated from each watershed, sexes within the same age grouping display differences in length, thus supporting the creation of sex-specific age-length keys (Figured D). The truncated lengths and younger ages seen in the Roanoke River suggest overharvesting is occurring, and this may also explain the smaller fish within the Tar River (Figure 2-14). The age-length key was applied to the ECU Rulifson Lab data, NCDMF Creel Survey data, NCWRC Creel Survey data, and the NCWRC Electrofishing Survey data to estimate ages from total length. The majority of females were found to be age 4 and males age 3 (Table 2-13). Male Hickory Shad have been known to mature earlier than female Hickory Shad, which may explain this difference (Rulifson and Batsavage 2014). This theory can also be seen in Table 2-16, where average age for males is almost always lower than females in each river.

The length frequency plot for female Hickory Shad showed a normal distribution of ages, whereas the male plot had a slightly right skew indicating smaller individuals in the spawning run (Figures 2-15, 2-16). The wide distributions seen in both the male and female density plots for younger fish are associated with the rapid growth early in life. As Hickory Shad age, their energy stores are used less for growth and more for reproduction, which may explain the tighter distributions for older age classes (Figures 2-17, 2-18). The initial hypothesis on age-6 males and age-7 females was that individuals were separated by watershed, and their differences in growth caused the bimodal distribution. To test this, length frequency plots were created for only age-6 males and age-7 females (Figures 2-19, 2-20). Based on both graphs, it does not appear that the bimodal distribution is due to differences between rivers. Because the ocean overwintering and summer locations are unknown for Hickory Shad, we can assume that ocean environmental parameters are not greatly influencing their growth because they are likely exposed to the same ocean habitat.

It is beneficial to separate mean age and total length to evaluate differences between capture years. Some rivers had huge gaps in between adequate (more than 10 individuals per sex) sampling years, so changes in the age and length structure were apparent. For example, female and male Hickory Shad from Contentnea Creek were sampled well in 2006 and 2018, a 12-year gap that may uncover changes from anthropogenic and ecological effects (Tables 2-16, 2-20). One study found that the Neuse River was a major stream for Hickory Shad recreational harvest, and that still seems true today based on the apparent decreases in mean total length and mean age (Hawkins 1980). In Figures 2-21 and 2-22, males and females from Contentnea Creek and Pitchkettle Creek, both tributaries of the Neuse River, show a large drop in both average age and TL between sampling years. This may be due to an increase in fishing pressure, especially for the largest individuals. When the largest individuals are taken out of the gene pool, smaller, quick to mature individuals are left to contribute to the next generation. Over time, this causes the age and size structure of a mature population to get younger and smaller. Another interesting aspect is the majority of negative slopes for females, and majority of positive slopes for males (Figures 2-21, 2-22). Because Hickory Shad are sexually dimorphic, females are usually larger. This life history parameter may be why females seem to be decreasing in average age and total length at maturity, and males are increasing. Average age for each watershed can help infer the age structure of each spawning population and highlight rivers that have high levels of anthropogenic impacts that man contribute to premature death, slow growth, and early maturity in adults.

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Table and Figures

Table 2-1. Number of paired Hickory Shad otoliths and scales by sex completed by three readers. Rivers ordered from north to south.

River	State	Sex F	Sex M	Total
Choptank	MD	7	13	20
James	VA	10	10	20
Roanoke	NC	10	10	20
Cashie	NC	11	9	20
Tar	NC	10	10	20
Pamlico	NC	10	10	20
Pamlico Sound	NC	9	11	20
Neuse	NC	19	21	40
Cape Fear	NC	7	13	20
Ogeechee	GA	10	10	20
St. Johns	FL	7	13	20
Total		110	130	240

Table 2-2. Precision of age estimates of paired Hickory Shad otoliths and scales examined by three readers. Percent agreement and average percent error (APE) for each comparison.

Comparison	Method	Agreement (%)	APE (%)
Reader 1 vs 2	Scale	36.25	11.53
	Otolith	34.58	11.54
Reader 1 vs 3	Scale	63.33	6.45
	Otolith	66.25	5.79
Reader 2 vs 3	Scale	22.5	15.06
	Otolith	26.25	13.65

Table 2-3. Absolute difference of Hickory Shad scale and otolith age estimates between three readers (n=240). Values shown as percent agreement (±0), and disagreement within 1 year (±1), 2 years (±2), 3 years (±3), and 4 years (±4).

	Scale ages					Otolith ages				
Readers	±0	±1	±2	±3	±4	±0	±1	±2	±3	±4
1 vs. 2	36.25	40.83	15.83	6.67	0.42	34.58	44.58	17.08	3.33	0.42
1 vs. 3	63.33	26.25	10.00	0.42		66.25	27.08	5.42	1.25	
2 vs. 3	22.50	43.75	25.42	7.92	0.42	26.25	47.50	21.25	4.58	0.42

Table 2-4. The precision and absolute difference of age estimates obtained between Hickory Shad otoliths and scales. The percent agreement and average percent error (APE) are presented for each comparison. Values shown as percent agreement (±0), and disagreement within 1 year (±1), 2 years (±2), and 3 years (±3).

Estimated Ages					
±0	±1	±2	±3	Agreement (%)	APE (%)
43.75	43.33	11.67	1.25	43.75	9.46

Table 2-5. GLM results of ageing Hickory Shad based on sex, method (scales vs otoliths), and reader. Full model also included age as a variable. Asterisk (*) indicates significant difference at $p < 0.05$; Triple asterisk (***) = $p<0.0001$.

Group	n	df	X^2	$P>X^2$	Effect tests (effect, L-R X^2, P)
Full model	355	9	304.70	<0.0001	Age = 173.74***; Sex = 133.64***; Method = 17.66***; Reader = 14.12***
Age 2	34	3	4.37	0.2246	NSD
Age 3	88	3	60.96	<0.0001	Reader = 41.69***; Sex = 28.37***; Method = 1.527, P = 0.2165
Age 4	138	3	99.68	<0.0001	Sex = 74.80***; Method = 21.37***; Reader = 2.813, P = 0.0935
Age 5	57	3	16.76	0.0008	Sex = 13.488***; Reader = 4.416*; Method = 1.655, P = 0.1982
Age 6	29	3	33.37	<0.0001	Sex = 23.268***; Reader = 0.978, P = 0.32; Method = 0.218, P = 0.6408

Table 2-6: Coastwide summary of age frequency (%) by year class of Hickory Shad collected from 10 locations in 2016, 2017, and 2018 (n=240). Locations are Choptank, James, Cape Fear, Cashie, Roanoke, Tar, Pamlico, Ogeechee, and St. Johns rivers (each n=20); Pamlico Sound (n=20); and Neuse River (n=40).

			Age											
Year	n		2		3		4		5		6		7	
class	M	F	M	F	M	F	M	F	M	F	M	F	M	F
2010	1	2									100	50		50
2011	4	7							50	57	25	29	25	14
2012	21	21					71	62	29	33		5		
2013	42	41			41	46	60	54						
2014	38	25	8	8	68	52	24	40						
2015	22	14	14	14	86	86								
2016	2	0	100											
Totals(n)	130	110	8	4	61	45	49	45	8	11	2	4	1	2

Table 2-7. Coastwide summary of repeat spawning (%) by age class of Hickory Shad collected from 11 locations in 2016, 2017, and 2018 (n=240). Locations are Choptank, James, Cape Fear, Cashie, Roanoke, Tar, Pamlico, Ogeechee, and St. Johns rivers (each n=20); Pamlico Sound (n=20); and Neuse River (n=40).

			Spawning marks									
	n		0		1		2		3		4	
Age	M	F	M	F	M	F	M	F	M	F	M	F
2	8	4	4	8								
3	61	45	33	28	28	17						
4	50	44	19	10	23	28	8	6				
5	8	11	3	2	4	5	1	4				
6	2	4			1	1	1	1				2
7	1	2							1	2		
Totals	130	110	59	48	56	51	10	11	1	2	0	2

Table 2-8. Repeat spawning (% of total) of Hickory shad estimated from scales of adults collected from 11 watersheds (n=240).

	Female spawning marks						Male spawning marks					
Location	n	Virgin	1	2	3	4	n	Virgin	1	2	3	4
Choptank R.	7	14	72	14			13	31	46	23		
James R.	10	40	40	20			10	30	50	20		
Cape Fear R.	7	43	43	14			13	46	54			
Cashie R.	11	27	64	9			9	22	78			
Neuse R.	19	53	32	5	5	5	21	48	37	14	1	
Pamlico R.	10	60	30	10			10	80	10	10		
Pamlico Sound	10	30	50	10	10		10	60	40			
Roanoke R.	10	40	60				10	70	30			
Tar R.	10	40	30	20	0	10	10	60	40			
Ogeechee R.	10	20	70	10			10	10	70	20		
St. Johns R.	7	86	14				13	69	31			

Table 2-9. Repeat spawning of Hickory Shad summarized by state from scales of adults collected from 10 locations (n=220). Mean = average number of spawning marks ± standard deviation.

State	n	Mean	SD
1-MD	20	1.95	0.686
3-VA	20	1.85	0.745
4-NC	140	1.64	0.768
6-GA	20	2.00	0.562
7-FL	20	1.25	0.444

Table 2-10. Repeat spawning of Hickory Shad by river estimated from spawning marks on scales of adult fish collected from 10 watersheds (n=220). Mean = average number of spawning marks ± standard deviation.

River	n	Mean	SD
Ogeechee	20	2.00	0.562
Choptank	20	1.95	0.686
James	20	1.85	0.745
Cashie	20	1.80	0.523
Tar	20	1.76	0.995
Neuse	40	1.73	0.933
Cape Fear	20	1.60	0.598
Roanoke	20	1.45	0.510
Pamlico	20	1.40	0.681
St. Johns	20	1.25	0.444

Table 2-11. Wilcoxon Rank Sum Test for Hickory Shad spawning and repeat spawning by state (n=220). Asterisk (*) indicates significant difference at $p < 0.05$.

State	MD	VA	NC	GA
VA	0.708			
NC	0.054*	0.224		
GA	0.790	0.547	0.019*	
FL	0.005*	0.019*	0.043*	0.001*

Table 2-12. Wilcoxon Rank Sum Test for Hickory Shad spawning and repeat spawning by river (n=220). Asterisk (*) indicates significant difference at $p < 0.05$.

River	Cape Fear	Cashie	Choptank	James	Neuse	Ogeechee	Pamlico	Roanoke	St. Johns
Cashie	0.403								
Choptank	0.241	0.582							
James	0.452	0.936	0.717						
Neuse	0.945	0.433	0.276	0.499					
Ogeechee	0.138	0.422	0.867	0.562	0.138				
Pamlico	0.365	0.096	0.065	0.138	0.339	0.028*			
Roanoke	0.562	0.138	0.096	0.219	0.561	0.035*	0.597		
St. Johns	0.138	0.023*	0.021*	0.046*	0.138	0.005*	0.696	0.365	
Tar	0.924	0.553	0.365	0.562	0.936	0.233	0.353	0.557	0.138

Table 2-13. North Carolina Hickory Shad length-at-age distribution summary statistics. Data provided by the ECU Rulifson Lab data, the NCDMF Creel Survey, the NCWRC Creel Survey, and NCWRC Electrofishing Survey data.

	Female					Male				
Age	n	Mean TL	SD	Min TL	Max TL	n	Mean TL	SD	Min TL	Max TL
2	13	344	21.39	306	359	105	328.0	28.44	230	369
3	517	379	23.63	284	419	1300	359.5	29.79	282	409
4	1067	417	30.29	321	469	856	368.6	20.31	288	399
5	198	405.4	22.84	321	429	560	408.7	26.4	302	439
6	192	479.1	23.6	364	554	135	387.9	10.02	370	399
7	113	442.6	19.71	420	469	88	452.1	11.51	440	492

Table 2-14. Summary contingency table for the North Carolina female Hickory Shad age-length key. Length categories in 10-mm increments; age estimates from otoliths (n=77).

	Female age (years)					
TL(mm)	2	3	4	5	6	7
280		1				
300	1					
310		1				
320			1	1		
330		1	1			
340		1				
350	1	4	2			
360		7	5	1	1	
370		7	4	1		
380		4	1	1		
390		1	6	0		
400		3	3	1		
410		1	5	2		
420			1	1		1
430			3			
440			1			
460			1			1
470					1	
480					2	
n	2	31	34	8	4	2
Mean	333	369	393	389	452	444
SD	33.9	25.4	31.9	33.2	58.9	30.4

Table 2-15. Summary contingency table for the North Carolina male Hickory Shad age-length key. Length categories were in 10mm increments. Age estimates were from otoliths (n=83).

	Male age (years)					
TL(mm)	2	3	4	5	6	7
230	1					
250	1					
260	1					
270	2					
280		4	1			
290	1	4				
300		2	1	1		
310	3	2		1		
320		4				
330		3	2			
340	1	5	2			
350		7	6			
360	1	7	6			
370		4	2	1	1	
380		1	6			
390			1	1	1	
400		1				
410				1		
440						1
n	11	44	27	5	2	1
Mean	296	339	360	360	384	445
SD	41.4	31.7	23.7	46.7	13.4	

Table 2-16. Mean age and total length for North Carolina male and female Hickory Shad. Data provided by the ECU Rulifson Lab data, the NCDMF Creel Survey, the NCWRC Creel Survey, and NCWRC electrofishing data. Rivers in order from north to south.

	Female			Male		
River	n	Mean age	Mean TL	n	Mean age	Mean TL
Roanoke	20	3.9	376.9	23	3.4	342.7
Cashie	17	4.1	395.8	17	3.6	356.6
Tar (Upper)	119	4.1	407.8	100	3.9	383.6
Tar	32	3.5	375.0	24	3.2	328.3
Pamlico	38	3.6	384.5	26	3.5	350.8
Neuse (Upper)	60	3.9	404.3	131	3.6	365.6
Neuse (Contentnea Creek)	28	4.5	428.8	28	3.8	384.0
Neuse (Contentnea Creek Mouth)	25	4.5	439.8	33	4.2	386.9
Neuse (Middle)	666	3.9	400.8	540	3.7	368.7
Neuse (Pitchkettle Creek)	209	4.5	432.7	227	3.9	372.8
Neuse (Lower)	80	4.1	410.7	74	4.1	381.5
Neuse (Swift Creek)	17	3.7	387.1	25	3.5	370.6
Cape Fear	13	4.0	407.0	40	3.8	371.1

Table 2-17. Mean age and total length for female Hickory Shad by river and capture year. Data provided by the ECU Rulifson Lab data, the NCDMF Creel Survey, the NCWRC Creel Survey, and NCWRC electrofishing data. Rivers in order from north to south.

River	Capture year	n	Mean age	Mean TL	SD
Upper Tar	2017	14	3.9	409.9	1.231
Upper Tar	2019	93	4.1	408.8	0.971
Upper Neuse	2013	16	4.1	402.4	0.854
Upper Neuse	2016	13	3.7	381.8	0.855
Neuse (Contentnea Creek)	2006	11	5.1	450.6	0.944
Neuse (Contentnea Creek)	2018	17	4.1	414.6	1.166
Middle Neuse	2012	70	3.9	389.1	0.900
Middle Neuse	2013	102	3.8	387.4	0.814
Middle Neuse	2014	144	3.8	393.3	0.752
Middle Neuse	2015	44	3.9	396.5	0.802
Middle Neuse	2016	45	3.9	399.0	0.809
Middle Neuse	2017	84	4.2	411.5	1.141
Middle Neuse	2018	115	4.1	415.4	0.890
Middle Neuse	2019	62	4.2	416.4	0.955
Neuse (Pitchkettle)	2005	149	4.5	433.2	1.250
Neuse (Pitchkettle)	2007	30	4.8	444.7	1.073
Neuse (Pitchkettle)	2018	15	3.7	395.3	0.594
Lower Neuse	2014	28	4.4	408.9	1.162
Lower Neuse	2017	12	3.8	404.8	0.835
Lower Neuse	2018	12	4.0	414.5	0.739
Lower Neuse	2019	21	4.1	414.8	0.995

Table 2-18. Results of Wilcoxon Rank Sum Test for female Hickory Shad based on mean age, total length, and capture year for Contentnea Creek, a tributary of the Neuse River. Asterisk (*) indicates significant difference at $p < 0.05$.

Mean age vs capture year		Mean TL vs capture year	
	2006		2006
2018	0.023*	2018	0.038*

Table 2-19. Results of Wilcoxon Rank Sum Test for female Hickory Shad based on mean age, total length, and capture year for Pitchkettle Creek, a tributary of the Neuse River. Asterisk (*) indicates significant difference at $p < 0.05$; Double asterisk (**) = $p<0.001$.

Mean age vs capture year			Mean TL vs capture year		
	2005	2007		2005	2007
2007	0.160		2007	0.511	
2018	0.0380*	0.0051*	2018	0.0033*	0.0009**

Table 2-20. Results of Wilcoxon Rank Sum Test for female Hickory Shad based on mean age, total length, and capture year for the Middle Neuse River. Asterisk (*) indicates significant difference at $p < 0.05$; Double asterisk (**) = $p<0.001$.

Mean age vs capture year								Mean TL vs capture year							
	2012	2013	2014	2015	2016	2017	2018		2012	2013	2014	2015	2016	2017	2018
2013	0.604							2013	0.600						
2014	0.757	0.757						2014	0.453	0.134					
2015	0.693	0.495	0.509					2015	0.288	0.092	0.417				
2016	0.604	0.390	0.498	0.874				2016	0.288	0.078	0.417	0.967			
2017	0.200	0.037*	0.044*	0.498	0.509			2017	0.001**	0.000**	0.00024**	0.063	0.050		
2018	0.170	0.029*	0.037*	0.509	0.580	0.794		2018	0.000**	0.000**	0.000**	0.001**	0.001**	0.288	
2019	0.070	0.029*	0.029*	0.319	0.390	0.734	0.509	2019	0.000**	0.000**	0.000**	0.000**	0.000**	0.084	0.641

Table 2-21. Mean age and total length for male Hickory Shad by river and capture year. Data provided by the ECU Rulifson Lab data, the NCDMF Creel Survey, the NCWRC Creel Survey, and NCWRC Electrofishing Survey data. Rivers in order from north to south.

River	Capture year	n	Mean age	Mean TL	SD
Roanoke	2016	11	3.4	336.4	0.505
Roanoke	2017	12	3.4	348.6	0.996
Upper Tar	2017	15	3.9	375.7	1.125
Upper Tar	2019	73	4.0	387.3	0.993
Upper Neuse	2012	36	3.5	352.9	0.655
Upper Neuse	2013	18	3.4	369.3	0.856
Upper Neuse	2014	20	3.4	367.6	0.883
Upper Neuse	2015	27	4.0	377.3	1.018
Upper Neuse	2016	23	3.5	352.3	0.846
Neuse (Contentnea Creek)	2006	13	4.6	404.8	1.710
Neuse (Contentnea Creek)	2018	15	3.1	366.0	0.516
Middle Neuse	2012	76	3.6	365.8	1.018
Middle Neuse	2013	58	3.4	349.6	0.795
Middle Neuse	2014	92	3.3	352.6	0.638
Middle Neuse	2015	64	4.0	373.5	0.984
Middle Neuse	2016	70	3.7	374.4	0.877
Middle Neuse	2017	76	3.9	373.7	1.173
Middle Neuse	2018	64	3.7	378.1	0.903
Middle Neuse	2019	40	4.5	396.3	1.062
Neuse (Pitchkettle)	2005	130	3.7	368.3	1.145
Neuse (Pitchkettle)	2006	11	4.9	413.7	1.300
Neuse (Pitchkettle)	2007	50	4.1	391.4	1.096
Neuse (Pitchkettle)	2018	16	4.1	363.1	1.204

Lower Neuse	2014	38	3.9	373.7	0.906
Lower Neuse	2018	10	4.1	375.0	1.101
Lower Neuse	2019	16	4.4	402.9	1.455
Cape Fear	2017	13	3.8	349.8	0.689
Cape Fear	2018	27	3.8	381.4	1.178

Table 2-22. Results of Wilcoxon Rank Sum Test for male Hickory Shad based on mean age, total length, and capture year for Contentnea Creek, a tributary of the Neuse River. Asterisk (*) indicates significant difference at $p < 0.05$.

Mean age vs capture year		Mean TL vs capture year	
	2006		2006
2018	0.016*	2018	0.013*

Table 2-23. Results of Wilcoxon Rank Sum Test for male Hickory Shad based on mean age, total length, and capture year for Pitchkettle Creek, a tributary of the Neuse River. Asterisk (*) indicates significant difference at $p < 0.05$; Double asterisk (**) = $p<0.001$.

Mean age vs capture year				Mean TL vs capture year			
	2005	2006	2007		2005	2006	2007
2006	0.020*			2006	0.0015*		
2007	0.099	0.099		2007	0.0034*	0.016*	
2018	0.212	0.117	0.988	2018	0.96	0.0014*	0.001**

Table 2-24. Results of Wilcoxon Rank Sum Test for male Hickory Shad based on mean total length and capture year per river. Asterisk (*) indicates significant difference at p < 0.05.

Cape Fear		Lower Neuse River			Upper Neuse River				
	2017		2014	2018		2012	2013	2014	2015
2018	0.0023*	2018	0.712		2013	0.046*			
		2019	0.045*	0.06	2014	0.337	0.895		
					2015	0.016*	0.586	0.588	
					2016	0.895	0.141	0.19	0.023*

Table 2-25. Results of Wilcoxon Rank Sum Test for male Hickory Shad based on mean age, total length, and capture year for the Middle Neuse River. Asterisk (*) indicates significant difference at p < 0.05; Double asterisk (**) = p<0.001.

Mean age vs capture year								Mean TL vs capture year							
	2012	2013	2014	2015	2016	2017	2018		2012	2013	2014	2015	2016	2017	2018
2013	0.406							2013	0.005*						
2014	0.0947	0.511						2014	0.046*	0.275					
2015	0.0178*	0.002*	0.000**					2015	0.17	0.000**	0.000**				
2016	0.467	0.124	0.013*	0.095				2016	0.051	0.000**	0.000**	0.848			
2017	0.154	0.032*	0.002*	0.467	0.435			2017	0.097	0.000**	0.000**	0.983	0.848		
2018	0.467	0.124	0.017*	0.124	0.946	0.468		2018	0.013*	0.000**	0.000**	0.514	0.431	0.514	
2019	0.000**	0.000**	0.000**	0.044*	0.001**	0.017*	0.0016*	2019	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.001**

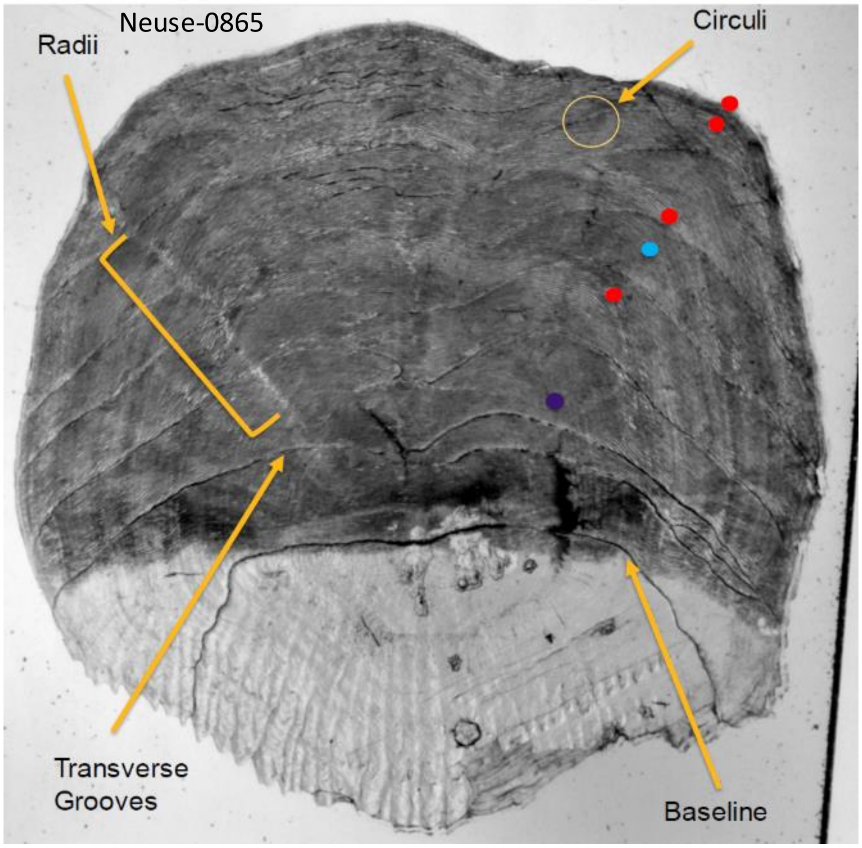

Figure 2-1. Photograph of an age-4 adult female Hickory Shad scale indicating the freshwater zone (purple point), a false annulus (blue point), and the corresponding annuli (red points) with the edge counted as the final annulus.

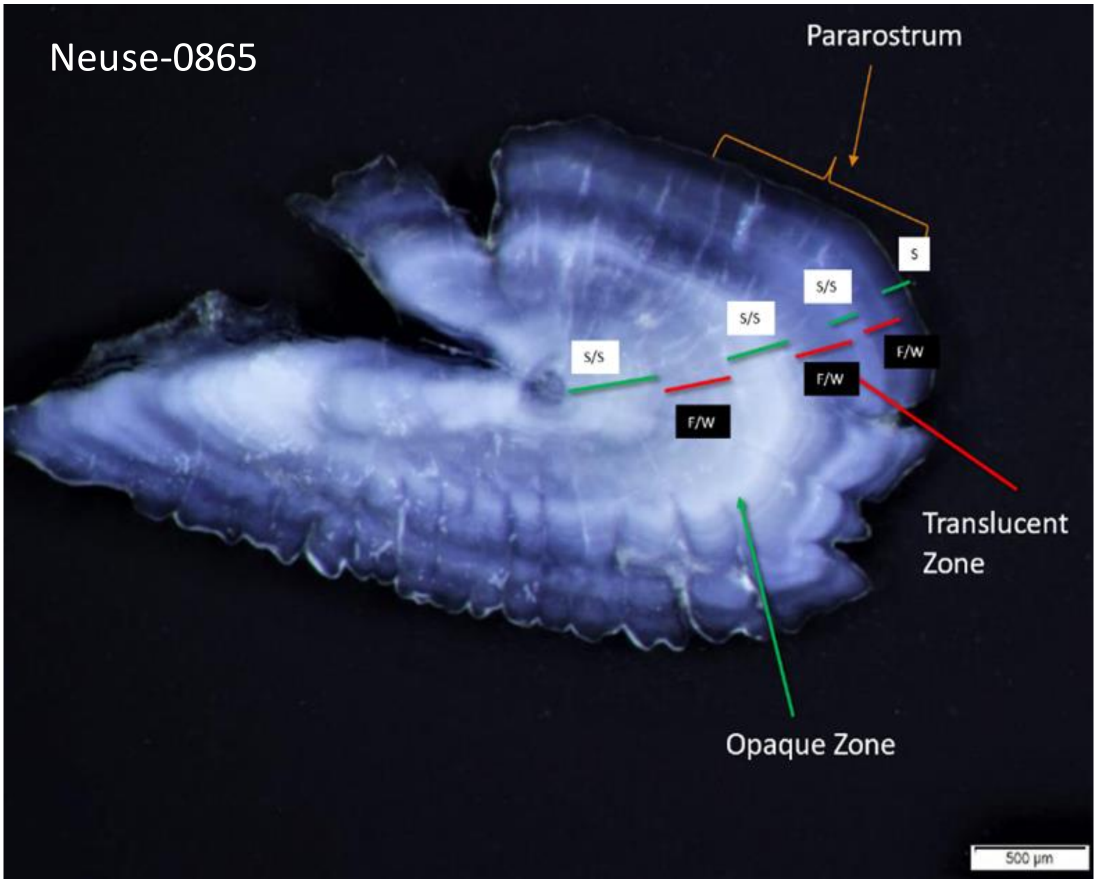

Figure 2-2. Photograph of an age-4 adult female Hickory Shad otolith displaying the translucent (fall/winter[F/W]) and opaque(spring/summer[S/S]) bands. The pararostrum indicates where ages were assessed.

Figure 2-3. Photograph of a regenerated adult Hickory Shad scale not suitable for ageing.

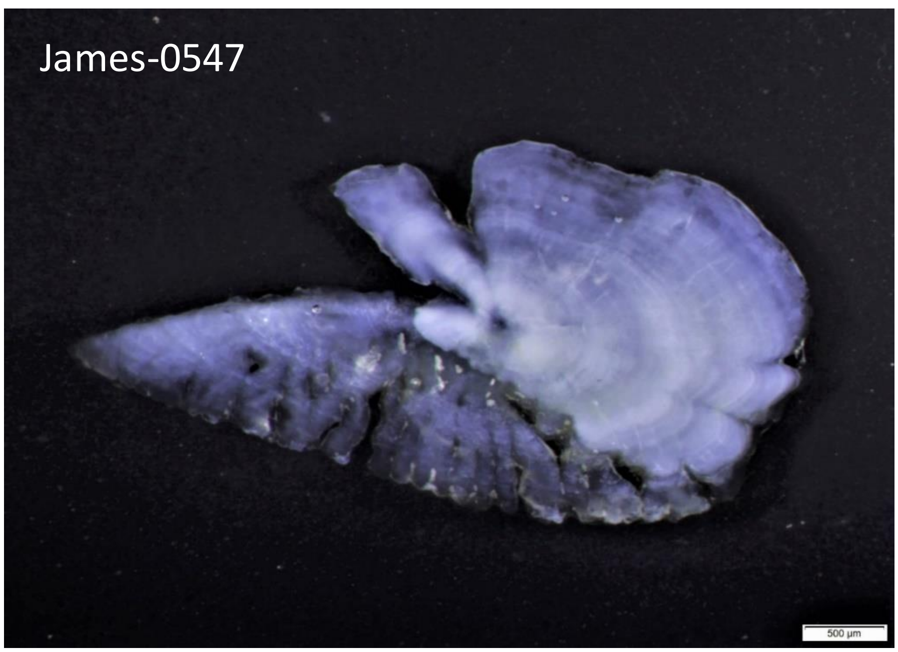

Figure 2-4. Photograph of a crystallized adult Hickory Shad otolith not suitable for ageing.

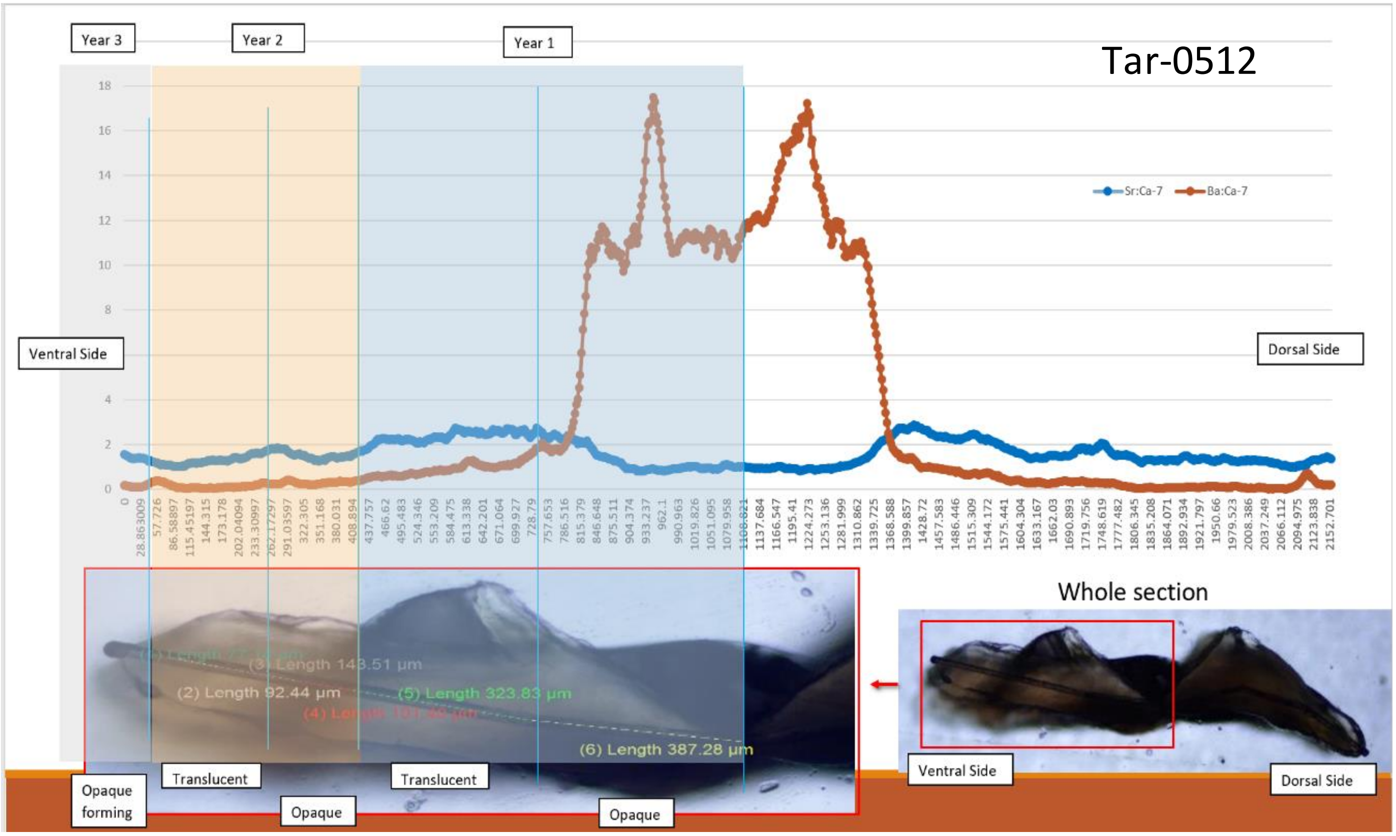

Figure 2-5. Hickory Shad whole otolith transverse section indicating the opaque and translucent zones on the ventral side of the section. The shaded regions indicate each year of the fish life, with the edge counted as the beginning of the third year. The graph indicates the strontium and barium otolith microchemistry aligning with each opaque and translucent zone.

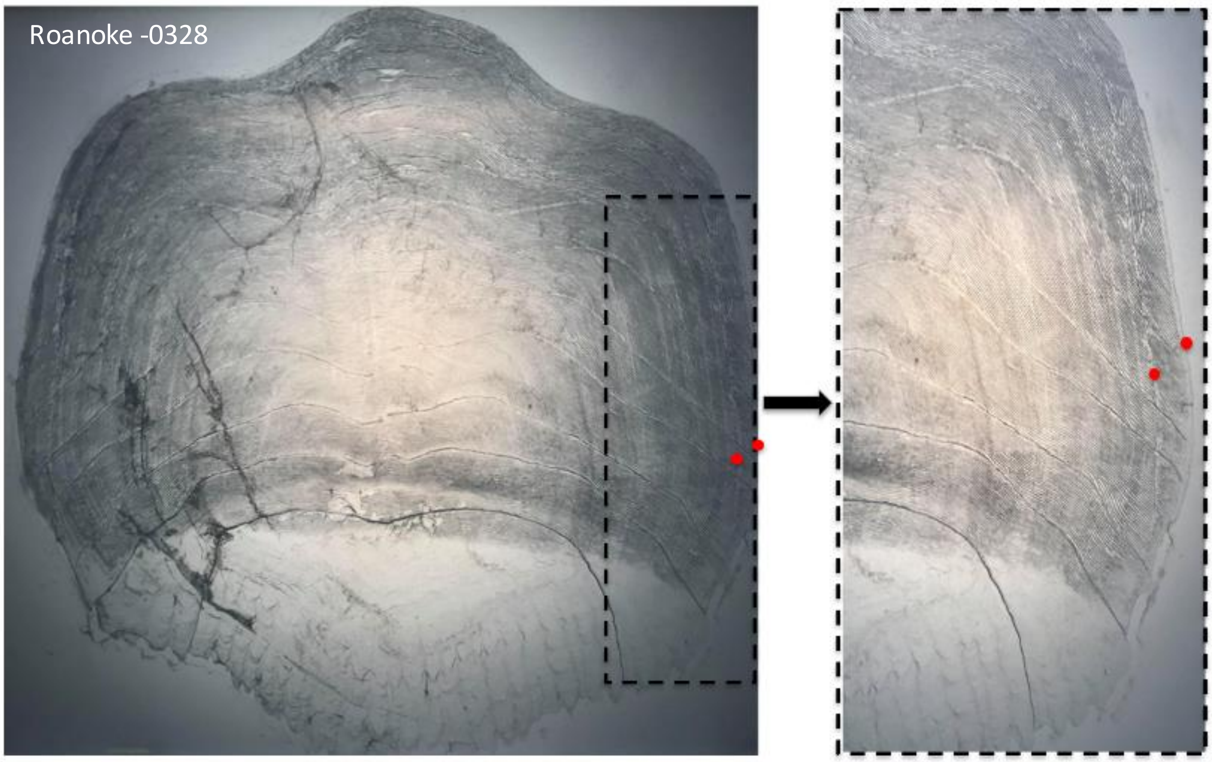

Figure 2-6. Photograph of an adult Hickory Shad scale indicating repeat spawning marks. Red points indicate spawning marks.

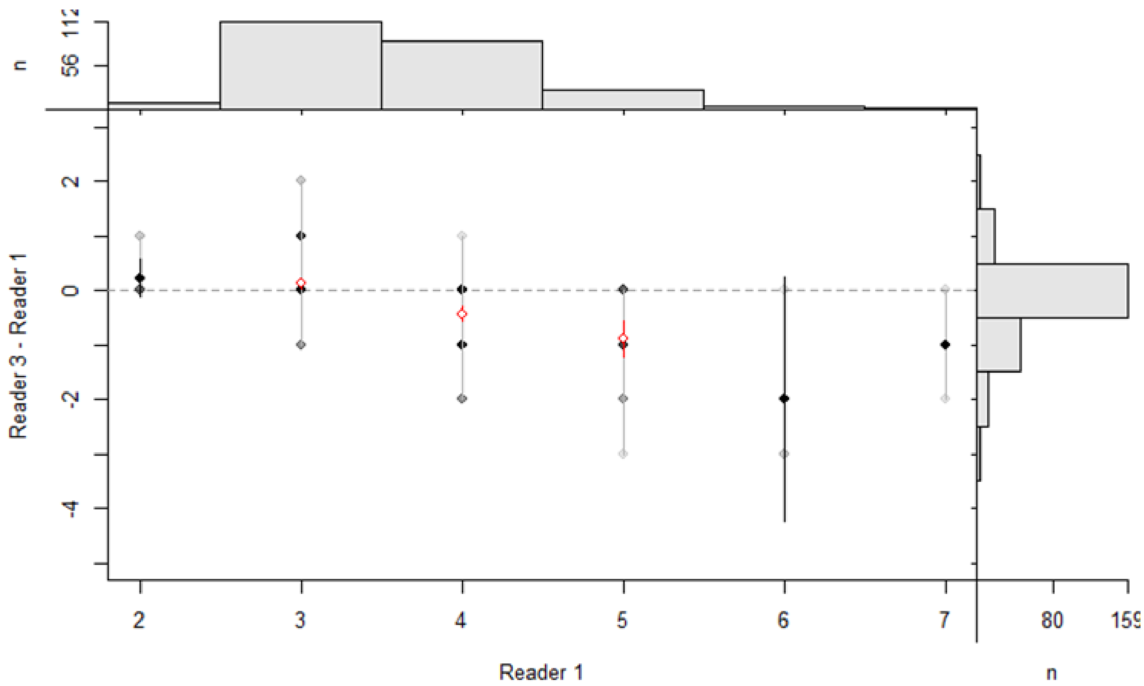

Figure 2-7. Age-bias plot for Hickory Shad otolith age estimates between Readers 1 and 3. The difference in age estimates is on the y-axis, and the reference age estimates are on the x-axis. The red points and darkest point on ages 2, 6, and 7 are the mean with 95% confidence intervals, and open red points represent mean differences in otolith age estimates between Readers 1 and 3 that are significantly different from zero (dashed gray horizontal line, a reference line to indicate a difference in age estimates of zero). The points extending vertically from the mean indicate the range for a given age, with a darker circle indicating more individuals for that age estimate. The light grey intervals also indicate the range of age estimates found between otoliths and scales for individual Hickory Shad (n=240). The marginal histogram at the top shows the distribution and sample sizes of the reference age estimates (Reader 1) and the marginal histogram on the right shows the distribution of the difference in age estimates between Readers 1 and 3.

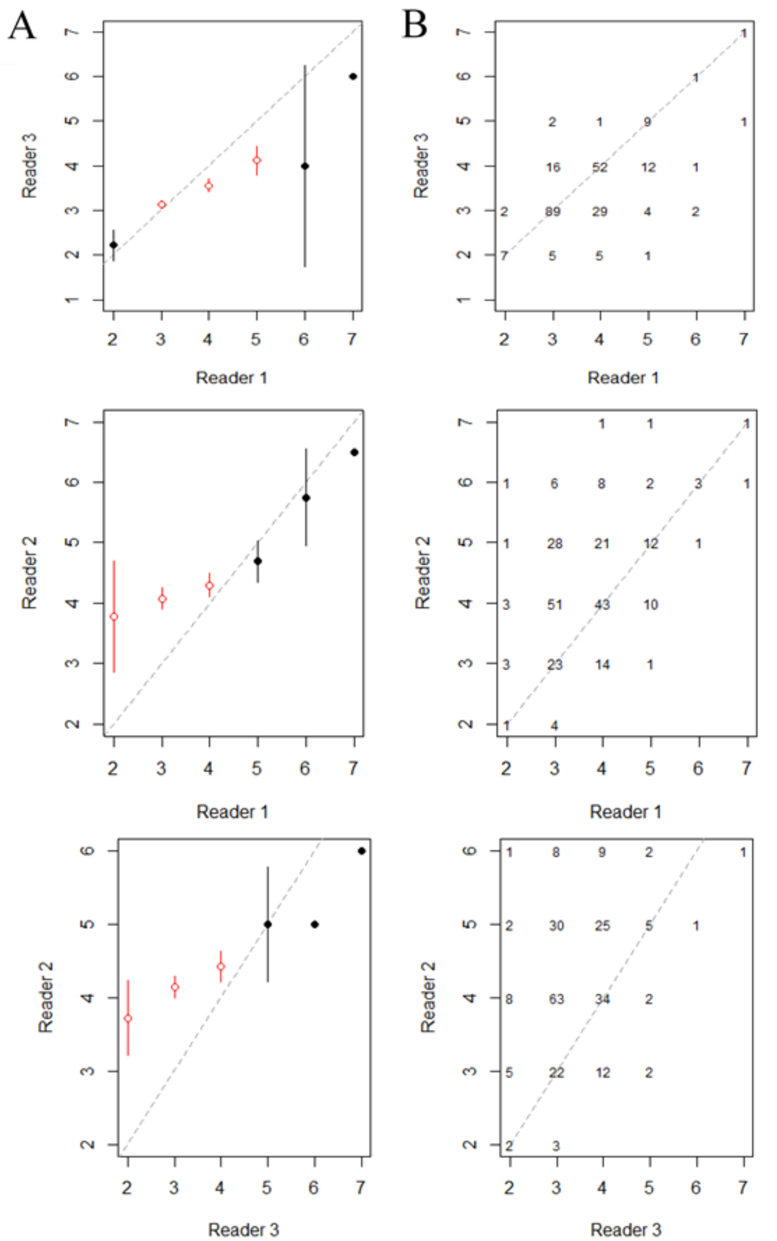

Figure 2-8. Column (A): Mean (points) and 95% confidence intervals of Hickory Shad otolith age estimates between readers. The dashed gray line represents age estimates that agree. Open points indicate mean reader estimates on the x-axis that differ significantly from the corresponding reader estimate on the y- axis. (B) Number of individuals by reader estimates. The dashed gray line represents age estimates that agree (n=240).

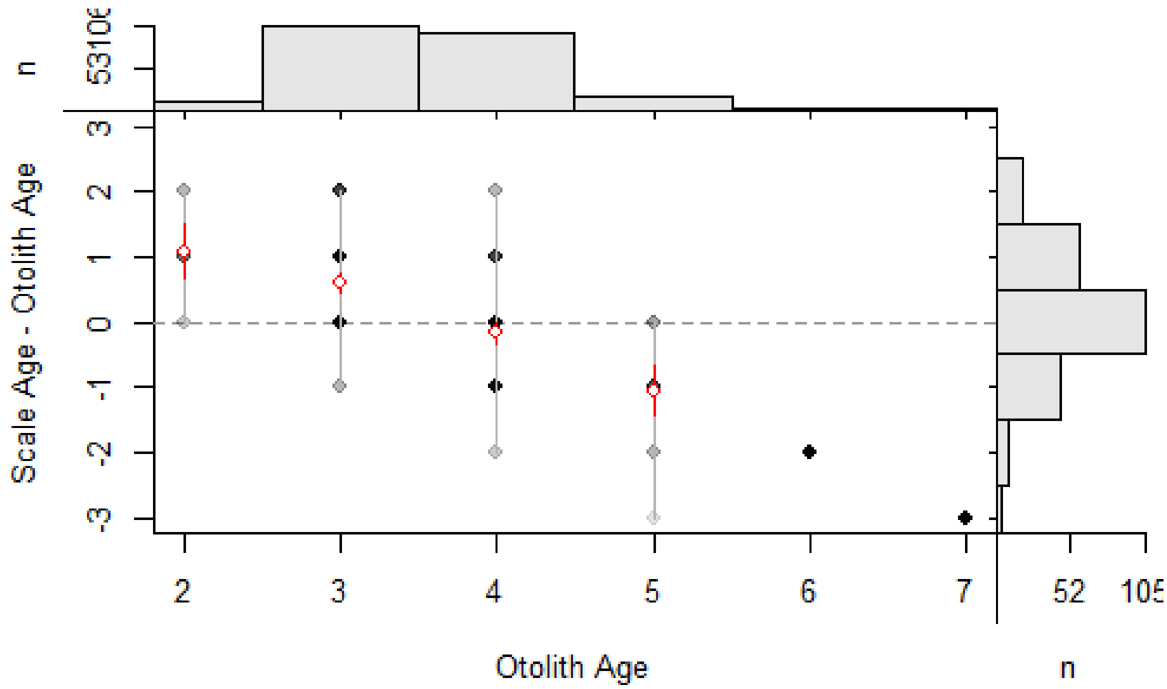

Figure 2-9. Age-bias plot for Hickory Shad age estimates between otoliths and scales. The difference in age estimates is on the y-axis, and the reference age estimates are on the x-axis. The red points (and black points for ages 6 and 7) are the mean with 95% confidence intervals, and open red points represent mean differences in otolith and scale estimates that are significantly different from zero (dashed gray horizontal line, a reference line to indicate a difference in age estimates of zero). The points extending vertically from the mean point indicate the range for a given age, with a darker circle indicating more individuals for that age estimate. The light grey intervals also indicate the range of age estimates found between otoliths and scales for individual Hickory Shad (n=240). The marginal histogram at the top shows the distribution and sample sizes of the reference age estimates (otoliths) and the marginal histogram on the right shows the distribution of the difference in age estimates for scale and otolith estimates.

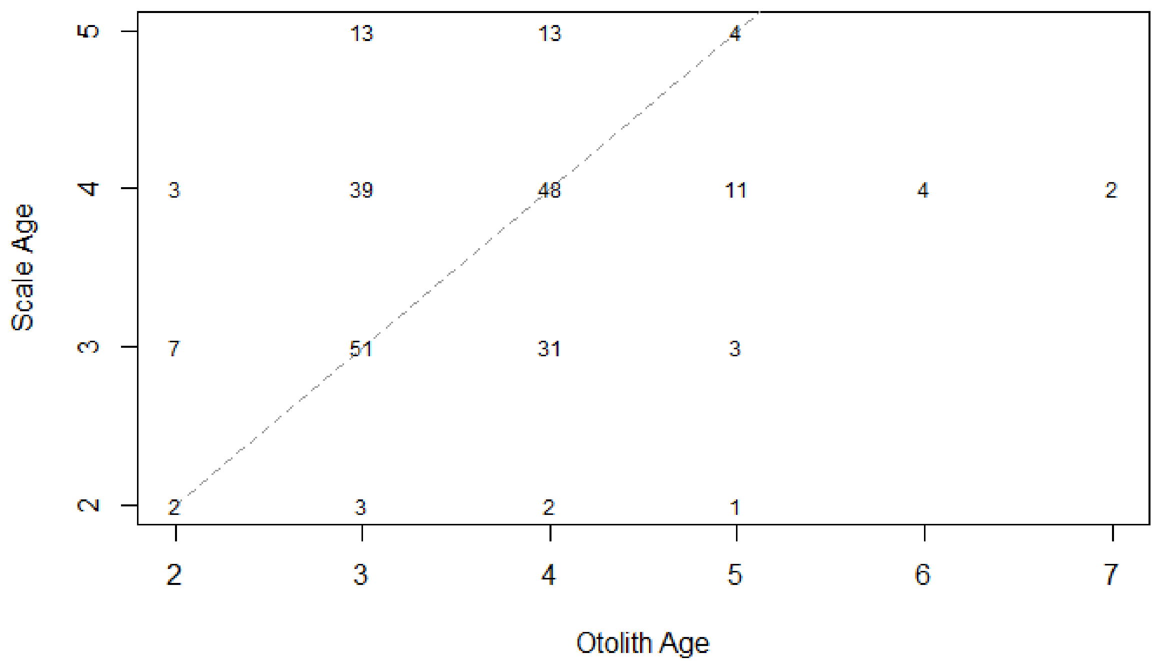

Figure 2-10. Number of individuals by each scale and otolith age estimate combination for Hickory Shad. The dashed gray line represents age estimates that agree (n=240).

Figure 2-11. Photograph of an age-5 Hickory Shad scale indicating repeat and skip spawning. Red points indicate spawning marks. Blue points indicate a normal annulus where spawning has not occurred.

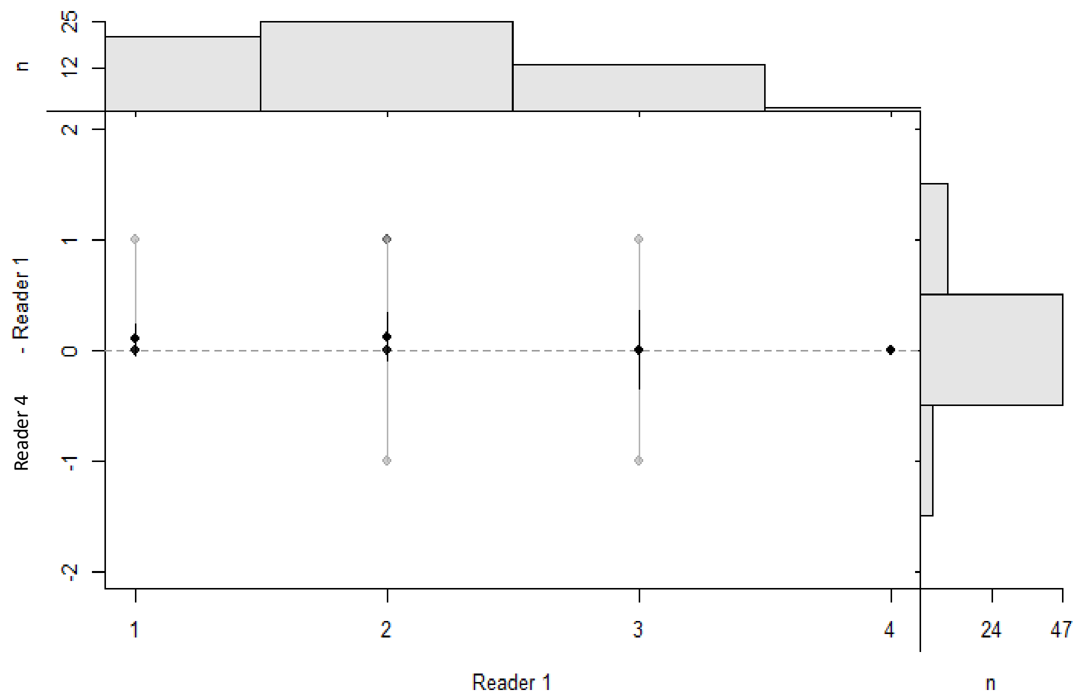

Figure 2-12. Age-bias plot for Hickory Shad spawning mark estimates between Reader 1 and 4. The difference in spawning mark number estimates is on the y-axis, and the reference number of spawning mark estimates are on the x-axis. The black points are the mean with 95% confidence intervals, and closed points represent no mean differences in Reader 1 and Reader 4 estimates that are significantly different from zero (dashed gray horizontal line, a reference line to indicate a difference in age estimates of zero). The points extending vertically from the mean indicate the range for a given estimate, with a darker point indicating more individuals for that estimate. The light grey intervals also indicate the range of spawning mark estimates found between Readers 1 and 4 for individual Hickory Shad (n=60). The marginal histogram at the top shows the distribution and sample sizes of the reference spawning mark estimates (Reader 4) and the marginal histogram on the right shows the distribution of the difference in estimates between Readers 1 and 4.

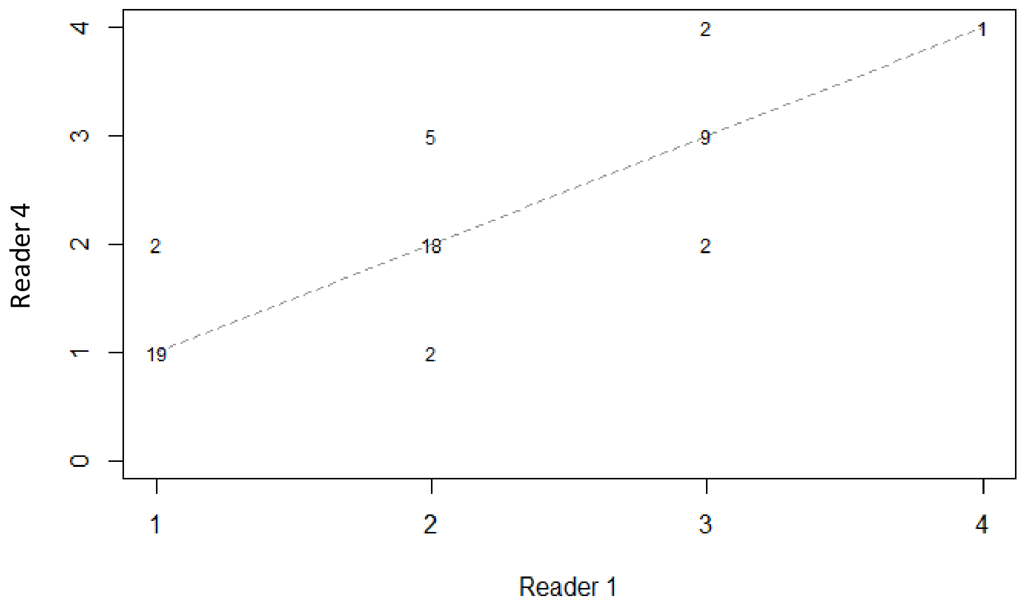

Figure 2-13. Number of individuals by Reader 1 and Reader 4 spawning mark estimates for Hickory Shad (n=60). The dashed gray line represents spawning mark estimates that agree.

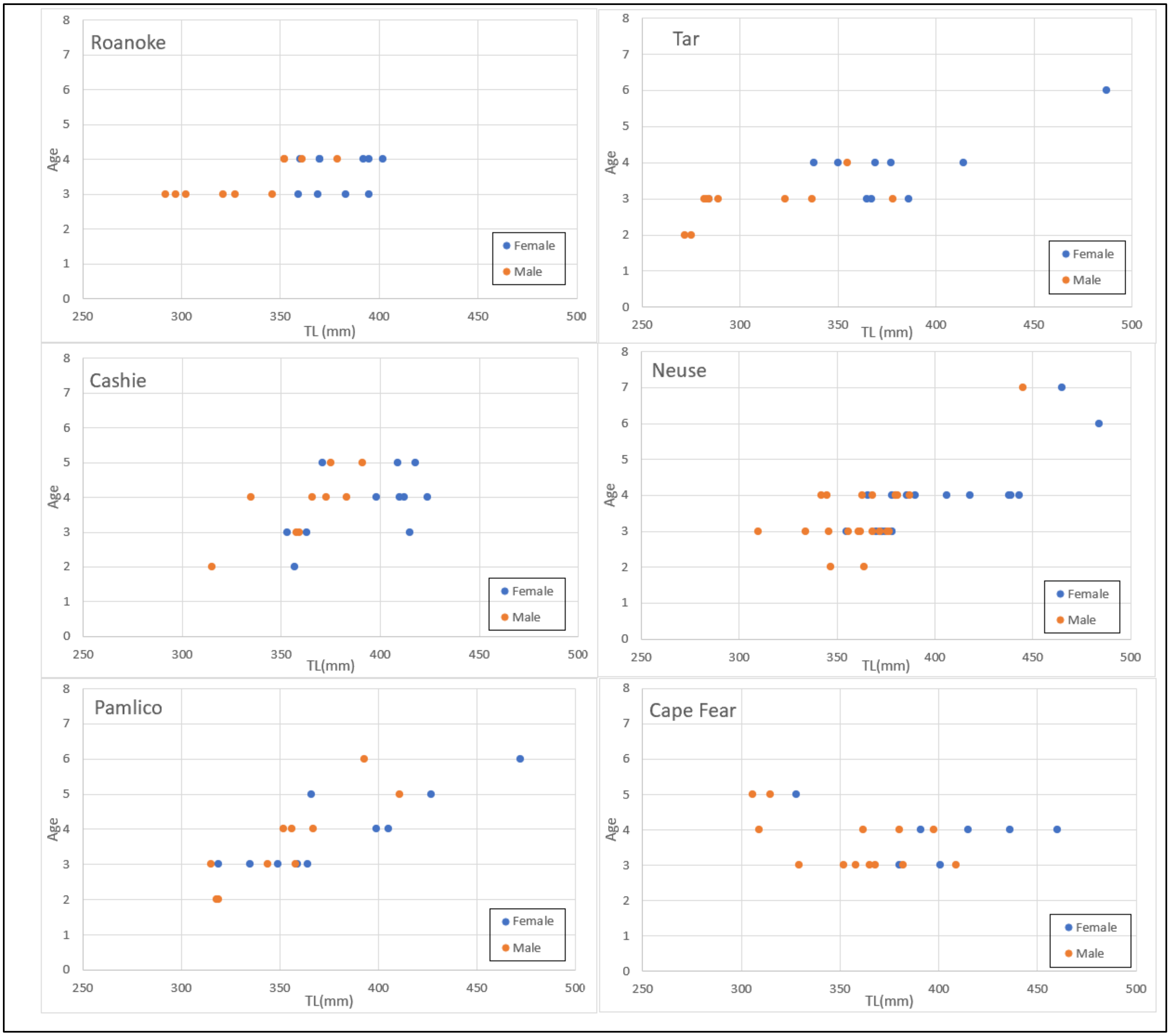

Figure 2-14. ECU Rulifson Lab final estimated otolith ages used for the age-length key (n=160). Ages separated by watershed.

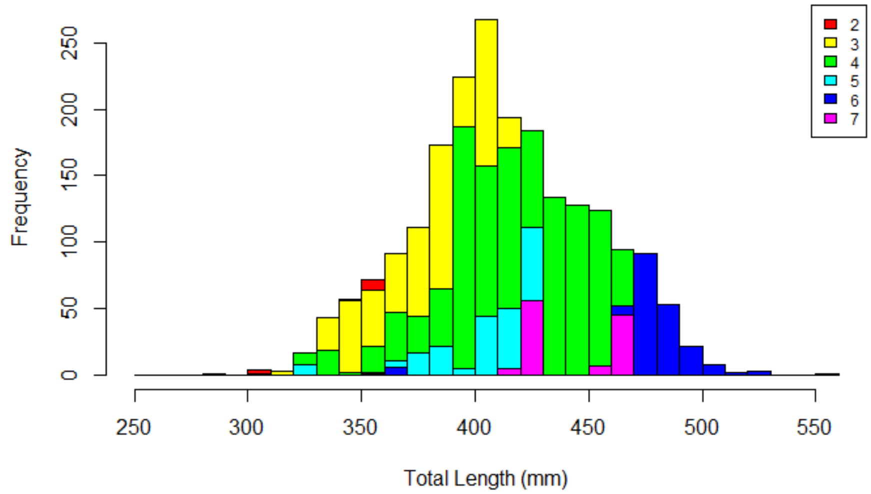

Figure 2-15. Length frequency plot for North Carolina female Hickory Shad. Each color indicates a different age within each length category. The individuals included are from the ECU Rulifson Lab, the NCDMF Creel Survey, the NCWRC Creel Survey, and the NCWRC Electrofishing Survey (n=2100).

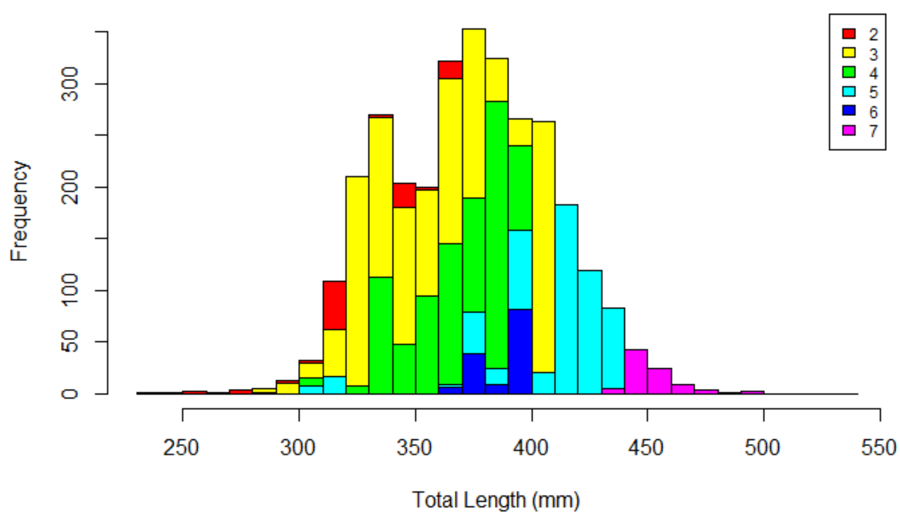

Figure 2-16. Length frequency plot for North Carolina male Hickory Shad. Each color indicates a different age within each length category. The individuals included are from the ECU Rulifson Lab, the NCDMF Creel Survey, the NCWRC Creel Survey, and the NCWRC Electrofishing Survey (n=3044).

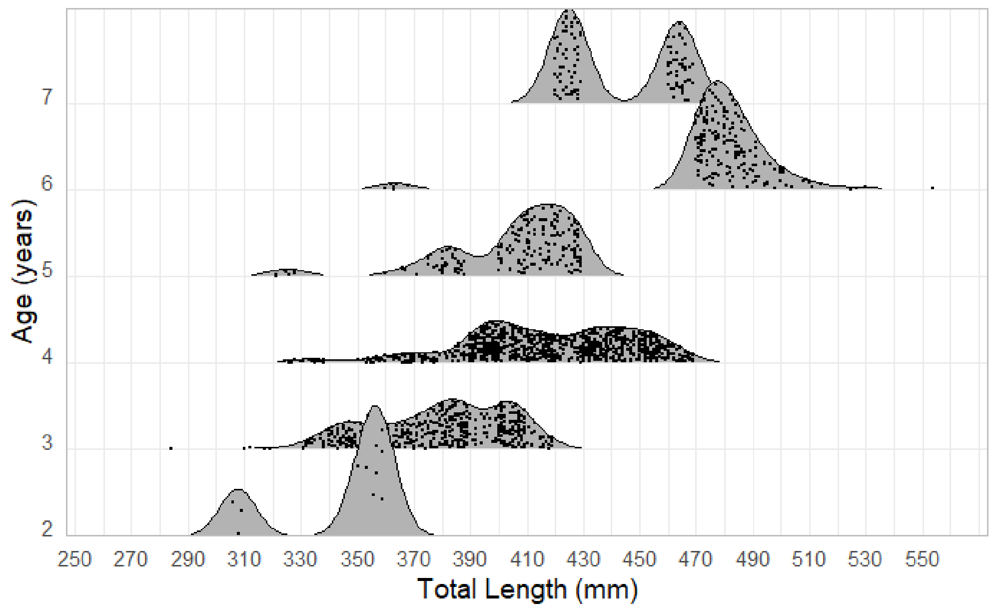

Figure 2-17. Density Plot for North Carolina female Hickory Shad. The individuals included are from the ECU Rulifson Lab, the NCDMF Creel Survey, the NCWRC Creel Survey, and the NCWRC Electrofishing Survey(n=2100).

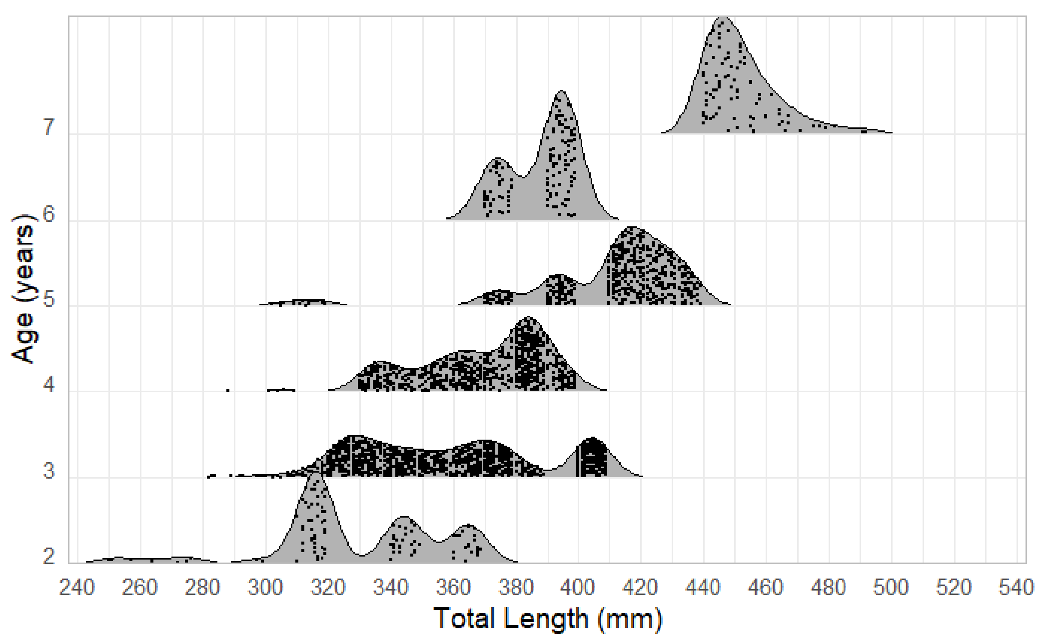

Figure 2-18. Density Plot for North Carolina male Hickory Shad. The individuals included are from the ECU Rulifson Lab, the NCDMF Creel Survey, the NCWRC Creel Survey, and the NCWRC Electrofishing Survey(n=3044).

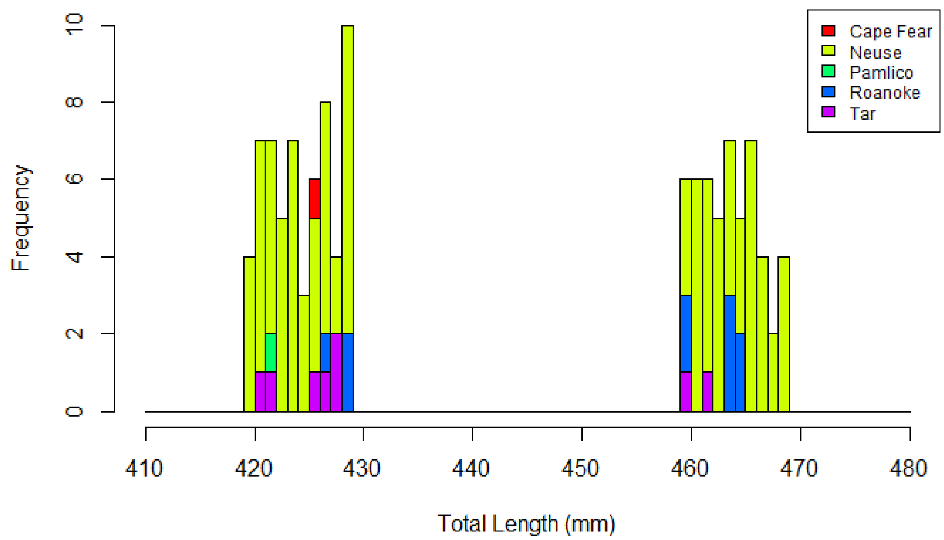

Figure 2-19: Age-7 females from the ECU Rulifson Lab, the NCDMF Creel Survey, the NCWRC Creel Survey, and the NCWRC Electrofishing Survey (n=113). This graph focuses on the bimodal distribution seen in Figure 2-17 and looks at the distribution of total length by watershed.

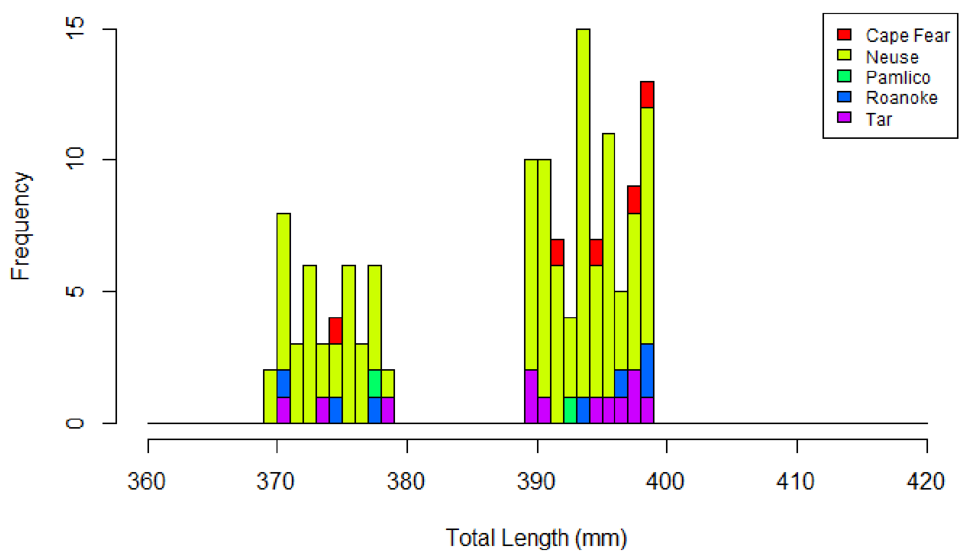

Figure 2-20. Age-6 males from the ECU Rulifson Lab, the NCDMF Creel Survey, the NCWRC Creel Survey, and the NCWRC Electrofishing Survey (n=135). This graph focuses on the bimodal distribution seen in Figure 2-18 and looks at the distribution of total length by watershed.

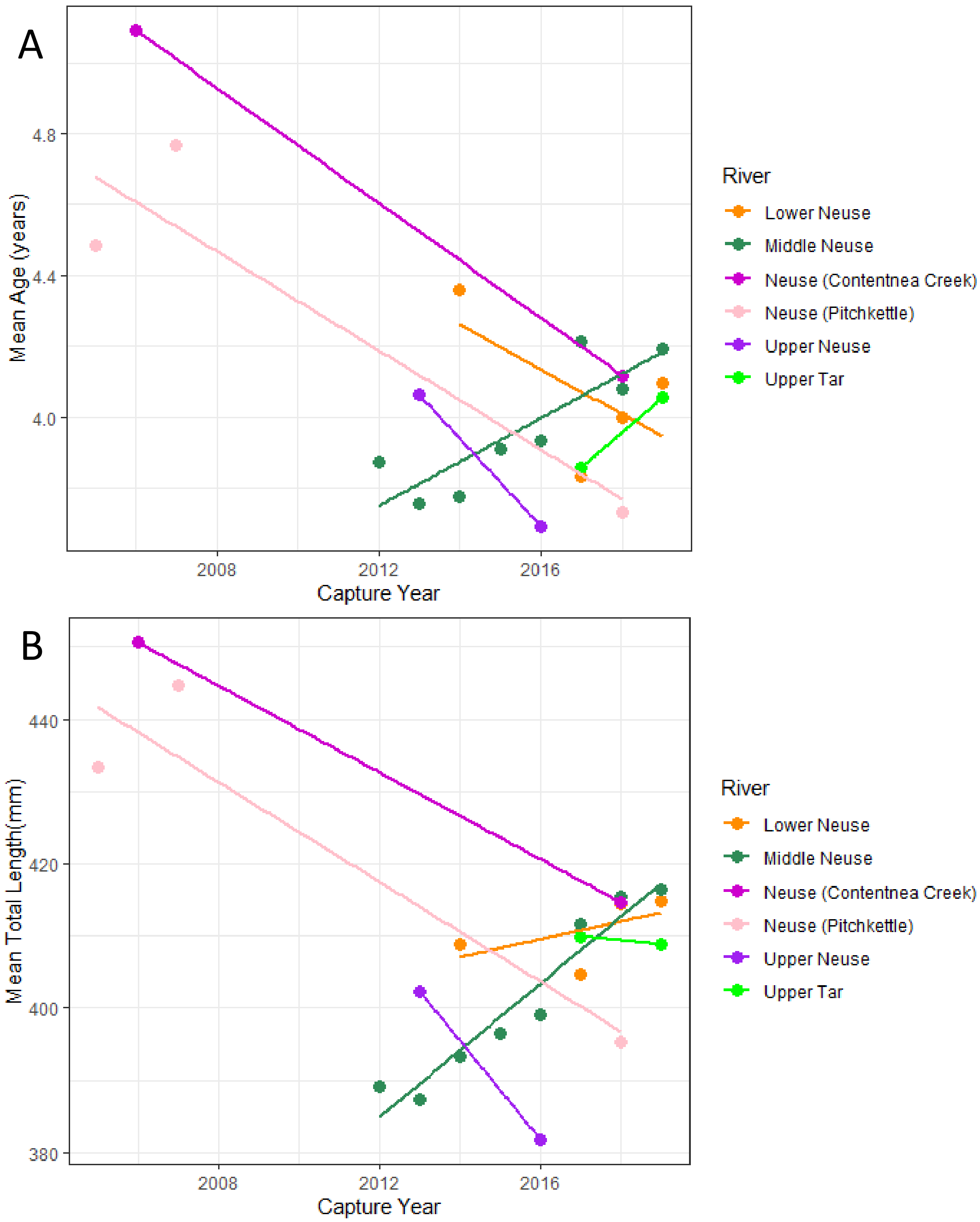

Figure 2-21. A) Mean age per capture year and B) mean total length per capture year for female Hickory Shad separated by river. The linear regression for each river is indicated.

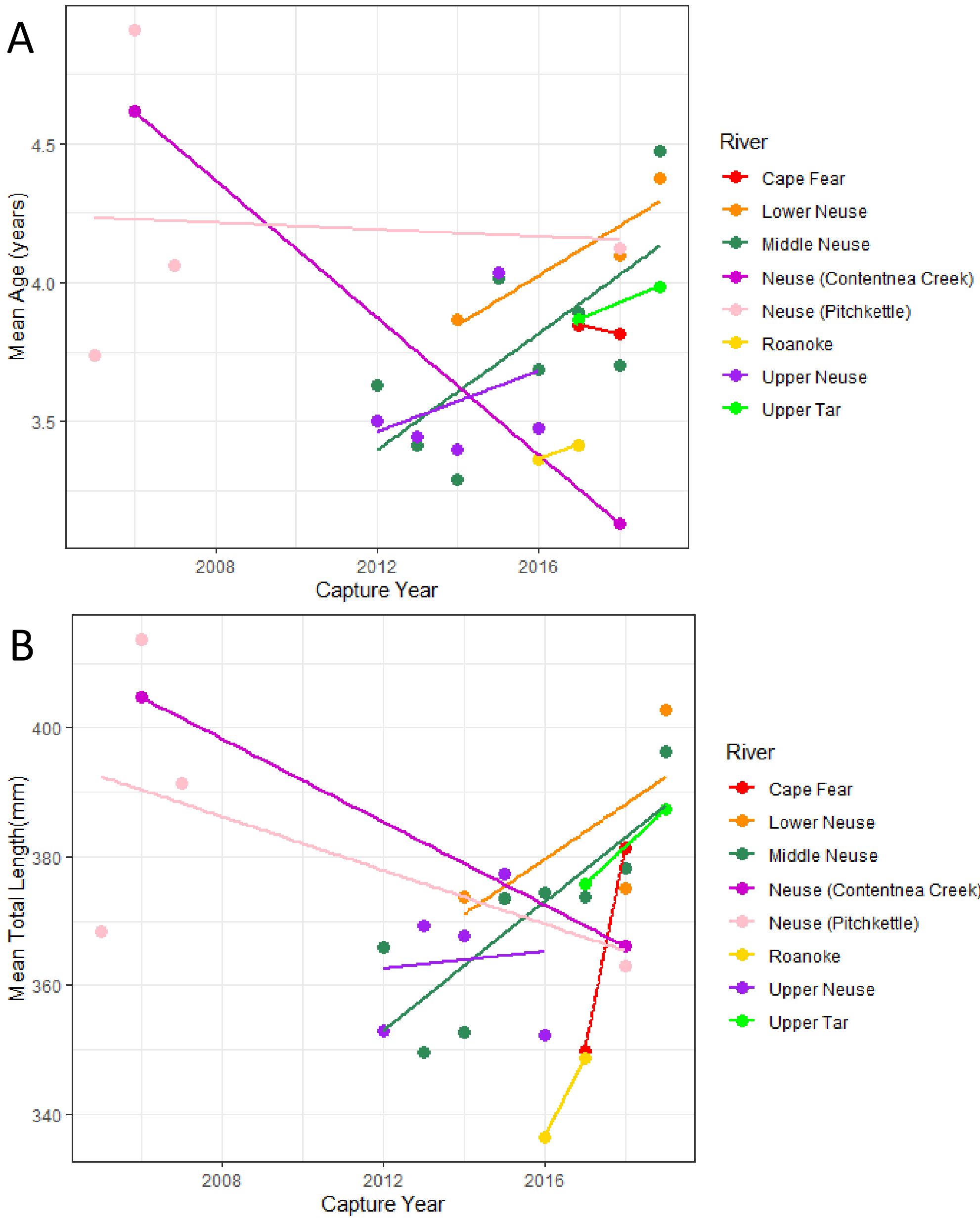

Figure 2-22. A) Mean age per capture year and B) mean total length per capture year for male Hickory Shad separated by river. The linear regression for each river is indicated.

CHAPTER 3: SOCIAL MEDIA AS A MANAGEMENT TOOL: ANGLER TRENDS AND SPECIES DISTRIBUTION USING HICKORY AND AMERICAN SHADS AS MODELS

Abstract

The Facebook group "NC-Shad" was mined for data from 2013-2020 on Hickory Shad (*Alosa mediocris*) and American Shad (*A. sapidissima*) fishing location, catch information, lure characteristics, and the social constructs of the anglers and members of the group. A total of 1,790 posts and comments from 13 rivers across two states were reported but reports from the Susquehanna River in Maryland (n=4) were removed to strictly obtain analyses from North Carolina. From all posts, 78% (n=1,398) included location information, so Geographic Information Systems (GIS) was employed to examine spatiotemporal patterns in fishing location and Hickory Shad and American Shad Catch Per Post (CPP) throughout the study period. Catch Per Post was used in place of Catch Per Unit Effort (CPUE) because not every post indicated the number of anglers present during a fishing trip, so effort could not be assessed based the data collection method in this study. CPP was calculated where one social media post = one unit of effort, and this information was compared to the Central Southern Management Area (CSMA) anadromous creel survey for the Tar, Neuse, and Cape Fear rivers of North Carolina to determine if the methods came to the same conclusion. An apparent increase in membership over time may have influenced some results, but overall, Local Ecological Knowledge (LEK) was a major force guiding this group, and members could provide novel information on habitat use, spawning grounds, and distribution where Conventional Scientific Knowledge (CSK) is inadequate. No major differences were apparent between lure type or color preference between species, but chartreuse, pink, and white were the most successful colors for both species. The majority of Hickory Shad were captured from the Roanoke River (n=10,158), whereas the majority of

American Shad were captured from the Tar River (n=507). Hickory Shad and American Shad CPP was compared per year and per river, and from the four main rivers (Roanoke, Tar, Neuse, and Cape Fear), the Roanoke River had the highest Hickory Shad CPP (CPP=26.9). This may be a result of the Roanoke Rapids Dam restricting upstream migration, forcing the species to pool at the most upstream location making them more susceptible to recreational fishing pressure. As for American Shad, the Tar River had the highest overall American Shad CPP (CPP = 0.9), suggesting that the Cape Fear River may not provide the bulk of the American Shad fishery as once thought. Although an overall statistically significant spatiotemporal trend was not found for either Hickory or American shad, multiple Consecutive Hot Spots near Goldsboro for American Shad CPP suggests that the Neuse River stocking program may have successful natal homing individuals. A New Hot Spot for Hickory Shad CPP and a Sporadic Hot Spot for American Shad CPP in the Cape Fear River implies that Hickory Shad may be outcompeting American Shad for spawning habitat over time; this may be due to the American Shad stock of the Cape Fear being the most semelparous of their North Carolina range, whereas Hickory Shad are iteroparous throughout North Carolina. As for the creel survey and social media CPP comparison, multiple years were found to have statistically significant differences. One caveat in this comparison is that creel surveys do not collect information from bank anglers, but many posts from “NC-Shad” were from bank anglers, which may explain some of the CPP differences. On the other hand, many of the years were not statistically significantly different between the two data sources, demonstrating that similar inferences could be made from either of the two methods. While the information on “NC-Shad” may not accurately reflect the fishing activity by each member, there may be potential to form a network of anglers willing to participate in monitoring programs or take part in controlled citizen science studies. This study demonstrates that social media data mining could be a cost-effective alternative to obtain supplementary information on recreationally important fish species.

Introduction

Alosine management and restoration are challenged by the limited amounts of data about migration, behavior, and distribution in both riverine and marine environments. Throughout the Hickory Shad (*Alosa mediocris*) and American Shad (*A. sapidissima*) spawning ranges, many state agencies routinely conduct recreational fishery surveys to collect information on effort and harvest for stock assessments, but such monitoring efforts tend to be undersupported in most river systems due to cost (Venturelli et al. 2017). Commercial and recreational harvests of American Shad is regulated by the North Carolina Division of Marine Fisheries (NCDMF) for coastal waters, and the North Carolina Wildlife Resource Commission (NCWRC) Division of Inland Fisheries for inland waters (ASMFC 2020). The two state agencies obtain information on sustainability parameters such as indices of abundance and biological data to characterize the populations over time through the NCDMF Independent Gill Net Survey (IGNS) and the NCWRC Adult Spawning Electrofishing Survey. The Marine Recreational Information Program (MRIP) estimates harvest by recreational anglers through fishing effort surveys, but many estimates have been found to be imprecise and deemed not useful for management purposes (ASMFC 2020). MRIP also focuses only on sampling coastal waters, so recreational angling on inland waters upstream of dams is not sampled. The Central Southern Management Area (CSMA) comprehensive anadromous creel survey began in 2012 and is employed throughout the upper, middle, and lower sections downstream of the last dam on the Neuse, Trent, Tar/Pamlico, Cape Fear, and Pungo rivers in North Carolina, and this survey obtains information on effort, harvested and released fish, fishing method, and location (ASMFC 2020). The annual Tar River creel survey is conducted at Boat Access Areas (BAAs) from Battle Park to Falkland (Rundle 2016), the Neuse River creel survey between the old Milburnie Dam location and the mouth of the Neuse River (Ricks and Rachels 2015), and the Cape Fear creel survey between Fayetteville downstream to Lock and Dam #1 (Hadley 2015). The annual creel survey conducted on the Roanoke River targets Striped Bass catch and effort, but information on Hickory Shad and American Shad is also collected (ASMFC 2020). All North Carolina creel surveys are non-uniform probability-based access point creel surveys conducted on only boat anglers, which means that the BAA chosen, the time, and day of the week are given probabilities that are assigned based on observed effort from past years and direct observation from creel clerks (Pollock et al. 1994). A stratified random sampling design for each river and zone is used for monthly sampling (ASMFC 2020). A common trend among these fishery-independent data collection methods is the costly nature and the excessive amount of manpower needed to sample large geographical distances, so novel approaches are required to obtain data in bulk in a cost-effective manner.

We wanted to determine whether social media could be used to supplement state agency data collection efforts. The use of social media could be a new and innovative approach for obtaining data in fisheries science by providing additional information on the abundance, harvest rates, migratory habits, and geographical distribution of any fish species. Understanding the dynamics of recreational angler use of social media could help pinpoint members who are central in the information-sharing network, or those that have better fishing success and have access to a wide range of information from their peers. Identifying these individuals may be useful to managers who are seeking information on spatial and temporal distributions, productive fishing grounds, and the ways in which anglers use their knowledge and experiences to adapt to changes with the resource, environment, or management policies (Turner et al. 2014). Rizgalla et al. (2017) used posts from spearfishermen Facebook groups to assess skin lesions on Dusky Grouper *(Epinephelus marginatus)* and found that this approach was a valuable supplementary source of epidemiological data for examining the health of this species. Social media posts were also used to obtain biological and geographical information on the endangered Hawaiian monk seal *(Monachus schauinslandi)* and found higher amounts of human-seal interactions compared to traditional reports, a metric that can complement future conservation research (Sullivan et al. 2019). Lopes et al. (2018) compared spatial models, one using scientific information gathered from literature, and the other gathered from fishers on species presence or absence, and found that the predicted occurrence of the target species overlapped widely suggesting that fisher knowledge may be a viable data collection method in the future.

Several aspects of resource knowledge by fishers can be observed in postings to social media. Local Ecological Knowledge (LEK) is knowledge gained from hands-on experience, interactions within the environment, and observing or using natural resources over one's lifetime, whereas Traditional Ecological Knowledge (TEK) is accumulated knowledge that is passed down through generations and is usually associated with elders in the community (Berkström et al. 2019). On the other hand, Conventional Scientific Knowledge (CSK) is knowledge gained from data collected based on a scientific design and is theoretically interpreted, such as fisheries-independent data (Berkström et al. 2019). Many scientists hesitate when coupling LEK with CSK, mainly because it is epistemologically different from traditional science-based methods to the point where the two forms may not be directly comparable (McLean and Forrester 2018). Nonetheless, some researchers have presented instances where angler LEK and CSK could be compared; studies have used LEK to measure population trends (Beaudreau and Levin 2014, Katikiro 2014, Giglio et al. 2015), describe location and timing of spawning (Griffith et al. 2013), and identify migration patterns (Silvano et al. 2006, Murray et al. 2008). LEK through social media can provide integral information on the geographical range and aggregation locations of these species during the spawning ascension, especially with anthropogenic changes that impact spawning habitat.

Another aspect of social media posting by fishers is the anecdotal information provided about location of quality fishing habitats, including areas not managed or believed to be not accessible by fishery resource staff. Habitat quantity is greatly reduced from historic levels and a spawning migration limiting factor for both species (ASMFC 2020). Fish passage, or the movement of migratory fish across a manmade barrier obstructing a migratory pathway, is a concern for the upstream passage of adults, the downstream passage of adults, and the downstream passage of early life stages (ASMFC 2020).

The 2020 American Shad Stock Assessment found that over 40% of historical American Shad spawning habitat is obstructed by locks and dams in the major rivers across its range. Here in North Carolina, the most downstream dam in the Roanoke River limits access to 60% of the historically available American Shad spawning habitat (Mack et al. 2021). The lower Roanoke River is currently unobstructed for 221 river kilometers (rkm) until meeting at the hydroelectric Roanoke Rapids Dam just upstream of the Fall Line (American Shad 2020 Stock Assessment). There are plans to build a trap and transport facility to allow American Shad to continue upstream to historical spawning grounds, but Dominion Energy, the operator of this dam, annually petitions a delay in constructing fish passage for the Roanoke Rapids Dam (White and McCargo 2018). Above this dam are two additional dams -- Gaston Dam (rkm 233) operated by Dominion Energy, and Kerr Dam (rkm 288) in Virginia controlled by the US Army Corps of

Engineers. Read (2004) estimated over 300 rkm of potential spawning habitat above Kerr Dam. With the recent relicensing of the Roanoke Rapids and Gaston dams by the Federal Energy Regulatory Commission (FERC), plans are being made to trap and transport American Shad above the Kerr Dam to the currently inaccessible spawning habitat (American Shad 2020 Stock Assessment). Harris and Hightower 2011 found that adult American Shad can be successfully collected, transported, and released upstream of Kerr Dam with low overall mortality. In the Tar River, the Rocky Mount Mills Dam is the most downstream obstruction for American Shad and Hickory Shad migration (Smith and Rulifson 2015). This hydro-dam produced electricity to power the adjacent textile mills, but it is unlikely this dam will ever be removed because it is considered a historical site and the city has a drinking water intake just above the dam (2014 American Shad Habitat Plan). Currently there are no plans for developing fish passage at this site (2014 American Shad Habitat Plan). The Neuse River has had several dams removed, and from earliest removal onwards they are: Quaker Neck (rkm 225) and Cherry Hospital dams (3.7 rkm from the Neuse River confluence, 1998), Rains Mill Dam (37.7 rkm from the Neuse River confluence, 1999), Lowell Mill Dam (56.2 rkm from the Neuse River confluence, 2005), Crantock Mill Dam (rkm 292, 2008), and the Milburnie Dam (rkm 352, 2017). The Quaker Neck Dam removal increased the potential spawning habitat by 127 main stem rkm (Beasley and Hightower 2000), and the Milburnie Dam removal increased that by another 10 kilometers (White and McCargo 2018). The Cherry Hospital, Rains Mill, and Lowell Mill dams off the Little River reconnected over 230 rkm of the mainstem Neuse and Little River tributaries (2014 American Shad Habitat Plan). The two remaining dams are the Atkinson Mill Dam (82 rkm from the Neuse River confluence), the highest priority dam for removal, and the Falls Lake Dam at rkm 370 (2014 American Shad Habitat Plan). The Cape Fear River's northernmost dam, the

Buckhorn Dam (rkm 316), was removed in 2009 and the remining three dams, Lock and Dam #1 (rkm 97) and #2 (rkm 149), and the William O'Husk Dam (rmk 187), cannot be removed because of water supply intakes above each dam (2014 American Shad Habitat Plan). In 2012, the Army Corps of Engineers constructed a Rock Arch Ramp at Lock and Dam #1, and there has been speculation of constructing similar fish passages at the remaining two locks (2014 American Shad Habitat Plan).

Along with a reduction in spawning habitat, other factors such as overfishing, predation, pollution, water withdrawals, channelizing of rivers, changing ocean conditions, and climate change are likely responsible for Hickory Shad and American Shad declines (ASMFC 2020). One way North Carolina is attempting to increase the population of American Shad is through stocking. The NCWRC first began stocking the Roanoke River, and since 1998, over 72 million American Shad fry have been stocked at Weldon, NC (ASMFC 2020). American Shad broodfish were collected by electrofishing from the Neuse, Tar, Cape Fear and Roanoke rivers, but starting in 2011 only broodfish were taken from the Roanoke River (ASMFC 2020). From 1998-2008, hormone injections were used to initiate spawning in the hatchery but starting in 2009 hormones were no longer being injected (ASMFC 2020). Until 2009, evaluation of hatchery raised fish was done from oxytetracycline (OTC) marks, but because of the unreliability, parentage-based tagging (PBT) methods began in 2010 (ASMFC 2020). In 2016, 56.1% of the American Shad collected during sampling surveys were of hatchery origin (ASMFC 2020), indicating stocking success. Starting in 2012, the NCWRC began an American Shad restoration stocking program to supplement the wild population. American Shad broodfish are collected from the Neuse River in Goldsboro, NC each year, are transferred to the Edenton National Fish Hatchery, and 100 broodfish are placed in a tank to spawn and those fry are stocked back at Goldsboro, NC (ASMFC 2020). Evaluation of the stocked fish uses the PBT method as mentioned above.

The objective of this chapter was to ascertain whether social media, specifically the Facebook site "NC-Shad", could be used to generate data about both Hickory and American shad species that could be used as supplemental information for stock assessment and fishery management plans. The Facebook group was initiated in 2013 by a North Carolina fisher interested in attracting other fishers interested in the shad fishery of coastal waters and inland tributaries. This is not a citizen science Facebook group; this group contains public information that was created by anglers for anglers, and not for scientific purposes. Recreational fishing can have a sufficient impact on fisheries and the associated ecosystems (Monkman et al. 2017), therefore novel data sources have been and should continue to be explored to enable formal stock assessments in data poor fisheries.

Methods

Social Structure

A Facebook group called "NC-Shad" was initiated in 2013 to connect recreational fishers interested in fishing for Hickory and American shads. A pilot study by our lab showed that location and angler data could be identified from reported posts for the Neuse and Tar rivers in North Carolina. Postings to this Facebook group include photos, videos, and comments about fisher location and catch information. An Excel database was created to include records of relevant information gathered from each post such as the member who posted, member sex, member age class (youth, teen, adult, 60+), date the post was made, calendar day, time (military), time of day the angler fished (daytime until sunset, or nighttime until sunrise), location, watershed, state, species (Hickory Shad, American Shad, or other), lure type, lure color, rig type (single or double), angler name (if different from the member), angler sex, angler age class (youth, teen, adult, 60+), the number of each species caught, and the script of the posting. Any photo or video included in the post was also marked in the database. A photograph or video embedded within the post can provide information such as species type, lure type, lure color, rig type, and the count of captured fish. Unlike the American Shad, the Hickory Shad exhibits a projecting lower jaw (Mitchill 1814); each photograph was examined to ensure species identification was correct. To avoid the duplication of information, the process of obtaining post information was conducted from the earliest Facebook group member to the most recent member. All member profiles within "NC-Shad" were assessed from the earliest post to the most recent, and all posts with relevant fishing trip information were recorded in the Excel database.

The procedure for a post with a photo and/or video was to determine species, count the number of clearly visible fish, and note the lure type, color, and rig type if identifiable. If the post contained more than one photo, each photo was counted as a new fish unless clearly identified as the same fish (distinguishable markings on fish or common background) or unless the script reported the total caught. Some special cases occurred. In the case of joint Facebook accounts, the sex of the members was listed as both members of the account, but the angler was reported as the person fishing at the time of the post. In many instances the posts reported the number of each species caught, but posts that stated "a few" or had no specified number were counted as one fish. Sometimes the content of a post might only be about a previous visit and catches at that time (i.e., "last year"), and these posts were not recorded. In many cases only the word "shad" was reported; therefore "Hickory Shad" was recorded because results of the NCDMF recreational creel surveys reported 1-10 times more Hickory Shad than American Shad for five out of the six years from 2012-2017 (NCDEQ 2017a, NCDEQ 2017b). All pertinent comments from each post were also recorded with the same methodology as listed above. None of the "NC-Shad" Facebook group members were contacted throughout the study to avoid compromising the methods and influence the member posts. The Excel database was checked to ensure that all statistics presented were based on unique records. Collected data was visualized and analyzed using R Studio (Version 3.5.2) and Microsoft Excel.

Lure type and lure color were separated between the two species in order to determine any major differences. Posts where only Hickory Shad were caught were used to determine lure type and color preferences, and the same was done for American Shad. One post could have included information on multiple types and colors of lures, so all data were recorded and included in analyses. One lure type also could have included multiple colors (i.e., the jig head was a different color from the grub), and this information was also included in analyses.

For calendar day and day of the week comparisons, the data were transformed to match the 2020 calendar day. It was assumed that the post was made on the day of the fishing trip unless otherwise specified, so "date" was considered the date of capture for all fish. For example, if a person posted on Friday, March 1st of 2013 (calendar day 60), it would be transformed to match Sunday, March 1st of 2020 (calendar day 61). This was completed for all dates prior to January 1st, 2020. The year 2020 was chosen as the baseline because it holds the highest number of posts when compared to other sample years, and Leap Years were considered during calculations.

A one-way Analysis of Variance (ANOVA) was used to assess the differences of the number of posts per day of the week with all rivers combined. Initially a Shapiro Wilks test was conducted to determine if the data passed normality and a Bartlett's Test was conducted to assess homogeneity of variances. Because the data failed to pass normality, a nonparametric Fligner-

Killeen's test checked homogeneity of variances and the Kruskal-Wallis Rank Sum Test determined if there was a difference in the mean number of posts per day of the week.

Catch Per Post

The Facebook group "NC-Shad" was created to exchange information about fishing for Hickory Shad and/or American Shad, so it was assumed that all members and anglers were attempting to catch one or both species. Catch Per Post was used in place of Catch Per Unit Effort (CPUE) because not every post indicated the number of anglers present during a fishing trip, so effort could not be assessed based the data collection method in this study. Hickory Shad and American Shad Catch Per Post (CPP) was calculated per year with all rivers combined and per river with all years combined with the following formula:

$$CPP\ per\ year\ or\ per\ river = \frac{total\ sum\ of catch}{total\ \#\ of\ posts}$$

where one post = one unit of effort and catch is either the sum of Hickory Shad or American Shad caught. Posts that recorded zero catch were included. All data were analyzed using R Studio (Version 3.5.2).

A one-way Analysis of Variance (ANOVA) was used to assess the differences of Hickory Shad and American Shad CPP per year for each river. Initially a Shapiro Wilks test was conducted to determine if the data passed normality, and a Bartlett's test checked homogeneity of variances across groups. If data were normally distributed, a Power Analysis, or a test to determine the probability of finding an effect if significance is found, was conducted to determine if sample size was adequate to lessen the chances of a Type-II Error. A Type-II Error is a false negative result, or, in other words, not finding statistical significance when a significant effect is present. The rule of thumb is a Power Analysis over 80% (power = 0.8) is acceptable. If the data were normally distributed with a sufficient Power Analysis and a statistically significant one-way ANOVA then a Tukey HSD Post Hoc test determined which years were significantly different based on Hickory Shad CPP. If the data failed to pass normality, a nonparametric Fligner-Killeen's test checked homogeneity of variances across groups, and a Kruskal-Wallis Rank Sum Test and Wilcoxon Rank Sum Test were used in place of the one-way ANOVA and Tukey HSD Post Hoc tests.

Geographic Information Systems

Many postings from "NC-Shad" Facebook posts included specific names of Boat Access Areas (BAA), bridges, or landmarks; that information was used to manually identify approximate latitude and longitude waypoints symbolizing fishing locations, so no geocoding was involved in this thesis. Not all posts were easy to geocode because many members provided vague descriptions. For example, a few posts mentioned that they fished "behind Cherry Hospital", so an approximate latitude and longitude was assumed, and a waypoint was placed in the Little River in Goldsboro behind the Cherry Hospital. Any post that only mentioned a river name was not given a waypoint. Latitude and longitude waypoints were taken from the entire study period (2013-2020). Geographic Information Systems (GIS) using ArcGIS Pro (Version 2.7.1) was employed for all analyses.

Along with the spatial and temporal data, the following feature layers were obtained from NC OneMap: BAA, which is the Boat Access Area data provided by the North Carolina Wildlife Resources Commission, Major Hydrograph (Streams/Rivers) data provided by the North Carolina Center for Geographic Information and Analysis, State Maintained Roads data provided by the North Carolina Department of Transportation, and the North Carolina State and County Boundary Polygon data sourced from the North Carolina Geodetic Survey, North Carolina Department of Transportation, and the United States Geological Survey. A CSV file with current and removed lock and dam latitude and longitude locations was also included.

Using ArcGIS Pro (Version 2.7.1), the first objective was to display all BAAs and fishing locations. It is assumed that all fishing locations mentioned in "NC-Shad" were used to attempt to capture Hickory Shad and/or American Shad. First, the BAA, Major Hydrography, and State Maintained Roads feature layers were added. The fishing location, latitude and longitude, and specific date were input into a CSV file and imported into the program. A shapefile was created by employing "Display XY Data" with the CSV as the input and was given the WGS 1984 Geographic Coordinate System as a spatial reference to display the waypoints. This shapefile will be referred to as "Fishing Locations" for the remainder of this chapter. It is important to note that the fishing location waypoints are areas with both successful and unsuccessful Hickory Shad and/or American Shad captures. A layout was then created displaying all fishing locations and NCWRC BAA locations.

The second objective was to determine areas where Hickory Shad and/or American Shad were captured. A CSV file with current and removed lock and dam latitude and longitude locations was imported, and a shapefile was created by employing "Display XY Data" with the CSV as the input and was given the WGS 1984 Geographic Coordinate System as a spatial reference to display the waypoints. The same fishing location shapefile and BAA feature classes as described in the previous paragraph were added to the new map in ArcGIS Pro. In order to obtain locations where only Hickory Shad were captured, "Select By Attributes" was employed where the input was "Fishing Locations", and the Expression was defined to include fishing locations with Hickory Shad captures equal to or greater than one. The selected attributes were then exported into their own shapefile and named "Hickory Shad Capture Locations." The same methodology was used with American Shad postings and the shapefile was named "American Shad Capture Locations." The last objective for the map was to obtain locations where both Hickory Shad and American Shad were captured. To do this, a new selection using "Select By Attributes" was employed where the input was "Fishing Locations" and the first Expression included fishing locations that had Hickory Shad captures equal to or greater than one, and the second Expression used "And" and included fishing locations with American Shad captures equal to or greater than one. The use of "And" in between the two expressions forced the selections to include fishing locations where both Hickory Shad and American Shad were captured at least once from 2013-2020.

The third objective was to determine if there were statistically significant hot and cold fishing spot locations from 2013-2020. It is assumed that all fishing trips were targeting Hickory Shad and/or American Shad. In ArcMap (Version 10.7.1), a CSV file containing the latitude, longitude, date, and number of Hickory Shad and American Shad caught was imported. A shapefile was created by employing "Display XY Data" with the CSV as the input and was given the WGS 1984 Geographic Coordinate System as a spatial reference. Next, the BAA, Major Hydrography, State Maintained Roads, and North Carolina State and County Boundary feature layers were added. In order to identify spatial and temporal patterns associated with fishing locations, the "Create Space Time Cube by Aggregating Points" tool in the Space Time Pattern Mining toolbox was employed to summarize and aggregate waypoints into space-time bins. Each bin is thought of as a three-dimensional cube where x and y dimensions are longitude and latitude, and the z dimension represents time. Within this tool, the Time Step Interval was set to one month, with a total of 89 timesteps between January 2013 to May 2020. To identify trends, the "Emerging Hot Spot Analysis" tool in the Space Time Pattern Mining toolbox was employed. The Space Time Cube was the input, and the Analysis Variable was set to "Count" which counts the number of times each fishing location was used throughout the eight-year period, and the default was used for the spatial neighborhood distance. This tool considers both space and time and analyzes all fishing spot locations to determine whether clustering is statistically significant based on the Getis-Ord Gi* statistic.

The last objective was split into two maps: the first located any statistically significant spatiotemporal hot and cold spots based on Hickory Shad CPP from 2013-2020, and the second located any statistically significant spatiotemporal hot and cold spots based on American Shad CPP during the same timeframe. Like the previous objective, this analysis was completed in ArcGIS Pro (Version 2.7.1). A CSV file containing the date, latitude, longitude, river, mean Hickory Shad CPP, and mean American Shad CPP was imported. Hickory Shad and American Shad CPP was calculated per date per geographical location with the following formula:

$$CPP = \frac{total\ sum\ of\ f\ catch}{post\ \ ID}$$

where one post = one unit of effort, and f is either Hickory Shad or American Shad catch. The CPP for each species was then averaged per date per geographic location (waypoint created by the latitude and longitude). Next, a shapefile was created with "Display XY Data" and was given the WGS 1984 Geographic Coordinate System as a spatial reference. The remainder of the methods were complete for Hickory Shad and American Shad individually. Similar to the first objective, the "Create Space Time Cube by Aggregating Points" tool in the Space Time Pattern Mining toolbox was employed to identify spatial and temporal patterns associated with Hickory

Shad or American Shad CPP by aggregating waypoints into space-time bins. Within this tool, the Time Step Interval was set to one month, the Aggregation Shape Type was set to Fishnet Grid, and the Summary Fields were set to Hickory Shad or American Shad CPP with Statistic set to "Mean" and the Fill Empty Bins with "Zero". Statistic was set to mean because the average Hickory Shad or American Shad CPP would be used as the input for each space-time bin, and the empty bins were filled with zeros because that indicates that no Hickory Shad or American Shad were captured in those bins through space and time. Furthermore, the "Emerging Hot Spot Analysis" tool in the Space Time Pattern Mining toolbox was employed to identify spatiotemporal trends based on Hickory Shad or American Shad CPP. The Space Time Cube was the input, and the Analysis Variable was set to "Mean Hickory Shad CPP" or "Mean American Shad CPP", which allows the tool utilize the Getis-Ord Gi* statistic to discern if the mean Hickory Shad or American Shad CPP had statistically significant spatiotemporal changes throughout the eight-year period, and the default was used for the spatial neighborhood distance.

Creel Survey Comparison

The NCDMF oversees data collection for the CSMA anadromous creel survey in North Carolina rivers, specifically the Neuse, Trent, Tar/Pamlico, Cape Fear, and Pungo rivers. The database ranged from 2012-2019 and included information such as angler socioeconomics, date, location, quantitative data on harvested and released fish, and the targeted species of the anglers. The three main sections of importance to this study from this database are the interview, available catch, and unavailable catch. Within the interview dataset, a unique interview ID was assigned to each fishing trip (similar a member creating a unique post in "NC-Shad"), and the angler specified their first and second species targets. Because it is assumed that the anglers of

"NC-Shad" were targeting Hickory Shad and/or American Shad, only the entries with those species as the first or second target were included in further analyses. Available catch included the interview ID, the species caught, and number harvested. Unavailable catch included the interview ID, the species caught, and number released due to inadequate size, creel limit, or other unknown reasons.

All future analyses were performed in R Studio (Version 3.5.2). Initially the interview section outlined above was reduced to include only interviews where Hickory Shad and/or American Shad were the primary or secondary targets of the fishing trip. The reduced dataset was then matched with the available and unavailable catch based on the interview ID. Of the five rivers sampled, only information on the Neuse, Tar/Pamlico, and Cape Fear Rivers were included. Hickory Shad and American Shad Catch Per Interview (CPI), from creel survey data were calculated the same as the "NC-Shad" CPP mentioned above, but the interview ID was used in place of post ID for the denominator. The formula is as follows:

$$CPI = \frac{total\ sum\ of\ f\ catch}{interview\ ID}$$

where an individual interview = one unit of effort, and f is either Hickory Shad or American Shad catch. Both the creel survey and the social media data contained fishing trips with zero catch, an important aspect to consider when calculating CPI. For each species, the CPI was also averaged per year per river, and descriptive statistics such as the summed total catch, minimum catch in one trip, maximum catch in one trip, catch standard deviation, and number of interviews/posts were also calculated.

All future inferential statistics were completed separately for each species. A Student t-test was used to assess statistically significant differences between the creel survey and social media CPP/CPI per year for each river. Only the years 2013-2019 were analyzed based on data availability between the creel survey and social media. Initially a Shapiro Wilks test was conducted to determine if the data passed normality, and a Bartlett's test checked homogeneity of variances across groups. If data were normally distributed, a Power Analysis was conducted to determine if sample size was adequate to lessen the chances of a Type-II Error. If the data failed to pass normality, a nonparametric Fligner-Killeen's test checked homogeneity of variances across groups, and an unpaired 2-sample Wilcoxon test was used in place of the Student t-test.

Results

Social Structure

Species Reported

"NC-Shad" was created on January 10th, 2013, but my study did not start collecting data until January 7th, 2019. On that date, a total of 1,763 members were reported, and at the end of data collection on January 26th, 2021, a total of 3,680 members were reported for an over two-fold increase; it can be assumed that use of this Facebook group will increase, and membership will continue to rise. Not all members participated by posting or commenting in the group, so all future analyses should include only those members that submitted a post or comment.

A total of 1,790 posts and comments indicating a fishing trip, and success or failure of a fish capture were recorded during the 2013-2020 period. Out of those posts, 13% reported no catch, 70% reported catching at least one Hickory Shad and 17% reported catching at least one American Shad. Out of the 22,440 reported fish caught, 91% were Hickory Shad, 4% were American Shad, and 5% were other species. Although "NC-Shad" focuses on Hickory Shad and American Shad, the category "other" included other species such as Blue Catfish (*Ictalurus furcatus*), crappie (*Pomoxis* spp), Bluegill (*Lepomis macrochirus*), Gizzard Shad (*Dorosoma* *cepedianum*), Largemouth Bass (*Micropterus salmoides*), Striped Bass (*Morone saxatilis*), Blueback Herring (*Alosa aestivalis*), Bowfin (Amia calva), Brook Trout (*Salvelinus fontinalis*), Common Carp (*Cyprinus carpio*), Chain Pickerel (*Esox niger*), Flathead Catfish (*Pylodictis olivaris*), gar (*Lepisosteidae* spp), White Bass (*Morone chrysops*), Alewife (*Alosa pseudoharengus*), White Perch (*Morone americana*), Speckled Sea Trout (*Cynoscion nebulosus*), flounder (*Paralichthys* spp), sea robin (*Prionotus* spp), and Yellow Perch (*Perca flavescens*). From all of the posts, a total of 83 locations were mentioned for 13 rivers across two states. The Susquehanna River, Maryland was the only river mentioned outside of North Carolina (n = 4 posts). Since my study focuses on fish captured in North Carolina, those posts outside North Carolina were removed from the analyses.

Days of the Week

Social media is used sporadically, and this is no different for the Facebook group members of "NC-Shad." Of the 1,786 posts, Wednesdays had the highest number of posts overall, with Sundays coming in at a close second (Figure 3-1). Because the data failed to pass normality (Shapiro Wilk Test = 0.86, P <0.000), for mean number of posts and day of the week, a non-parametric Fligner-Killeen's test passed homogeneity of variances (Fligner-Killeen Chi-Square=1.9, P=0.93) and Kruskal-Wallis Rank Sum Test was performed (Kruskal-Wallis χ^2=2.88, df=6, P=0.82) where no significant differences were reported. Figure 3-2 reports the number of posts per calendar day. The highest number of posts in one day (n=55) was on day 68, which equates to Sunday, March 8th of 2020.

Number of Individuals Reporting

As time progressed and membership grew, the percentage of total posts provided by any single member declined (Table 3-2). A total of 536 members (37.5%) posted or commented (n =

1430) about catching at least one Hickory Shad or American Shad, whether it be personally or by another angler. The highest number of postings by a single member (n = 58) represented 3% of all total posts and comments. One member posted 39 times; his reports described 8% of all Hickory Shad caught by anglers (himself, wife, children, others) mentioned in his posts, which represented the largest number of Hickory Shad reported in posts by any member. On the other hand, 16 posts made by another member held 17% of the total American Shad catch, the highest compared to any other member. For example, in 2013, more than 20% of the total posts (n=66) were reported by one member (Tables 3-1 and 3-2). One member being responsible for a considerable amount of the posts alludes to potential bias in reporting either one fishing location or one river. Yet in 2020, a majority of the members (n=227) contributed less than 1% of the total posts (n=580), with the remaining members contributing between 1-5% (n=58, Tables 3-1 and 3-2). A larger number of reporting members reduces bias in posts, or the potential for one member to greatly influence data on catch, location, lure type, lure color, etc. Post bias per river was common across all rivers: the Roanoke, Tar, and Neuse rivers each had a majority of the members providing less than 1% of the posts (Table 3-4).

Gender and Age

Of the 1837 anglers identified, a majority were male (89%), 8% were female and 3% were unknown. Sexes combined, a majority of the anglers were adults under the estimated age of 60 (62%), with 60+, youth, teens, and unknown anglers representing 26%, 6%, 2%, and 4% of the population, respectively (Figure 3-3). Unknown angler sex and age resulted from either ambiguous wording or lack of specific information in the posts and comments.

Lure and Bait Type

Thirty-eight percent of reports with a successful Hickory Shad or American Shad capture included lure type. Lure type and lure color were compared between Hickory Shad and American Shad to determine if each species exhibited a gear preference (Figure 3-4 and 3-5). Only posts where exclusively Hickory or American shad were caught were used in analyses. A total of 426 posts reported on lure type for Hickory Shad, and 49 reported for American Shad (Figure 3-4). The four main lure types were grubs, spoons, darts, and flies. The "other" category included lure types such as rattle traps and swim bait lures, which are not traditionally used to fish for Hickory Shad or American Shad. Out of the 622 lures reported to capture one or more Hickory Shad, the most common were grubs (44%), with spoons, darts, flies, and other representing 29%, 14%, 11%, and 2%, respectively (Figure 3-4). Out of the 66 reported to capture one or more American Shad, the most common were grubs (45%), with spoons, darts, flies, and other representing 32%, 15%, 6%, and 2%, respectively (Figure 3-4). Hickory Shad preferred flies 5% more than American Shad, but American Shad preferred spoons 3% more often than Hickory Shad (Figure 3-4).

Lure Color

Thirty-five percent of reports with a successful Hickory Shad or American Shad capture included lure color. A total of 401 posts reported on lure color for Hickory Shad, and 47 reported for American Shad (Figure 3-5). The colors reported were white, red, green, chartreuse, orange, pink, black, silver, gold, and yellow. Lure colors in the "other" category, such as clear, sparkled, etc., were not often mentioned. Out of the 844 lures reported to capture one or more Hickory Shad, the most common was chartreuse (21%), with pink and white tied for second at 17% (Figure 3-5). Out of the 87 lures reported to capture one or more American Shad, the most common was chartreuse (27%) with pink second at 21% (Figure 3-5). Chartreuse, pink, and white were the most common colors for both species, and silver spoons were preferred more often than gold spoons (Figure 3-5).

Catch Per Post

CPP by Year

Catch Per Post (CPP) was measured per year with all rivers combined and an overall increasing trend was found for Hickory Shad, whereas an overall decreasing trend was found for American Shad (Table 3-1, Figure 3-6). A total of 1,790 postings from the Facebook group "NC-Shad" were recorded from the years 2013-2020. All posts with locations outside of North Carolina (n=4) were omitted from future analyses. Posts from the coastal Atlantic Ocean (n=6) were included in analyses. CPP was measured where one post = one unit of effort. All posts were used because it is assumed that anglers were targeting either Hickory Shad or American Shad. Table 3-1 displays the Hickory Shad and American Shad summary statistics and CPP per year with all rivers combined based on all posts (n=1786). The year 2013 had the lowest number of posts (n=66), whereas 2020 had the highest number of posts (n=580, Table 3-1). The total number of Hickory Shad caught was also lowest in 2013 (n=406) and highest in 2020 (n=7095), an almost 20-fold increase. Similarly, the highest number of American Shad caught was also in 2020 (n=233), but the lowest number was recorded in 2014 (n=46, Table 3-1). Based on a linear regression, Hickory Shad have an overall positive slope of 0.49 indicating an increase in CPP over time, but American Shad had an overall negative slope of -0.20 indicating a decrease in CPP over time (Figure 3-6). From all samples years with all rivers combined, 2013 had the lowest average Hickory Shad CPP (CPP=6.2), whereas 2018 had the highest overall (CPP=15.1,

Table 3-1). Contrastingly, 2018 had the lowest American Shad CPP (CPP=0.2) and 2013 held the highest (CPP = 2.4, Table 3-1).

CPP by River

CPP was measured per river with all years combined, and the Meherrin River held the highest overall CPP for Hickory Shad, whereas the Pamlico River held the highest CPP for American Shad (Table 3-5, Figure 3-7). Table 3-5 displays the Hickory Shad and American Shad summary statistics and CPP per river with all years combined (n=1550). Only posts with a specified river were included in these analyses. The Tar River held the highest number of posts overall (n=587), with the Lumber and Catawba Rivers having only one post each (Table 3-5). The total number of Hickory Shad caught was highest from the Roanoke River (n=10,158) and lowest at the Catawba River with zero catch (Table 3-5). On the other hand, the highest number of American Shad caught came from the Tar River (n=507), with the Meherrin, Cashie, Bay, Lumber, Catawba, and coastal Atlantic Ocean recording no catch for the species (Table 3-5). The highest average Hickory Shad CPP came from the Meherrin River (CPP = 32.9), and the highest American Shad CPP came from the Pamlico River (CPP = 2.1, Table 3-5).

CPP Comparisons by River and Year

Although a majority of the rivers mentioned did not provide a clear trend in CPP over time, the Roanoke, Neuse, Tar, and Cape Fear rivers provided enough data to examine any differences between years for Hickory Shad (Figures 3-8 and 3-9). Each river was examined for statistically significant differences for mean Hickory Shad CPP by year using a one-way ANOVA. A statistical power analysis was performed for sample size estimation and indicated that years with five or more posts (power = 0.97) were sufficient for the Neuse River data. All years, from 2013-2020, followed that criteria, and although the data passed normality (Shapiro

Wilk Test = 0.96, P = 0.45) and had homogeneity of variances (Bartlett's Test= 6.5, P=0.48), there were no statistically significant differences between Hickory Shad CPP means as determined by one-way ANOVA ($F_{(6,20)} = 0.88$, $P = 0.53$). The Cape Fear River power analysis also indicated that years with five or more posts (power = 0.88) were sufficient, so all years with submitted posts (2013, 2016-2020) were included. No posts for the Cape Fear River were recorded in 2014 and 2015. The data passed normality (Shapiro Wilk Test = 0.96, P = 0.65) and had homogeneity of variances (Bartlett's Test = 0.08, P = 0.77), and the one-way ANOVA showed that the mean Hickory Shad CPP and year had statistically significant differences ($F_{(5,7)} =$ 10.65, $P = 0.0036$). In order to determine which means were significantly different from one another by year, a Tukey's HSD Post Hoc was performed and indicated that 2020 was significantly different from all other sample years (Table 3-6). Because the Tar River failed to pass normality (Shapiro Wilk Test = 0.84, P <0.001), for mean Hickory Shad CPP and year, a non-parametric Fligner-Killeen's test passed homogeneity of variances (Fligner-Killeen $\chi^2 = 6.2$, P = 0.51) and the Kruskal-Wallis rank sum test was performed (Kruskal-Wallis $\chi^2 = 3.91$, df = 7, P = 0.79) where no significant differences were reported. The Roanoke River power analysis indicated years with 98 or more posts (power = 0.79) were sufficient, so years 2018 and 2020 were included. The data passed normality (Shapiro Wilk Test = 0.89, P = 0.17) and had homogeneity of variances (Bartlett's Test = 0.26, P = 0.61), but there were no statistically significant differences between Hickory Shad CPP means as determined by one-way ANOVA ($F_{(1,8)} = 0.92$, $P = 0.37$). All other rivers included in the study did not have enough samples for an acceptable power analysis, so they were not analyzed.

The Roanoke, Neuse, Tar, and Cape Fear rivers also provided substantial data to examine yearly differences for American Shad CPP, but no significant differences were found. The mentioned rivers were examined for statistically significant differences for mean American Shad CPP by year using a one-way ANOVA. The Neuse River failed to passed normality (Shapiro Wilk Test = 0.89, $P = 0.003$) for mean American Shad CPP and year, so non-parametric Fligner-Killeen's test passed homogeneity of variances (Fligner-Killeen $\chi^2 = 0.11$ $P = 0.74$) and the Kruskal-Wallis rank sum test was performed (Kruskal-Wallis $\chi^2 = 4.81$, df = 7, $P = 0.68$) where no significant differences were reported. The Cape Fear River power analysis also indicated that years with 10 or more posts (power = 0.80) were sufficient, so only 2018 and 2020 were included. No posts for the Cape Fear River were recorded in 2014 and 2015. The data passed normality (Shapiro Wilk Test = 0.91, $P = 0.20$) and had homogeneity of variances (Bartlett's Test = 0.42, $P = 0.51$), and the one-way ANOVA showed that the mean American Shad CPP and year had no statistically significant differences ($F_{(1,3)} = 0.06$, $P = 0.82$). Because the Tar River failed to pass normality (Shapiro Wilk Test = 0.52, $P < 0.001$), for mean American Shad CPP and year, a non-parametric Fligner-Killeen's test passed homogeneity of variances (Fligner-Killeen $\chi^2 = 10.43$, $P = 0.17$) and the Kruskal-Wallis rank sum test was performed (Kruskal-Wallis $\chi^2 = 9.63$, df = 7, $P = 0.21$) where no significant differences were reported. The Roanoke River data failed to pass normality (Shapiro Wilk Test = 0.62, $P < 0.001$), but the non-parametric Fligner-Killeen's test passed homogeneity of variances (Fligner-Killeen $\chi^2 = 8.23$, $P = 0.31$) and the Kruskal-Wallis rank sum test was performed (Kruskal-Wallis $\chi^2 = 4.62$, df = 7, $P = 0.71$) where no significant differences were reported. All other rivers included in the study did not have enough samples for an acceptable power analysis, so they were not analyzed.

Geographic Information System

The first objective was to display all fishing locations obtained from posts from the "NC-Shad" Facebook group (Figure 3-10). These locations do not consider whether a Hickory Shad and/or American Shad was caught, but instead were just mapped because they were mentioned in the posting. The assumption is that all anglers were attempting to capture one or both study species, and it was important to include locations where the angler was unsuccessful. From all posts, a total of 83 fishing locations were within 13 rivers located across North Carolina. A total of 1,389 posts, 78% of total posts, included location data and were used for all future analyses.

Figure 3-11 displays fishing locations where Hickory Shad and/or American Shad were captured. Out of the 1,389 posts for the 2013-2020 period, 75% (1,047) had one or more Hickory Shad captured, 21% (288) had one or more American Shad captured, and 13% (183) had one or more of both species. The earliest date of capture for an American Shad within the sounds and rivers of North Carolina was December 23rd, 2013 from the Tar River, and the earliest capture of a Hickory Shad was January 3rd, 2019 from the Bay River. Visually, only Hickory Shad were captured along the coastal Atlantic Ocean or within the Pamlico or Albemarle Sounds (Figure 3-11). Both species were found in the four major rivers of North Carolina, and from north to south they were the Roanoke, Tar/Pamlico, Neuse, and Cape Fear rivers. Figure 3-11 also revealed that American Shad were found farther upstream than Hickory Shad in the Cape Fear River, but Hickory Shad were found farthest upstream in the Roanoke River. Hickory Shad were also the only species caught in both the Cashie River of the Roanoke River basin, and Meherrin River of the Chowan River basin. There were a total of 16 locks and dams included, and they were split up into removed (n = 7) and current (n = 9) locks and dams. The seven dams that were removed were from north to south as follows: Milburnie Dam off the Neuse in 2017, Lowell Mill Dam off

Little River of the Neuse in 2005, Buckhorn Dam off the Cape Fear in 2009, Crantock Mill Dam off the Neuse in 2008, Rains Mill Dam off the Neuse in 1999, Cherry Hospital Dam off the Neuse in 1998, and Quaker Neck Dam off the Neuse in 1998. The nine remaining locks and dams from north to south are as follows: Gaston Dam and Roanoke Rapids Dam off the Roanoke, Falls Lake Dam off the Neuse, Rocky Mount Reservoir off the Tar, Atkinson Mill Pond Dam off the Neuse, Blewett Falls Lake Dam off the Pee Dee, and the William O'Husk Dam, Lock and Dam #2, and Lock and Dam #1 of the Cape Fear. Both Hickory and American Shad were found above the previous Quaker Neck Dam location, but only Hickory Shad were found above the Milburnie Dam location (Figure 3-11). Table 3-7 indicates the locations and years where Hickory Shad and American Shad were captured above locks and dams. Both current and removed dams were included. Only one Hickory Shad was caught above Milburnie Dam at the Falls Lake Spillway in 2013, but after dam removal in 2017 there were seven individuals caught in 2018 and two in 2020. As for the remaining operative dams, zero individuals were captured above the Gaston and Roanoke Rapid dams of the Roanoke River, or the Falls Lake Dam of the Neuse River. Both species surpassed Lock and Dam #1 and #2, but only one American Shad was captured in 2018 above the William O'Husk Dam of the Cape Fear (Table 3-7). Both species were also upstream of the Rocky Mount Reservoir (n = 24 Hickory Shad, n = 1 American Shad, Table 3-7).

The next objective was to determine statistically significant spatiotemporal hot and cold spots signifying fishing locations. A hot spot is considered higher than average number of posts for a fishing location, and a cold spot is lower than average number of posts for a fishing location. The Space Time Cube created 1-month time-steps beginning in January of 2013 and ending in May of 2020, with a total of 89 time-steps. There was not a strong justification for any particular distance interval, so the tool calculated the default value of 13,840 meters (~8.6 miles). This default value was calculated based on the input feature maximum extent and an algorithm based on the spatial distribution of the input features, so the output analysis covers all fishing location waypoints. Within the Emerging Hotspot Analysis, because there was no strong justification for a spatial neighborhood distance, the default value of 38,120 meters (~23.7 miles) was used. Mann-Kendall trend test was performed to determine if there was a statistically significant trend over time for every location based on the spatiotemporal data. Although the positive z-score of 0.39 indicates an overall increase in the use of the fishing locations from 2013-2020, there failed to be a statistically significant trend with the increased use (P = 0.69). The Emerging Hot Spot Analysis indicated a total of 59 polygons, and each polygon symbolizes an aggregated location of fishing spots (Figure 3-12). Five polygons were deemed as Sporadic Hot Spots, which indicates an on-again then off-again hot spot where less than 90% of the time-step intervals have been statistically significant hot spots and none of the time-step intervals have been statistically significant cold spots (Figure 3-12). The remaining 54 polygons had no pattern detected, and no cold spots were present. Out of the 60 BAA located within a mile of a fishing location, 50 were stationed within the Emerging Hot Spots Analysis output (Figure 3-12). The Sporadic Hot Spot polygons included three BAA, which from north to south are as follows: Gaston and Weldon of the Roanoke River, and Old Sparta and Falkland of the Tar River (Figure 3-12). The remaining 46 BAA were located within the polygons with no pattern detected.

The last objective created two separate maps to determine statistically significant spatiotemporal changes in mean Hickory Shad and American Shad CPP from 2013-2020. Hickory Shad CPP was calculated per date per location (n=1088) obtained from the posts from the “NC-Shad” Facebook group. A hot spot is considered statistically significantly higher than average CPP in that month compared to neighboring locations, and a cold spot is statistically significantly lower than average CPP in that month compared to neighboring locations. The Space Time Cubes created 1-month time-steps beginning in January of 2013 and ending in May of 2020, with a total of 89 time-steps, the same as the first objective. There was not a strong justification for any particular distance interval, so the tool calculated the default value of 13,840 meters (~8.6 miles). Within the Emerging Hotspot Analysis, because there was no strong justification for a spatial neighborhood distance, the default value of 38,120 meters (~23.7 miles) was used. The Mann-Kendall trend test was performed to determine if there was a statistically significant trend over time for every location based on the spatiotemporal data. Although the positive z-score of 0.40 indicates an overall increase in Hickory Shad CPP from 2013-2020, there failed to be a statistically significant trend with the increase in CPP ($P = 0.68$). Alternatively, with American Shad, the negative z-score of -0.18 indicates an overall decrease in CPP from 2013-2020, but there still failed to be a statistically significant trend direction ($P=0.86$).

The Emerging Hot Spot Analysis for both species indicated a total of 59 polygons, and each polygon symbolizes an aggregated location of average CPP. For Hickory Shad CPP, six polygons were deemed as Sporadic Hot Spots which indicates an on-again then off-again hot spot where less than 90% of the time-step intervals have been statistically significant hot spots and none of the time-step intervals have been statistically significant cold spots (Figure 3-13). A single polygon indicated a Consecutive Hot Spot which is a single uninterrupted run of statistically significant hot spot bins in the final time-step intervals, and the location has never been a statistically significant hot spot prior to the final hot spot run and less than 90% of all bins are statistically significant hot spots (Figure 3-13). One polygon was also assigned as a New Hot

Spot, which is a location that is a statistically significant hotspot for the final time-step and has never previously been a statistically significant hot spot (Figure 3-13). The remaining 51 polygons had no pattern detected, and no cold spots were present. Out of the 60 BAA located within a mile of a fishing location, 50 were stationed within the Emerging Hot Spots Analysis output (Figure 3-13). The Sporadic Hot Spot polygons included six BAAs, which from north to south are as follows: Gaston and Weldon of the Roanoke River, and Tar River locations including Old Sparta, Falkland, Port Terminal in Greenville, and Masons Landing on Tranter's Creek. The Consecutive Hot Spot polygon contained only the Murfreesboro BAA off the Meherrin River. The New Hot Spot polygon included only the Tar Heel BAA off the Cape Fear River.

As for American Shad CPP, a total of seven polygons were found to have statistically significant hotspots. Six of those hot spots were deemed Consecutive Hot Spots and one deemed a Sporadic Hot Spot (Figure 3-14). The remaining 52 polygons had no pattern detected, and no cold spots were present. Out of the 60 BAA located within a mile of a fishing location, 50 were stationed within the Emerging Hot Spots Analysis output (Figure 3-14). The Consecutive Hot Spot polygons contained five BAAs, which from north to south are as follows: Cox's Ferry, Steven's Mill, Goldsboro, Price's Landing, and Seven Springs, all off the Neuse River. The Sporadic Hot Spot polygon contained only the Tar Heel BAA off the Cape Fear River.

Creel Survey Comparison

Survey Overview

The CSMA Creel Survey database contains information on the Neuse, Trent, Tar/Pamlico, Cape Fear, and Pungo rivers in North Carolina from 2012-2019. A total of 25,756 recreational angler interviews were completed consisting of information on angler socioeconomics, catch and harvest information, and species targeted during each fishing trip. Between 2013-2019, 437 interviews (1.7% of the total) indicated that anglers targeted Hickory and/or American shad in the Neuse, Tar/Pamlico, and Cape Fear rivers of North Carolina. Of the 437 interviews, 38% were from the Tar River (n=165), 23% were from the Neuse River (n=100), and 39% were from the Cape Fear (n=172, Tables 3-7 and 3-8). A total of 728 posts were analyzed from “NC-Shad” of which 53% were from the Tar River (n=383), 42% were from the Neuse River (n=311), and 5% were from the Cape Fear River (n=34, Tables 3-7 and 3-8).

Descriptive Statistics

Descriptive statistics were calculated separately for both Hickory Shad and American Shad for the Tar, Neuse, and Cape Fear rivers. From 2013-2020 for the creel survey, a total of 980 Hickory Shad were captured: 29% from the Tar River (n=289), 70% from the Neuse River (n=689), and 1% from the Cape Fear River (n=2, Table 3-8). Within the same study period, a total of 5099 Hickory Shad were reported in social media posts: 41% from the Tar River (n=2101), 58% from the Neuse River (n=2933), and 1% from the Cape Fear River (n=65, Table 3-8). The creel survey minimum Hickory Shad catch for all three rivers was zero, with anglers fishing the Tar, Neuse, and Cape Fear rivers reporting a max catch in one fishing trip as 45, 120, and 1 fish, respectively (Table 3-8). The social media posts also had a minimum Hickory Shad catch of zero, with anglers fishing the Tar, Neuse, and Cape Fear rivers reporting a max catch of 100, 250, and 30 fish, respectively (Table 3-8). From 2013-2020 for the creel survey, a total of 1795 American Shad were captured: 17% from the Tar River (n=312), 3% from the Neuse River (n=52), and 80% from the Cape Fear River (n=1431, Table 3-9). Within the same study period, a total of 551 American Shad were reported in social media posts: 69% from the Tar River (n=381), 21% from the Neuse River (n=114), and 10% from the Cape Fear River (n=56, Table 3-9). The minimum American Shad catch for both the creel survey and social media posts between all three rivers was zero, with the Tar, Neuse, and Cape Fear rivers reporting a max catch in one fishing trip as 40, 19, and 109 fish for the creel survey, and 50, 18, and 4 for the social media data, respectively (Table 3-9).

CPP/CPI Comparison

The Tar and Neuse rivers provided substantial data to examine differences in Hickory Shad CPP/CPI between the creel survey and the social media data for each sample year, and some statistically significant differences were found. Hickory Shad data from the Neuse River ranged from 2013-2019, and because all comparisons failed to pass normality (Shapiro Wilk Test $P<0.001$) and passed Fligner-Killeen's test for homogeneity of variances(Fligner-Killeen $P>0.05$), the unpaired two-sample Wilcoxon Test was performed. Three years were found to have statistically significant differences between the median CPP/CPI calculated for the creel survey and the social media: 2014 (Wilcoxon Test = 58, P=0.008), 2015 (Wilcoxon Test = 31, P=0.04), and 2016 (Wilcoxon Test = 104, P=0.002). Only the years 2015-2019 could be compared for Tar River Hickory Shad CPP because 2013 and 2014 had a lack of creel survey catch for the species. All comparisons failed to pass normality (Shapiro Wilk Test $P<0.001$) and passed Fligner-Killeen's test for homogeneity of variances (Fligner-Killeen $P>0.05$), so the unpaired two-sample Wilcoxon Test was performed. Two years were found to have statistically significant differences between the median CPP/CPI calculated between the two sources: 2016 (Wilcoxon Test = 539, P=0.000) and 2018 (Wilcoxon Test = 4083, P=0.01). The Cape Fear River did not have enough Hickory Shad samples to compare, so it was not analyzed. Figure 3-16 displays the median Hickory Shad CPP/CPI per year per river along with the minimum and maximum values and any outliers. No outliers were considered atypical, so they were not removed.

The Tar, Neuse, and Cape Fear rivers provided substantial data to examine differences in American Shad CPP/CPI between the creel survey and the social media data for each sample year, and some statistically significant differences were found. The Neuse River data ranged from 2013-2018, but no American Shad were reported in the creel survey for 2019, so it was not analyzed. All Neuse River comparisons failed to pass normality (Shapiro Wilk Test $P<0.000$) and passed Fligner-Killeen's test for homogeneity of variances (Fligner-Killeen $P>0.05$), but the unpaired two-sample Wilcoxon Test found no significant differences for the median CPP/CPI between the creel survey and social media posts (Wilcoxon Test $P>0.05$). The Tar River could only be analyzed for the years 2016, 2018, and 2019 because all other years had insufficient data for proper analyses. The Tar River comparisons failed to pass normality (Shapiro Wilk Test $P<0.001$) and passed Fligner-Killeen's test for homogeneity of variances (Fligner-Killeen $P>0.05$), so the unpaired two-sample Wilcoxon Test was performed. Of the three years analyzed, two years were found to have statistically significant differences between the median CPP/CPI calculated between the two sources: 2016 (Wilcoxon Test =1453.5 , $P=0.02$) and 2018 (Wilcoxon Test = 6261.5, $P<0.001$). Only the year 2017 and 2018 could be analyzed for the Cape Fear river because of insufficient data, and after the comparisons failed to pass normality (Shapiro Wilk Test $P<0.001$) and passed Fligner-Killeen's test for homogeneity of variances (Fligner-Killeen $P>0.05$), the unpaired two-sample Wilcoxon Test found 2018 to have statistically significant differences between the creel survey and social media data (Wilcoxon Test =170.5 , $P<0.001$). Figure 3-17 displays the median American Shad CPP per year per river along with the minimum and maximum values and any outliers. No outliers were considered atypical, so they were not removed.

Discussion

Social Structure

The Facebook group "NC-Shad" is a voluntary platform that provided a plethora of fishing information on social categories, fishing location, fishing gear, and Hickory Shad and American Shad catches from 2013-2020. Socioeconomics is a huge driver of recreational fishery success, and the popularity of the spring shad spawning run contributes, among other factors, to the frequency and quality of the information that is posted in this group. Not all posts were about catching fish; some examples of other posts include selling a boat or fishing gear, providing information on fishing locations that were flooded, reporting on dam water releases, asking questions about fishing gear or creel limit, and providing insight on professional fishing guides. Many members also took pride in bringing their children and grandchildren fishing, and some expressed wanting this resource to be around in the future for their next of kin to enjoy.

This group is guided by Local Ecological Knowledge (LEK), or the knowledge formed through experiences and interactions within social networks that influences the timing, location, and method of fishing (McLean and Forrester 2018). The anglers from "NC-Shad" provided novel information on the biology and ecology of Hickory Shad and American Shad, and provided information about habitat use, spawning grounds, migration corridors, and nursery areas where Conventional Scientific Knowledge (CSK) is lacking. CSK is knowledge gained from data collected based on a scientific design and is theoretically interpreted (Berkström et al. 2019). One study demonstrated how LEK helped develop maps of detailed nursery locations and establish time periods of adult migration to spawning grounds in West Africa, and the same study also noted similarities between scientifically gathered data and LEK (Le Fur et al. 2011). Although LEK has been commonly combined with CSK for use in small-scale fisheries in developing countries, the posts from “NC-Shad” demonstrate how these societal constructs may benefit large-scale fisheries, especially with an incomplete stock assessment for Hickory Shad. LEK may be able to help fill scientific knowledge gaps, complementing CSK, and it would also make local resource stakeholders feel important and included in the management process (Berkström et al. 2019).

Understanding the dynamics of recreational angler use of social media could help pinpoint members who are central in the information-sharing network, or those that have better fishing success and have access to a wide range of information from their peers (Turner et al. 2014). Identifying these individuals may be useful to managers who are seeking information on spatial and temporal distributions, productive fishing grounds, and the ways in which anglers use their knowledge and experiences to adapt to changes with the resource, environment, or management policies (Turner et al. 2014). The social dynamic of “NC-Shad” was tricky, especially because this group was not created for scientific purposes. From a social standpoint, the anglers were categorized into three major groups: anglers who post, anglers who look, and anglers without social media (Figure 3-15). There is a chance that over time individuals left the group because of a lack of interest, discontinued posting, or that new individuals joined in, and there was a high chance that both successful and unsuccessful anglers did not always post. The flow chart in Figure 3-15 depicts the recreational angler participation options within a social media platform (in this case, it is the “NC-Shad” Facebook group). Anglers can either 1) physically participate in social media platforms by creating their own posts or commenting on other content, 2) use social media as a medium to obtain LEK, but not contribute to social media, or 3) not participate in social media at all. Options two and three mean the recreational angler could only be assessed from the creel survey. Option 1 is split into two groups, current users who have contributed previously to social media, and new users who have just joined the platform. The current users then have three options: 1) drop out of using the social media platform, 2) continue to use the social media platform, and 3) change social media platforms (i.e., switching from Facebook to Twitter). The first option would again mean the recreational angler could only be assessed from the creel survey, option two indicates that the member can continue to be assessed by the current social media survey (with the chance of also being assessed by the creel survey), and option three could be assessed by a separate social media survey or the creel survey. As for new members within the social media platform, they can either become anglers who contribute, or anglers who do not contribute, and the cycle continues (depicted by the red arrow and the red branches). One assumption is that all individuals have the same probability of being assessed by the creel survey, but those members that contribute to the social media platform will always be assessed, thus providing supplemental information on the recreational fishery. Angler information such as sex and age class (youth, teen, adult, 60+) could also be extrapolated to determine the demographics of fishing license holders, assuming all anglers are licensed. The lure type and lure color will not only help recreational anglers better target Hickory Shad and American Shad, but it also suggests the inventory bait and tackle stakeholders should consider for future shad seasons.

Some members explicitly stated whether they practiced catch and release, kept the allotted creel limit, or followed the single barbless hook rule in the Roanoke River after April 1st. Most members exhibited social capitol, or the combination of social structure and individual values that facilitates cooperative behavior (Rudd 2003) and enforced the management practices by the NCWRC and NCDMF; these individuals often alerted members that did not correctly follow these practices. It seems like the members wanted the Hickory Shad and American Shad recreational fishery to be sustainable as much as the fisheries agencies.

Some members may also depend on this fishery as their livelihood. One explanation for the large increase in the number of members posting and the number of posts could be because of the COVID-19 Pandemic. Based on data from the U.S. Bureau of Labor Statistics, the average unemployment rate for North Carolina from 2013-2020 was 5.6%, with the minimum from December of 2019 to February of 2020 at 3.6% and a maximum of 12.9% in April of 2020, the start of the COVID-19 Pandemic. The large spike in unemployment may have forced families to turn to subsistence fishing. Subsistence fishing refers to fishing that is carried out to feed one's family, so individuals who suffered from a lowered income or a job loss could have relied on fishing for this reason. Although Hickory Shad and American Shad are normally caught for sport, they can be eaten for their row or flash fried to eat the fish whole. There were "NC-Shad" posts that included recipes on how to cook these species, although no analyses were completed to compare the number of these types of posts to previous years.

The apparent disparity between the number of posts per year can be attributed to the number of members in the group. Because "NC-Shad" began in January of 2013, a very small number of members were responsible for the posts. Over time and as membership grew, so did the number of posts (Table 3-1). This trend must be taken into consideration for all analyses, because obviously a higher number of members means a higher probability of more posts. On the other hand, as time progressed, each member who posted provided less towards the overall percentage of total posts, indicating that the posts were not all biased from a select number of members (Table 3-2).

Although the number of trips based on the day of the week are not statistically significantly different, that information could help determine when electrofishing surveys are best employed and least likely to interrupt recreational anglers.

To understand if Hickory Shad and American Shad are opportunistic or target their prey during the spawning run, data on lure type and lure color were collected (Figure 3-4 and 3-5). Lure type and lure color were separated for analyses between the two species to determine if preferences differed between Hickory Shad and American Shad. No major differences were apparent between lure type and color. Hickory Shad were caught more often on flies compared to American Shad, but all other lure types were relatively similar (Figure 3-4). Chartreuse, pink, and white were the most common colors with successful captures for both species, and silver spoons were more successful than gold spoons (Figure 3-5). The brighter colors may have been more successful because they are the most visible in turbid waters. Harris and McBride (2009) found that American Shad from the St. Johns River in Florida targeted mainly pelagic copepods during their spawning migration, but also fed on benthic mollusks and surface insects, which suggested they feed based on prey availability. Rulifson and Batsavage (2014) identified the gut contents of 212 Hickory Shad from the Roanoke River and Albemarle Sound in North Carolina and found that an average of 27% contained fish, seeds, wood, and plastic, which suggests that they do feed during their spawning run, and based on the results from this study, there was no particular preferences on lure type or lure color, suggesting Hickory Shad are opportunistic feeders during the spawning run.

The ambiguity of the “NC-Shad” Facebook posts required many assumptions. It was assumed that every post (i.e., every fishing trip) was targeting Hickory Shad and/or American Shad. It was also assumed the date the post was submitted was the same day the angler fished unless otherwise specified. Fishing time was not considered, which is why each post was considered as one unit of effort. Future studies may be able to gain that information to obtain CPP based on trip length. Another limitation was the lack of consistency given the sporadic and unstructured provision of information; posts were most likely not done after every fishing trip, and there is a high probability of unshared data. While the information on “NC-Shad” may not accurately reflect the fishing activity by each member, there may be potential to form a network of anglers willing to participate in monitoring programs or take part in controlled citizen science studies. Citizen scientists, or volunteers who collect data on the natural world in collaboration with researchers, could be recruited from the “NC-Shad” Facebook group and could provide Hickory Shad and American Shad spawning migration and distribution surveillance information. Overall, social media sites may be employed as a cost-effective survey method for these species.

Catch Per Post

Obtaining CPP information from Facebook posts is an imperfect process. It is not possible to account for every fish that migrates through these river systems, and it impossible to know if the catch numbers are overestimated or underestimated for some posts. Ambiguous posts using terms such as “a few” or “some” were consciously underestimated because an exact number could not be speculated, so one individual was recorded for the sake of quality. A more accurate estimation requires further investigation, which may include directly contacting “NC-Shad” members to enquire about the total catch for each fishing trip. The use of a Facebook group to obtain Hickory Shad and/or American Shad CPP through the above methodologies has never been reported, so previous studies could not be compared to these findings.

CPP was calculated where one post = one unit of effort, and posts with and without successful Hickory Shad and American Shad captures were included. This methodology assumes that there is an equal probability in catching Hickory Shad and American Shad for each post. The American Shad Stock Assessment of 2020 indicated that American Shad are still at low abundances for most rivers, and a stock assessment has still never been completed for Hickory Shad, so it is impossible to know if the probabilities are equal. For the study period, 2013 had the lowest number of posts (n=66) most likely because it was the first year of existence for the "NC-Shad" Facebook group. This also explains 2020 having the highest number of posts (n=580) because membership continued to grow over time; as more people join the group, there is a higher probability for people to post (Table 3-1). This hypothesis also explains why the lowest and highest numbers of Hickory Shad were caught in 2013 and 2020, respectively. On the other hand, American Shad had the highest CPP in 2013 and the lowest in 2020, and an overall negative trend in CPP during the study period (Table 3-1, Figure 3-6). Because there was an increase in fishing pressure based on "NC-Shad" membership and post amount, this suggests an overall decrease in American Shad abundance over time. Based on all years combined, the Tar River had the highest number of posts (n=587), which suggests that members from "NC-Shad" either live in that geographical area, or believe through LEK and TEK that the Tar is the preferred river to target these species. Based on the four main rivers (Roanoke, Tar, Neuse, and Cape Fear) and overall Hickory Shad CPP, the Tar River reported the lowest (CPP= 6.3) and the Roanoke River the highest (CPP=26.9, Table 3-3, Figure 3-7). The Roanoke may have the highest out of the four main rivers because of the Roanoke Rapids Dam that restricts upstream migration. Out of all rivers mentioned in the postings, the Meherrin River in Virginia had the highest Hickory Shad CPP at 32.9 fish per post, but this is most likely due to 2020 and the low number of fishing trips (n=4) with a high number of fish caught (n=218,) which skewed the overall data for the river (Tables 3-3 and 3-5). The Pamlico River had the highest overall American Shad CPP (CPP = 2.1) which is probably due to the low number of posts (n=8) versus the number of fish caught (n=17, Table 3-3).

When comparing the CPP between years for each river, only the Cape Fear River was found to have statistically significant differences between Hickory Shad CPP per year. The significant difference between 2020 and all other sampling years could be due to the small post sample size from the years 2013-2019, and the large increase in postings for 2020. Along with the large increase in posts for 2020, the number of members posting for the Cape Fear greatly increased, which could explain the dramatic increase in Hickory Shad catch. No rivers had a statistically significant difference in average American Shad CPP per year. It is hard to determine why the Cape Fear had no posts for 2014 and 2015. An initial hypothesis was the severe sleet and freezing rain that affected the southern Outer Banks and other coastal areas in the 2013-2014 winter (Lonka 2014), but all Eastern North Carolina dealt with abnormal weather patterns and other rivers maintained a normal annual posting amount. A second hypothesis was the above normal rainfall events and abnormally cold temperatures due to ENSO (El Niño/ Southern Oscillation), but this still showed no impact based on posts made from other river systems. The 2015 Cape Fear River Creel Survey estimated over 10,000 American Shad caught during that fishing season, so the gap years were not due to the absence of the fish, and anglers were still able to capture these target species (Fisk 2016). Only two members provided the five total posts for 2013, and neither member provided any posts for 2014 and 2015 for any river. However, one of these same members provided posts for 2016 (Table 3-5), so I conclude that the gap in posting is likely a result of the lower fishing pressure from "NC-Shad" members in the Cape Fear compared to the other river systems.

Geographic Information System

The "NC-Shad" Facebook group had 1,398 posts from 2013-2020 that mentioned some form of location, whether it be a BAA, landmark, or bridge within a town. Although some of the posts provided vague descriptions, an approximate latitude and longitude waypoint was mapped for every post. Geographic Information Systems, more specifically ArcGIS Pro (Version 2.7.1), was used to display the fishing location waypoints, map areas where Hickory Shad and/or American Shad were captured and determined spatial and temporal patterns in both Hickory Shad and American Shad CPP.

About 75% of the posts had one or more Hickory Shad captured, 21% had one or more American Shad captured, and 13% had locations where both were captured during the eight-year study period. It is important to note that all fish captured within the river systems were most likely participating in the spawning run for that season, so it could be assumed these individuals either did spawn or planned to spawn near where they were captured. Adult Hickory Shad are present in shallow continental shelf waters starting in November between Cape Lookout and Cape Charles, Virginia and data collected by the NCDMF staff has indicated that small numbers enter the Albemarle Sound, North Carolina as early as October and Pamlico Sound, North Carolina as early as December (Rulifson et al. 2020). A previous study indicated that adult Hickory Shad are known to enter freshwater tributaries between February and June to spawn (Murauskas and Rulifson 2011), but my study found the earliest capture date of a Hickory Shad within a river system to be January 3rd, 2019 from the Bay River. American Shad have been known to enter the sounds and rivers of North Carolina as early as February (ASMFC 2020), but my study found the earliest date of capture for an American Shad within the sounds and rivers of North Carolina was December 23rd, 2013 from the Tar River. Spawning migrations for these alosines are largely triggered by increasing day length and temperature. However, recent studies noted that spawning runs have commenced earlier compared to studies done in the 1970s suggesting that the gradual warming offshore temperatures attributed to climate change may be causing these spawning runs to occur at the same temperatures, but earlier in the season (Smith and Rulifson 2015; Rulifson et al. 2020). It is hypothesized that Hickory Shad and American Shad migrate to the spawning grounds in waves (Rulifson, personal communication), which may explain some of the early arrivals. Although this aspect has not been documented, the data provided in postings gives evidence that Hickory Shad and American Shad inhabit the same rivers and utilize the same habitats during the spawning migration. The Emerging Hot Spot Analysis indicated no overall significant spatiotemporal trend in on fishing location, thus rejecting the hypothesis. Although there is no overall trend, the analysis still indicated which parts of the river systems are fishing pressure hot spots, and these locations may need to be a focus for future assessments, especially when considering the historically low American Shad stock status.

The oceanic migration of American Shad has been studied in some detail. Using a mark-recapture study, Dadswell et al. (1987) concluded that American Shad have separate winter and summer aggregation areas, that spawning individuals tend to migrate closer to shore in the spring while non-spawning individuals migrate offshore, and a general trend of northward migration in the spring and southward in the fall and winter. Only Hickory Shad (n=36) were captured along the coastal Atlantic Ocean, but there is a lack of information about their ocean migrations. If certain aspects of the two species life histories mirror one another, one hypothesis could be that the reported 36 Hickory Shad were planning to spawn and therefore were migrating closer to the coastal ocean like American Shad. Rulifson et al. (2020) was the first comprehensive compilation of information necessary to document the phenology of the spawning season of Hickory Shad, and although no samples were present from the ocean, samples within the sounds and estuaries indicated small numbers of adult Hickory Shad present as early as October. Because it is unknown if those individuals are outmigrants or early arrivals to the spawning grounds, a future study should look at scales and otoliths to estimate spawning marks and otolith ages. More information on the oceanic migrations of mature Hickory Shad is needed to determine if they overwinter within the same geographic range as American Shad.

The NCDEQ American Shad Species Profile states that recreational landings are minimal throughout the Roanoke, Tar/Pamlico, and Neuse rivers, and the bulk of the fishery occurs in the Cape Fear River (NCDEQ 2017a). From 2013-2019, the CSMA anadromous creel survey interviews targeting Hickory and/or American Shad also indicated that 80% of the American Shad catch came from the Cape Fear River (Table 3-9) but results of my study disagree. Not only did the Tar River have the highest number of American Shad caught (n=381), but the Pamlico River had the highest CPP (Table 3-3 and 3-9). The high Tar River American Shad catch could be due to the high number of fishing trips, and the high Pamlico River CPP could be because of the small number of fishing trips and large number of American Shad caught, but results show how the Cape Fear River may not provide the bulk of the fishery. The CSMA anadromous creel survey also indicated that the Tar River provided 17% of the total American Shad caught, suggesting that this river may be an important contributor to the stock (Table 3-9). Future population assessments for the species should give more attention to the Tar/Pamlico river system.

A major impedance to Hickory Shad and American Shad spawning is the loss of habitat due to lock and dam construction. Locks and dams block these species from reaching historical spawning grounds, but the removal of dams has shown to enhance the migration of these anadromous fish and provide many miles of additional spawning habitat (ASMFC 2020). It does not seem like any currently constructed dams were the main cause for zero captures during a fishing session because the fishing locations in Figure 3-10 are consistent with the capture locations in Figure 3-11. In this study, both Hickory and American Shad were found above the previous Quaker Neck and Cherry Hospital dams, indicating that the dam removal was successful in allowing both species to travel farther upstream. Before the Milburnie Dam was removed, only one Hickory Shad was captured above it, but after the removal in 2017, a total of seven Hickory Shad were caught in 2018 and two in 2020. This increase in captured Hickory Shad could be a result of dam removal, which allowed Hickory Shad to access spawning habitat available up to the Falls Lake Spillway below the Falls Lake Dam.

In order to combat the population declines of American Shad, stocking programs have been implemented in the Roanoke and Neuse rivers. The 2020 American Shad Stock Assessment indicated that the stocking program seems to be contributing very little to the overall American Shad population in the Neuse River, but the Emerging Hot Spot Analysis indicated a recent increase in American Shad CPP within and around the stocking location. The grouping of Consecutive Hot Spots near Goldsboro for American Shad CPP could be due to the success from the Neuse River stocking that began in 2012. The Cox Ferry BAA, located within one of the Consecutive Hotspots, happens to be the stocking location near the NC Highway 117 Bridge

(Ricks and Rachels 2015). Collections in 2017 found that 7.8% of the captured American Shad were from the 2012, 2013, and 2014 cohorts (White and McCargo 2018), and because the broodfish are also taken from Goldsboro, their return to their natal watershed could explain the increase in CPP compared to other locations.

Historically, American Shad migrated up the Roanoke River as far upstream as Salem, Virginia, but now most spawning occurs just below the Roanoke Rapids Dam (Hightower and Sparks 2003), a hypothesis with which my study agrees. When Old Dominion settles on a fish passage strategy, Hickory Shad and American Shad should be able to access historical spawning grounds upstream of Kerr Dam. The Roanoke Rapids Dam could be a major reason why a statistically significant spatiotemporal pattern was detected for Hickory Shad. If the majority of Hickory Shad are unable to continue their migration upstream, they will be forced to aggregate at their farthest upstream location, making them a prime target for recreational anglers. On the other hand, Mack et al. (2021) tracked 62 acoustically tagged American Shad over a six-year period and found that a majority made apparent spawning runs up the Chowan River and its tributaries instead of the Roanoke River. This result may explain why no American Shad were caught in the Cashie River, situated just north of the mouth of the Roanoke River. Hickory Shad were captured in the Cashie River, indicating a wider spawning distribution compared to American Shad from the Albemarle Sound. Although no American Shad were captured in the Chowan River, the Meherrin River, a branch of the Chowan, held the highest overall Hickory Shad CPP. The high CPP may result from a low number of fishing trips with high capture numbers, but this suggests that the Chowan River system may not only be a major American Shad spawning location but also a Hickory Shad hot spot.

As for the Cape Fear Lock and Dam #1, fish passage is most likely due to the successful construction of the Rock Arch Ramp. Cape Fear River surveys have documented evidence of American Shad successfully utilizing the Rock Arch Ramp (White and McCargo 2018), so it could be hypothesized that Hickory Shad also follow that passage. Both Hickory Shad and American Shad were found above Lock and Dam #2, but only American Shad were caught above the William O'Husk Dam. Smith and Hightower (2012) found that American Shad were able to pass all three locks and dams, but the number of eggs in plankton samples declined in relation to the number of surpassed locks. Of the four major rivers, the Cape Fear River had the lowest number of posts and lowest Hickory Shad catch, but this may be a result of lower fishing pressure from the "NC-Shad" members and not based on the species life history. As mentioned above, the Cape Fear was known to house the bulk of the American Shad fishery, but the American Shad CPP in this study had an overall downward trend, whereas from 2018-2020, a steady increase in Hickory Shad CPP was apparent (Table 3-5). This phenomenon may explain the New Hot Spot for Hickory Shad CPP in Figure 3-13 and the Sporadic Hot Spot for American Shad CPP in Figure 3-14, and it may suggest that Hickory Shad are outcompeting the species for spawning habitat in this river system over time. American Shad from the Cape Fear have shown to be the most semelparous stock in North Carolina (Fisk 2016), whereas Hickory Shad are believed to be iteroparous throughout their range (Chapter 2). Hickory Shad do exhibit natal homing with a degree of wandering (Smith 2018, Meyer 2019, Hill 2020, Rulifson et al. 2020), so these annual returns may explain the higher catch rates over time for Hickory Shad compared to American Shad. The Tar Heel BAA is also the only BAA where a statistically significant hot spot was recorded for both Hickory Shad and American Shad CPP, so scientific or recreational targeting of those species has a higher capture probability at that location compared to other fishing locations of the Cape Fear River in this study.

Although spatiotemporal trends for both species were not statistically significant, thus rejecting both hypotheses, an overall positive trend was indicated for Hickory Shad CPP and a negative trend was reported for American Shad CPP from 2013-2020. This may most likely due to the same few members posting in 2013 for the Pamlico and Cape Fear rivers, biasing the CPP for those years (Table 3-5).

Along with annual spawning ground electrofishing surveys, the NCDMF also utilizes recreational creel surveys to assess population trends over time. One issue with the creel surveys is that a majority of the anglers do not specify which shad they target, so results may be biased for trips where no catch occurs (Ricks and Rachels 2015). One measure taken to reduce bias is the non-uniform probability-based access point creel survey methodology done on boat anglers (ASMFC 2020, Pollock et al. 1994). One caveat with the current NCDMF creel survey methodology is the strict data collected centered around boat anglers. The methodology does not incorporate bank anglers due to budget restrictions and survey design constraints (ASMFC 2020), but a large proportion of recreational anglers do fish from banks. The Marine Recreational Information Program (MRIP) currently uses Access Point Angler Intercept Surveys (APAIS), which target anglers who fish at any publicly accessible fishing sites including banks and BAAs. The NCDMF creel clerks oversee these surveys in North Carolina, but they are only completed on the coastal region of the state (Hadley 2015). Sampling sites, dates, and times are selected based on expected fishing activity to ensure more active sites are sampled more often to increase efficiency (ACCSP 2018). If the APAISs were extended inland, Figure 3-12 displays locations that have higher fishing trip activity compared to neighboring locations, including BAAs within the hot spots, so this information could provide MRIP active public access locations to more efficiently complete their APAISs. Creel surveys also already face budget restrictions, so providing a smaller geographical range may help obtain information more efficiently. The current creel survey design can still be completed to a degree, but instead use the specific BAAs within the Sporadic Hot Spots in a non-uniform sampling strategy (Figure 3-12).

Creel Survey Comparison

Social, economic, and political factors are important alongside traditional biological practices, and recreational creel surveys are a way to gain greater amounts of information for management to exploit. The 2020 American Shad Stock Assessment indicated that a major weakness of the data is due to a lack of recreational fisheries catch, and although it is thought that the recreational fishery has declined in recent decades, the potential impact of this fishery is not well quantified besides the limited scope of the Roanoke River and CSMA creel surveys. A lack of data exists for the Roanoke River because the creel survey targets Striped Bass catch and effort, so one suggestion would be the completion comprehensive creel survey of the Roanoke River Management Area (RRMA) to identify and estimate Hickory and American shad, a similar objective initiated for the CSMA creel survey in 2012.

An awkward relationship exists between recreational anglers and fisheries managers. Some recreational anglers may be more inclined to fib about their catch to avoid getting in trouble or cause stricter management restrictions in the future. This study's method is a management-free way to obtain catch information on Hickory Shad and American Shad without the desire to misinform management. Because it is assumed that the posts from "NC-Shad" are targeting Hickory Shad and/or American Shad, this method of data collection cannot replace the random sampling method employed for the creel surveys, but because of the clear information deficit for this species, obtaining information in more cost-effective avenues is needed.

Social media could provide a large amount of supplemental information on specific species, with this study only being one example. Although over 25,000 recreational angler interviews were completed from 2012-2019, only a fraction were compared with the posts from “NC-Shad” for the sake of consistent methodology. Overall, a clear disparity existed based on the number of posts provided from each river. The creel survey had fairly consistent interviews between the three rivers sampled, but the Tar and Neuse rivers provided 95% of the posts from social media. This is most likely due to “NC-Shad” members’ lack of effort in the Cape Fear, for any number of reasons listed in previous sections (LEK, geographical location, lower fishing pressure, etc). Either method did not always have an abundance of data, for example with American Shad and the Cape Fear River in 2013 and 2014, but both sources could collectively provide substantial information on both species. Based on the CSMA anadromous creel survey, the Neuse River contributed the bulk of the Hickory Shad catch, consistent with the findings from this study (Table 3-8). Pate (1972) found that over 11,000 Hickory Shad were caught in the Neuse River from April 1967 to March 1968, suggesting that this river historically held a large population that seems to persist today based on this study. Marshall (1977) also noted that the Neuse and Tar/Pamlico rivers produce the highest landings of Hickory Shad in North Carolina, consistent with the creel survey and “NC-Shad” reports. Additionally, the Cape Fear River provided only 1% of the total Hickory Shad catch for both data sources (Table 3-8).

Contrastingly, the creel survey indicated that American Shad were caught more often in the Cape Fear River, but “NC-Shad” found that the Tar River provided the bulk of the catch. The 2015 creel survey results of the Tar River reported that bank anglers accounted for 85% of the effort at the Battle Park BAA alone, but bank anglers are not taken into consideration for the creel survey because of budgetary restrictions (Rundle 2016). It is possible that the creel survey is misrepresenting catch for rivers with popular bank fishing locations, such as the Tar River, and the information from "NC-Shad" is enhancing information collected by the state agencies. Another hypothesis could be that, because the Cape Fear River holds the most semelparous American Shad stock of North Carolina (Fisk 2016), individuals may linger longer in this river compared to others of the state because of low energy levels, making them an easier target for anglers.

The last objective of this chapter determined that differences exists between the CSMA anadromous creel survey and "NC-Shad" Hickory Shad and American Shad CPPs for multiple years and rivers, thus rejecting both hypotheses. These significant differences for Hickory Shad CPP were for the Neuse (years 2014-2016) and Tar (2016 and 2018) rivers, with the social media CPP median higher in every instance (Table 3-8, Figure 3-16). American Shad CPP was statistically different for the Tar (2016 and 2018) and Cape Fear (2018) rivers, with the creel survey CPP median higher in every instance (Table 3-9, Figure 3-17). The higher median Hickory Shad CPP and lower median American Shad CPP could be because any social media entry with unspecified species catch and a lack of photo evidence was considered Hickory Shad catch. This assumption may have overestimated Hickory Shad catch and underestimated American Shad catch, explaining these trends. On the other hand, the NCDMF creel survey data does not include all interviews when Hickory and/or American shad were caught, only interviews where they were being targeted by an angler. Future studies may consider comparing creel survey data against social media data without that assumption in mind. Management may also consider contacting the author of the social media post when an unspecified species arises, although recall bias should be considered. It is important to note that many of the years are also not statistically significantly different between the two data sources, demonstrating that similar inferences could be made from either of the two methods.

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Tables and Figures

Table 3-1. Hickory Shad Catch Per Post (CPP) per year with all rivers combined (n=1786 posts). CPP: one post = one unit of effort.

Year	# of posts	# of members posting	Sum of Hickory Shad	Hickory Shad Average CPP	Sum of American Shad	American Shad Average CPP
2013	66	21	406	6.2	156	2.4
2014	105	36	1408	13.4	46	0.4
2015	102	34	1055	10.3	66	0.6
2016	171	71	1475	8.6	189	1.1
2017	221	104	1764	8.0	86	0.4
2018	342	160	5165	15.1	77	0.2
2019	199	95	2067	10.4	56	0.3
2020	580	285	7095	12.2	233	0.4

Table 3-2. Number of members who provided the percentage of total posts per year. n= total number of members who provided a post for that year. Posts included may or may not have caught a fish.

	Percentage of Total Posts						
Year	<1%	1-5%	6-10%	11-15%	16-20%	>20%	n
2013	0	16	2	1	1	1	21
2014	0	31	4	0	1	0	36
2015	0	29	2	2	1	0	34
2016	0	68	3	0	0	0	71
2017	0	102	2	0	0	0	104
2018	89	71	0	0	0	0	160
2019	0	94	1	0	0	0	95
2020	227	58	0	0	0	0	285

Table 3-3. Hickory Shad Catch Per Post (CPP) per river with all years combined. Only included posts where river was indicated (n=1550 posts). CPP: one post = one unit of effort.

River	# of posts	# of members	Sum of Hickory Shad	Hickory Shad Average CPP	Sum of American Shad	American Shad Average CPP
Meherrin	7	5	230	32.9	0	0.0
Cashie	40	15	179	4.5	0	0.0
Roanoke	378	151	10158	26.9	54	0.1
Tar	587	215	3699	6.3	507	0.9
Pamlico	8	6	32	4.0	17	2.1
Bay	3	3	3	1.0	0	0.0
Neuse	455	170	4337	9.5	165	0.4
Cape Fear	61	39	408	6.7	71	1.2
Lumber	1	1	1	1.0	0	0.0
Pee Dee	3	3	1	0.3	1	0.3
Catawba	1	1	0	0.0	0	0.0
Ocean	6	4	36	6.0	0	0.0

Table 3-4. Number of members who provided the percentage of total posts per year. n= total number of members who provided a post for that year. Posts included may or may not have caught a fish.

	Percentage of Total Posts						
River	<1%	1-20%	21-40%	41-60%	61-80%	81-100%	n
Meherrin	0	4	0	1	0	0	5
Cashie	0	14	1	0	0	0	15
Roanoke	82	69	0	0	0	0	151
Tar	154	61	0	0	0	0	215
Pamlico	0	5	1	0	0	0	6
Bay	0	0	3	0	0	0	3
Neuse	131	39	0	0	0	0	170
Cape Fear	0	39	0	0	0	0	39
Lumber	0	0	0	0	0	1	1
Pee Dee	0	0	3	0	0	0	3
Catawba	0	0	0	0	0	1	1
Ocean	0	2	2	0	0	0	4

Table 3-5. Hickory Shad and American Shad Catch Per Post (CPP) per parent river per year. Only posts with a specified parent river were included (n=1550 posts). Rivers ordered from north to south. CPP: one post = one unit of effort.

River	Year	# of posts	# of members	Sum of Hickory Shad	Hickory Shad Average CPP	Sum of American Shad	American Shad Average CPP
Meherrin	2017	1	1	10	10	0	0
	2018	1	1	1	1	0	0
	2019	1	1	1	1	0	0
	2020	4	2	218	54.5	0	0
Cashie	2013	1	1	0	0	0	0
	2014	2	1	30	15	0	0
	2015	2	1	2	1	0	0
	2016	1	1	10	10	0	0
	2017	5	4	7	1.4	0	0
	2018	7	5	59	8.4	0	0
	2019	15	7	67	4.5	0	0
	2020	7	4	4	0.6	0	0
Roanoke	2013	10	4	222	22.2	0	0
	2014	27	14	906	33.6	1	0.04
	2015	28	12	397	14.2	11	0.4
	2016	32	18	390	12.2	3	0.1
	2017	39	20	847	21.7	5	0.1
	2018	98	56	3366	34.3	7	0.1
	2019	20	15	799	39.9	10	0.5
	2020	124	74	3231	26.1	17	0.1
Tar	2013	33	11	118	3.6	91	2.8
	2014	41	15	212	5.2	26	0.6
	2015	39	16	440	11.3	33	0.8
	2016	67	36	546	8.1	160	2.4
	2017	64	42	218	3.4	18	0.3
	2018	95	49	266	2.8	45	0.5
	2019	44	31	301	6.8	8	0.2
	2020	204	111	1598	7.8	126	0.6
Pamlico	2013	3	2	21	7	17	5.7
	2016	1	1	0	0	0	0
	2017	1	1	2	2	0	0
	2018	1	1	0	0	0	0
	2020	2	2	9	4.5	0	0
Bay	2019	1	1	1	1	0	0

	2020	2	2	2	1	0	0
Neuse	2013	8	7	31	3.9	3	0.4
	2014	21	10	118	5.6	16	0.8
	2015	12	6	115	9.6	2	0.2
	2016	25	13	454	18.2	15	0.6
	2017	74	33	623	8.4	46	0.6
	2018	84	46	1007	12	6	0.1
	2019	87	37	585	6.7	26	0.3
	2020	144	81	1404	9.8	51	0.4
Cape Fear	2013	5	2	10	2	38	7.6
	2016	5	4	10	2	1	0.2
	2017	7	6	7	1	5	0.8
	2018	12	8	7	0.6	10	0.8
	2019	5	5	31	6.2	1	0.8
	2020	27	18	343	12.7	15	0.6
Lumber	2013	1	1	1	1	0	0
Pee Dee	2016	1	1	0	0	1	1
	2019	2	2	1	0.5	0	0
Catawba	2016	1	1	0	0	0	0
Ocean	2016	1	1	1	1	0	0
	2017	2	1	3	1.5	0	0
	2018	1	1	1	1	0	0
	2019	2	1	31	15.5	0	0

Table 3-6. Tukey HSD Post Hoc results based on Hickory Shad CPP per year for the Cape Fear River (n=61). Asterisk (*) indicates significant difference at P < 0.05.

Year	2013	2016	2017	2018	2019
2016	0.999				
2017	0.997	0.998			
2018	0.988	0.986	0.999		
2019	0.931	0.806	0.535	0.436	
2020	0.028*	0.009*	0.003*	0.003*	0.034*

Table 3-7. Captured Hickory Shad and American Shad by year at locations above removed dams. It is important to note that the Milburnie Dam was removed during the study period (2017). Dam locations ordered from north to south. Some locations have repeated data because locks and dams are located below one another (i.e. locks on the Cape Fear). * indicates a removed dam.

Dam	Year	Location	# of Hickory Shad	# of American Shad
Gaston	-	-	-	-
Roanoke Rapids	-	-	-	-
Falls Lake	-	-	-	-
Rocky Mount Reservoir	2017	Nashville	24	1
Milburnie*	2013	Falls Lake Spillway	1	0
	2018	Falls Lake Spillway	7	0
	2020	Falls Lake Spillway	2	0
Atkinson Mill Pond	-	-	-	-
Lowell Mill*	-	-	-	-
Buckhorn*	-	-	-	-
Crantock Mill *	-	-	-	-
Rains Mill*	-	-	-	-
Cherry Hospital *	2016	Little River Bridge	6	1
	2017	Little River Bridge	6	0
	2017	Cherry Hospital	2	1
	2018	Cherry Hospital	45	0
	2019	Cherry Hospital	1	0
	2020	Little River Bridge	8	0
	2020	Cherry Hospital	16	6
Quaker Neck *	2016	Bentonville	1	1
	2016	Smithfield	0	1
	2017	Cox Ferry	1	1
	2020	Cox Ferry	0	1
Blewett Falls Lake	-	-	-	-
William O'Husk	2018	Fayetteville Boat Ramp	0	1
Lock and Dam #2	2013	William O'Husk Dam	0	1
	2016	William O'Husk Dam	4	0
	2017	William O'Husk Dam	0	1
	2017	Tory Hole (Elizabethtown)	2	2
	2018	Fayetteville Boat Ramp	0	1
	2018	Tar Heel	4	0

	2020	William O'Husk Dam	55	10
	2020	Tory Hole (Elizabethtown)	8	0
Lock and Dam #1	2013	William O'Husk Dam	0	1
	2013	Lock and Dam #2	10	37
	2016	William O'Husk Dam	4	0
	2016	Lock and Dam #2	0	1
	2017	William O'Husk Dam	0	1
	2017	Tory Hole (Elizabethtown)	2	2
	2018	Fayetteville Boat Ramp	0	1
	2018	Tar Heel	4	0
	2020	William O'Husk Dam	55	10
	2020	Lock and Dam #2	19	5

Table 3-8. CSMA creel survey and “NC-Shad” Hickory Shad data comparison. Data was absent for the years 2013 and 2015 for “NC-Shad’, and 2014 and 2015 for the creel survey for the Cape Fear River. CPP/CPI: one post (or interview for the creel survey) = one unit of effort. Rivers are ordered from north to south.

		Creel Survey						Social Media					
River	Year	# of interviews	Sum of Catch	Average CPI	SD	Min # Caught	Max # Caught	# of posts	Sum of Catch	Average CPP	SD	Min # Caught	Max # Caught
Tar	2013	4	0	0	0	0	0	33	118	3.6	9.7	0	52
	2014	4	0	0	0	0	0	41	212	5.2	17.5	0	100
	2015	4	7	1.8	3.5	0	7	39	440	11.3	19.5	0	70
	2016	35	7	0.2	1.0	0	6	67	546	8.1	15.0	0	83
	2017	8	1	0.1	0.4	0	1	64	218	3.4	8.8	0	55
	2018	106	227	2.1	5.7	0	40	95	266	2.8	5.6	0	30
	2019	4	47	11.8	22.2	0	45	44	301	6.8	11.3	0	50
Neuse	2013	15	71	4.7	9.8	0	29	8	31	3.9	6.7	0	20
	2014	12	9	0.8	2.0	0	7	21	118	5.6	15.1	0	70
	2015	10	23	2.3	6.9	0	22	12	115	9.6	17.3	0	60
	2016	18	165	9.2	28.4	0	120	25	454	18.2	50.9	0	250
	2017	32	360	11.3	21.1	0	86	74	623	8.4	16.8	0	100
	2018	9	32	3.6	8.5	0	26	84	1007	12.0	32.6	0	200
	2019	4	29	7.3	7.4	0	15	87	585	6.7	13.6	0	80
Cape Fear	2013	-	-	-	-	-	-	5	10	2.0	4.5	0	10
	2014	6	0	0	0	0	0	-	-	-	-	-	-
	2015	-	-	-	-	-	-	-	-	-	-	-	-
	2016	103	1	0.0	0.1	0	1	5	10	2.0	2.0	0	5
	2017	44	1	0.0	0.2	0	1	7	7	1.0	1.9	0	5
	2018	16	0	0	0	0	0	12	7	0.6	1.2	0	4
	2019	3	0	0	0	0	0	5	31	6.2	13.3	0	30

Table 3-9. CSMA creel survey and “NC-Shad” American Shad data comparison. Data was absent for the years 2013 and 2015 for “NC-Shad’, and 2014 and 2015 for the creel survey for the Cape Fear River. CPP/CPI: one post (or interview for the creel survey) = one unit of effort. Rivers are ordered from north to south.

		Creel Survey						Social Media					
River	Year	# of interviews	Sum of Catch	Average CPI	SD	Min # Caught	Max # Caught	# of posts	Sum of Catch	Average CPP	SD	Min # Caught	Max # Caught
Tar	2013	4	0	0	0	0	0	33	91	2.8	8.9	0	50
	2014	4	0	0	0	0	0	41	26	0.6	1.4	0	6
	2015	4	0	0	0	0	0	39	33	0.8	3.4	0	21
	2016	35	81	2.3	3.6	0	13	67	160	2.4	8.4	0	48
	2017	8	0	0	0	0	0	64	18	0.3	0.6	0	3
	2018	106	224	2.1	6.1	0	40	95	45	0.5	1.9	0	15
	2019	4	7	1.8	3.5	0	7	44	8	0.2	0.5	0	2
Neuse	2013	15	2	0.1	0.5	0	2	8	3	0.4	0.5	0	1
	2014	12	2	0.2	0.4	0	1	21	16	0.8	2.1	0	8
	2015	10	4	0.4	0.7	0	2	12	2	0.2	0.4	0	1
	2016	18	24	1.3	4.5	0	19	25	15	0.6	1.0	0	4
	2017	32	18	0.6	1.4	0	6	74	46	0.6	2.0	0	16
	2018	9	2	0.2	0.7	0	2	84	6	0.1	0.3	0	2
	2019	4	0	0	0	0	0	87	26	0.3	0.9	0	7
Cape Fear	2013	-	-	-	-	-	-	5	38	7.6	7.4	0	18
	2014	6	21	3.5	4.3	0	10	-	-	-	-	-	-
	2015	-	-	-	-	-	-	-	-	-	-	-	-
	2016	103	912	8.9	16.2	0	104	5	1	0.2	0.4	0	1
	2017	44	335	7.6	17.7	0	109	7	6	0.9	1.1	0	3
	2018	16	142	8.9	9.1	0	36	12	10	0.8	1.4	0	4
	2019	3	21	7.0	8.2	0	16	5	1	0.2	0.4	0	1

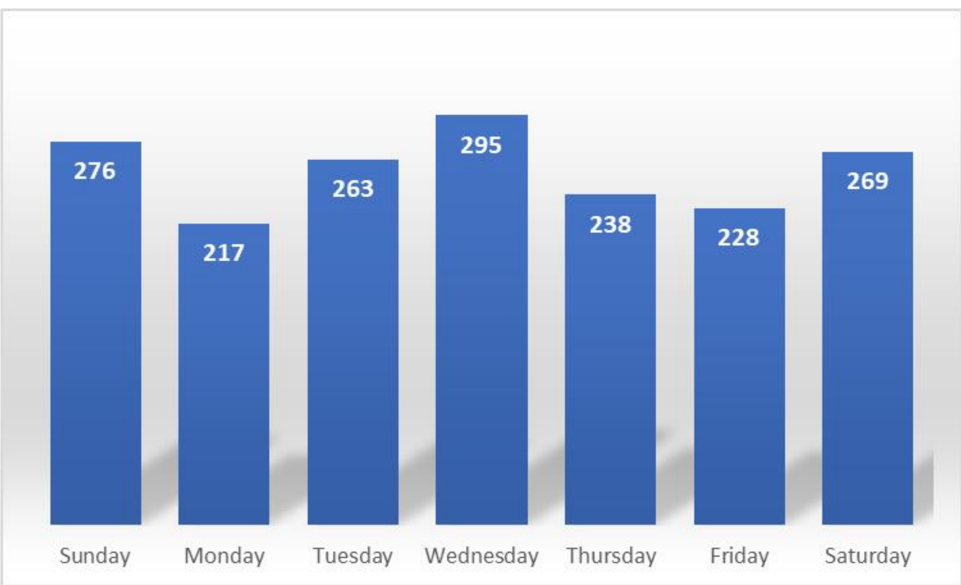

Figure 3-1. Total number of posts versus day of the week for all rivers and all years combined (n=1786).

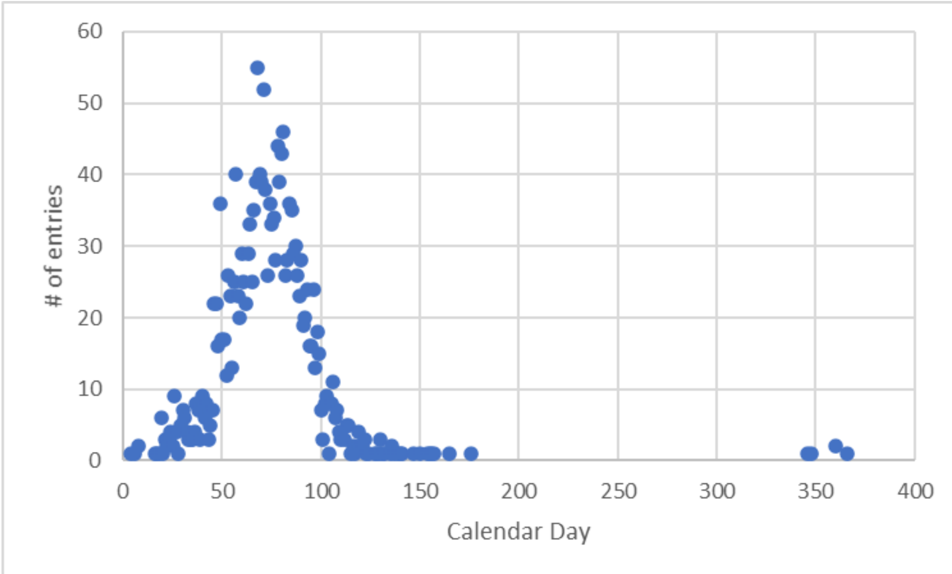

Figure 3-2. Number of posts made based on calendar day for all years and rivers combined (n=1786). Posts from each year were transformed to mirror the 2020 calendar day for analyses.

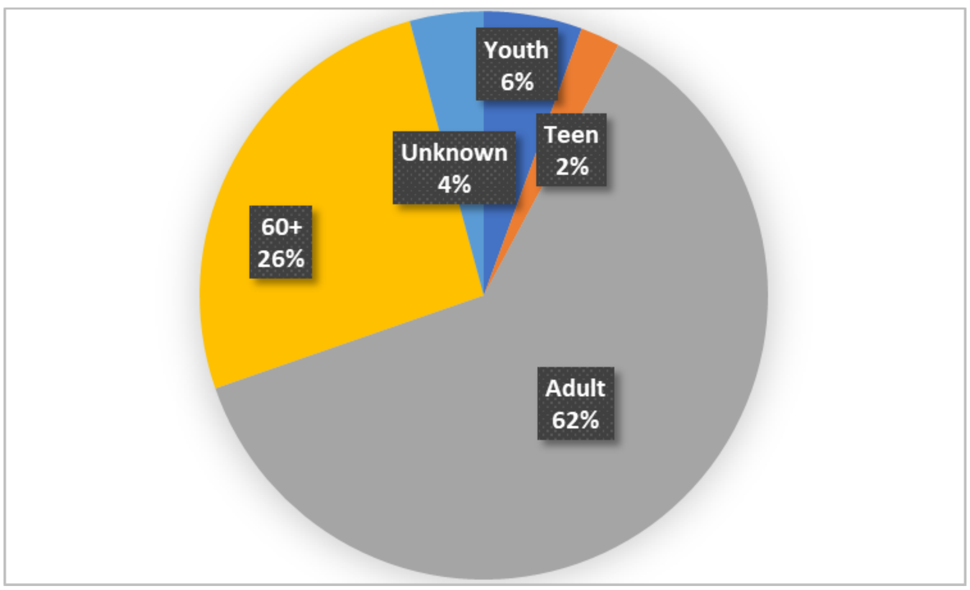

Figure 3-3. Angler age class distribution that were reported to catch one or more Hickory Shad and/or American Shad (n=1837). Unknown angler age resulted from either ambiguous wording or failure to report specifics in the posts and comments.

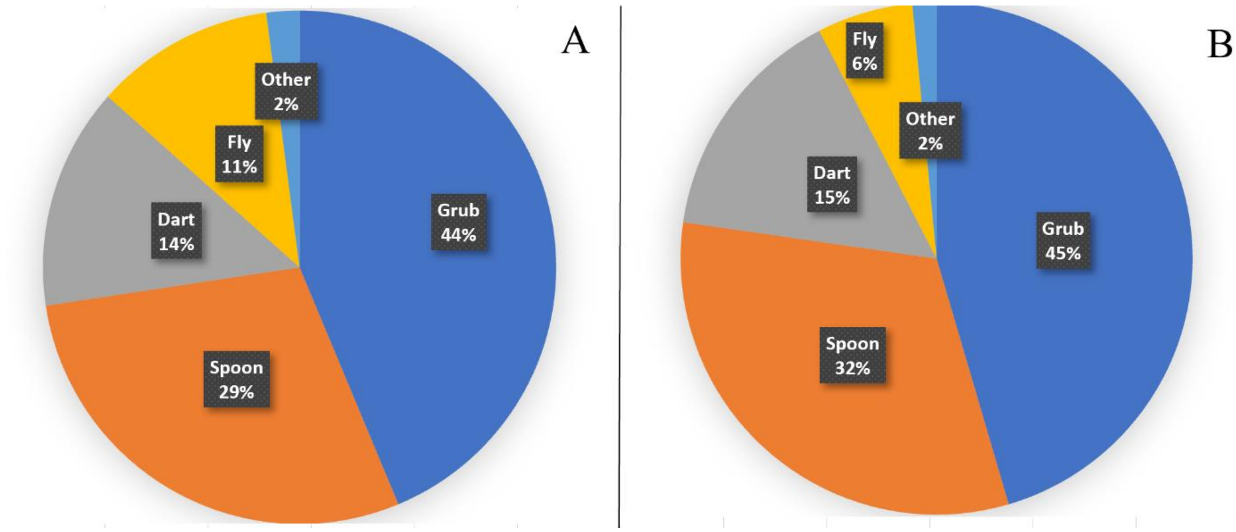

Figure 3-4. Lure types that reported to catch one or more A. Hickory Shad (n= number of posts containing lure type, n=426) and B. American Shad (n=49). The “other” category included lure types such as rattle traps and swim bait lures which are not traditionally used to fish for Hickory Shad or American Shad.

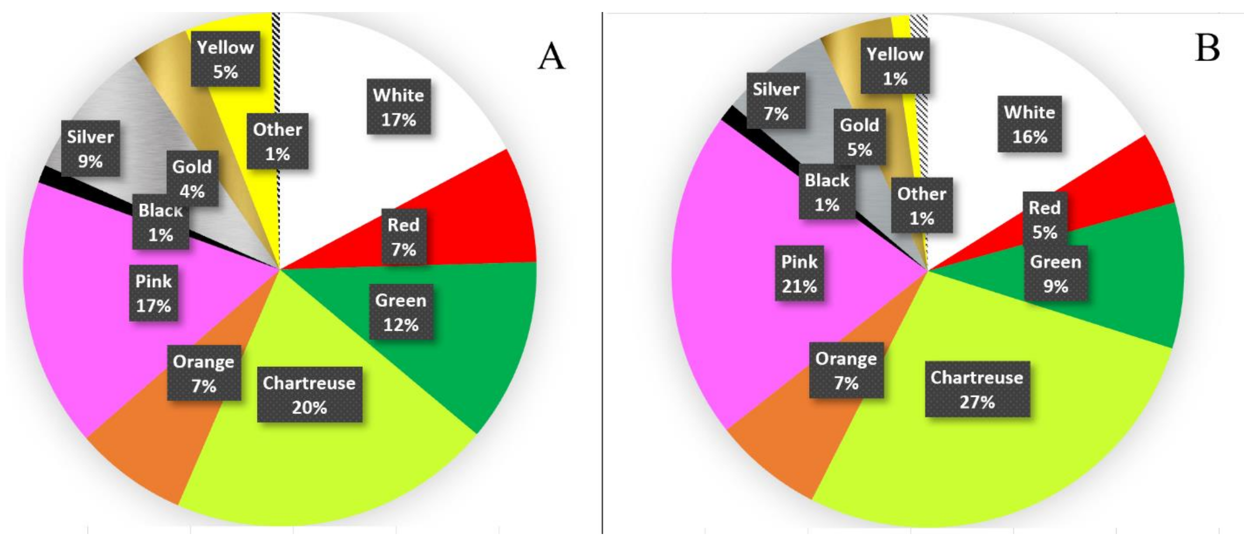

Figure 3-5. Lure colors that reported to catch one or more A. Hickory Shad (n= number of posts containing lure color, n=401) and B. American Shad (n=47). The colors of lures in the “other” category, such as clear, sparkled, etc., were not often mentioned.

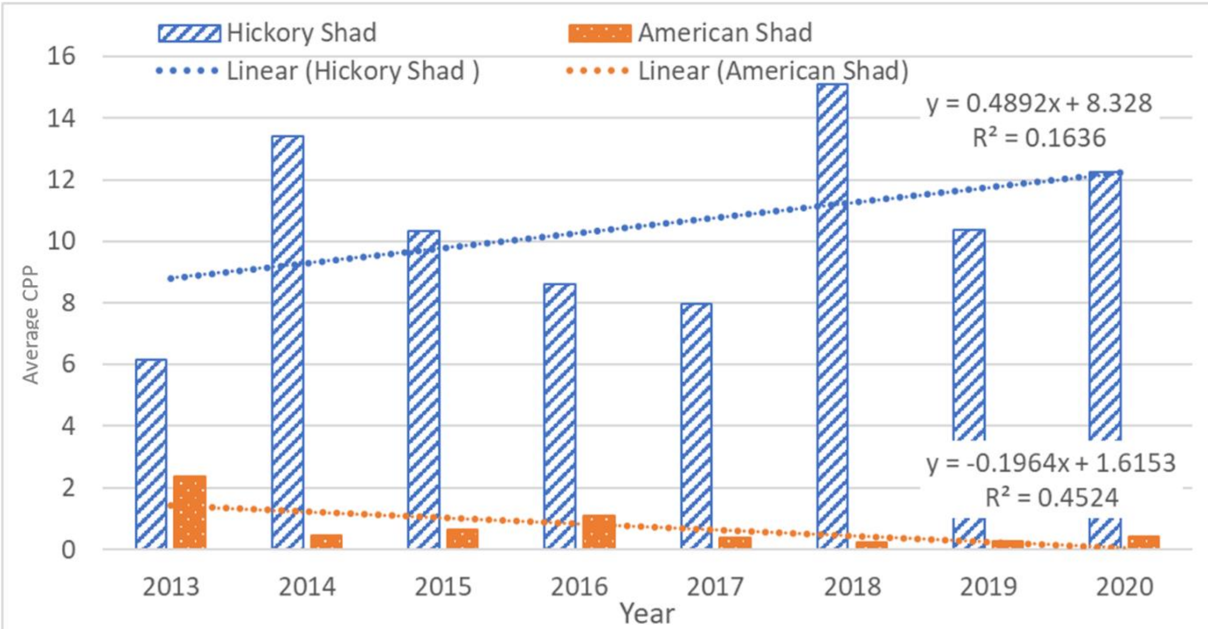

Figure 3-6. Average Hickory Shad and American Shad CPP obtained from "NC-Shad" per year with all rivers combined (n=1786 posts). Linear regressions were also included to display overall trend throughout the eight-year study period.

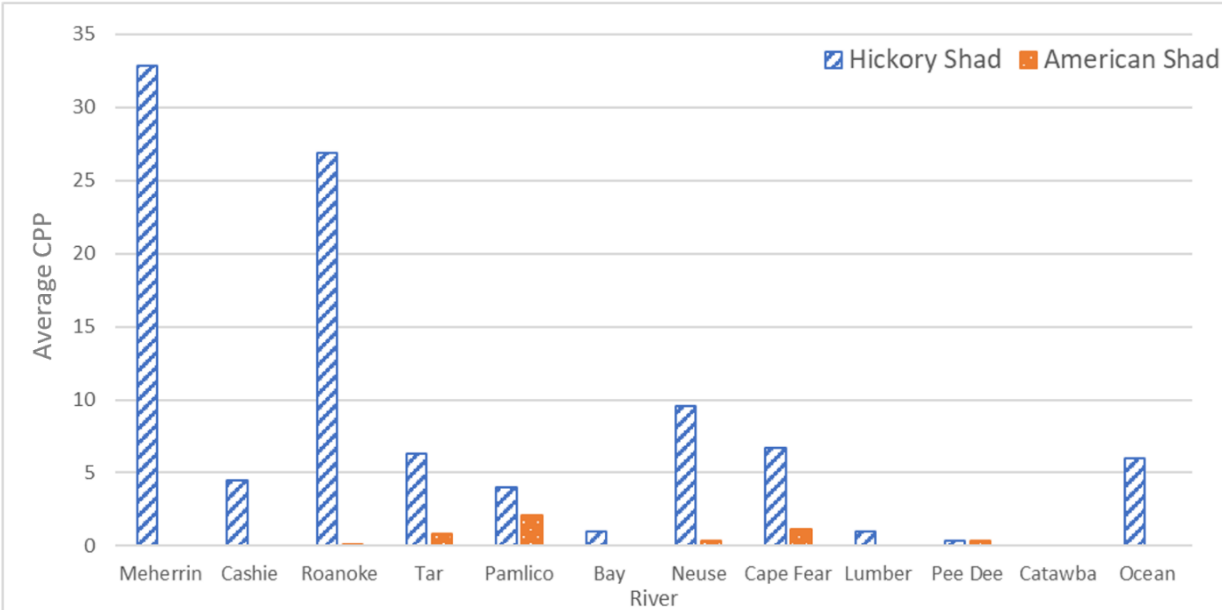

Figure 3-7. Average Hickory Shad and American Shad CPP obtained from “NC-Shad” per river with all years combined (n=1550 posts). The Catawba River is blank because neither species were caught from the one post attempted.

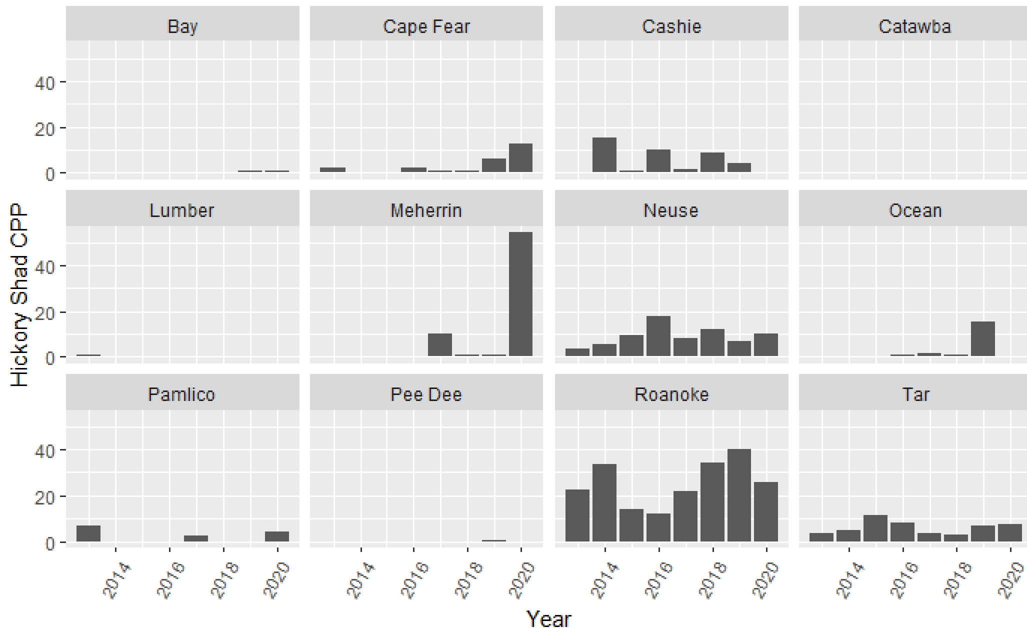

Figure 3-8. Average Hickory Shad CPP per year per river (n=1786 posts). The Catawba River is blank because no Hickory Shad were caught from the one post attempted.

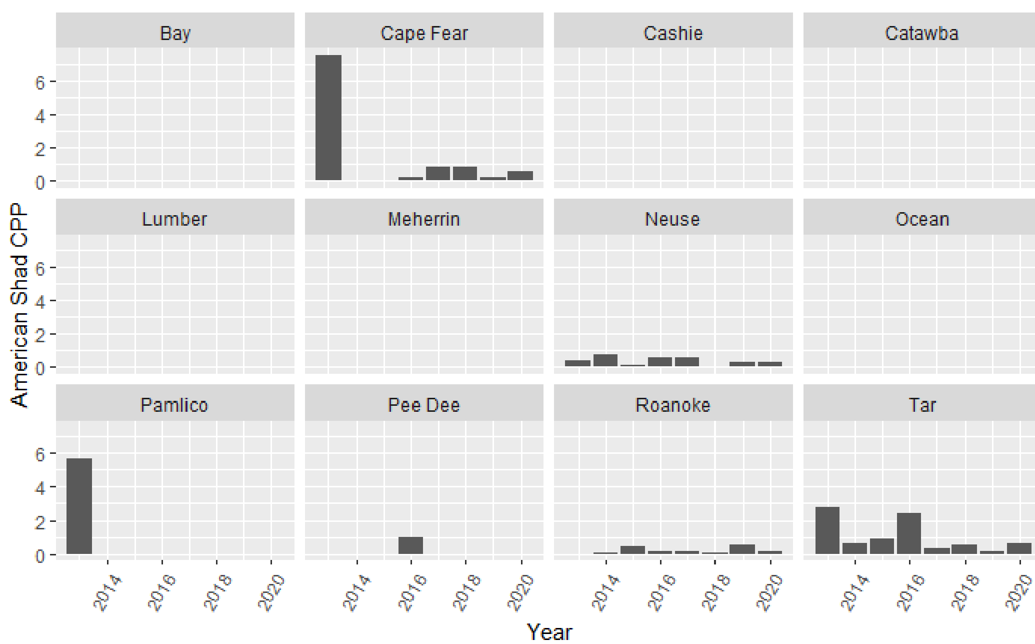

Figure 3-9. Average American Shad CPP per year per river (n=1786 posts). The Bay, Cashie, Catawba, Lumber, and Meherrin rivers and Ocean are blank because no American Shad were caught from the posts attempted.

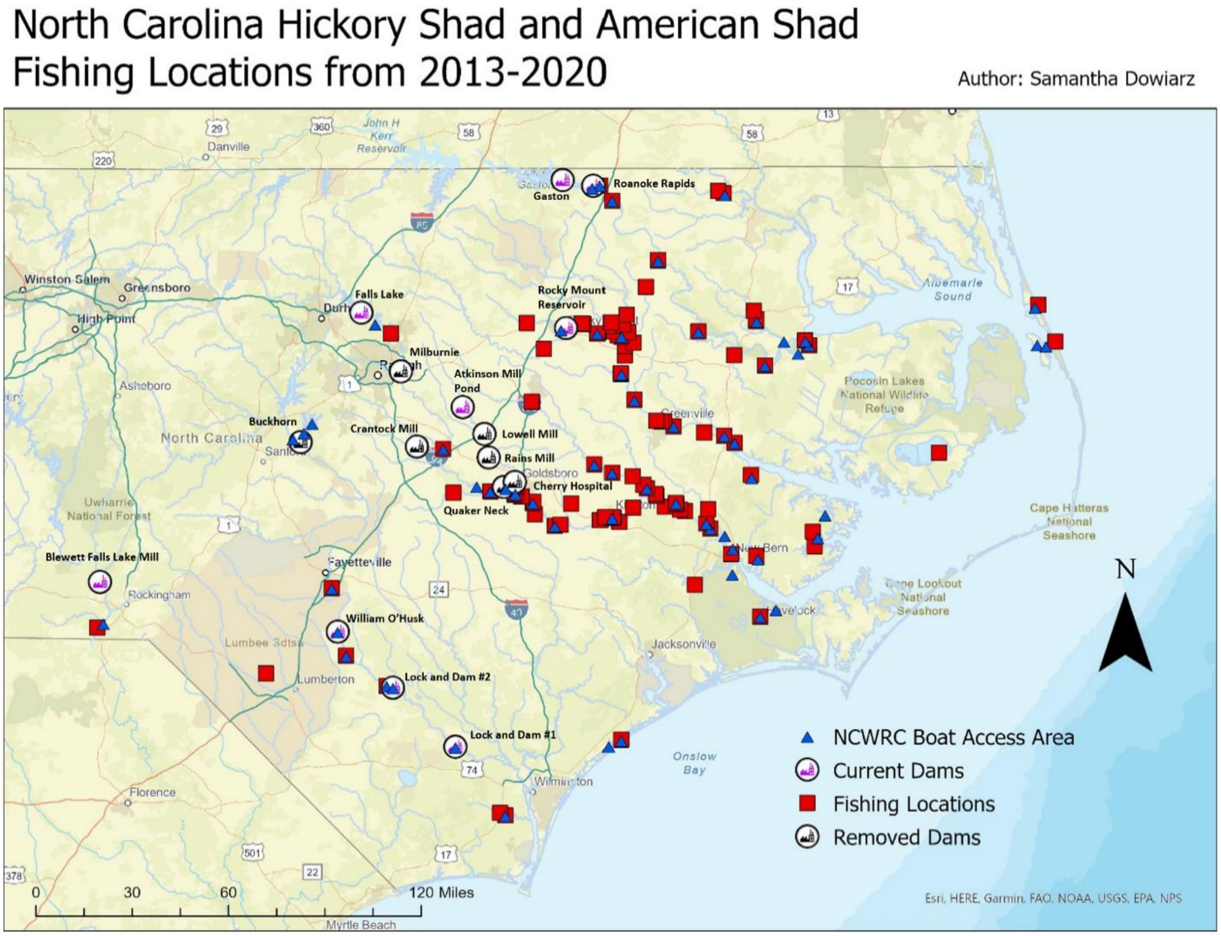

Figure 3-10. North Carolina fishing locations (n=83) reported from "NC-Shad" posts(n=1398). It is assumed that all fishing locations were an attempt to catch Hickory Shad and/or American Shad. This map does not show which locations successfully capture either or both species.

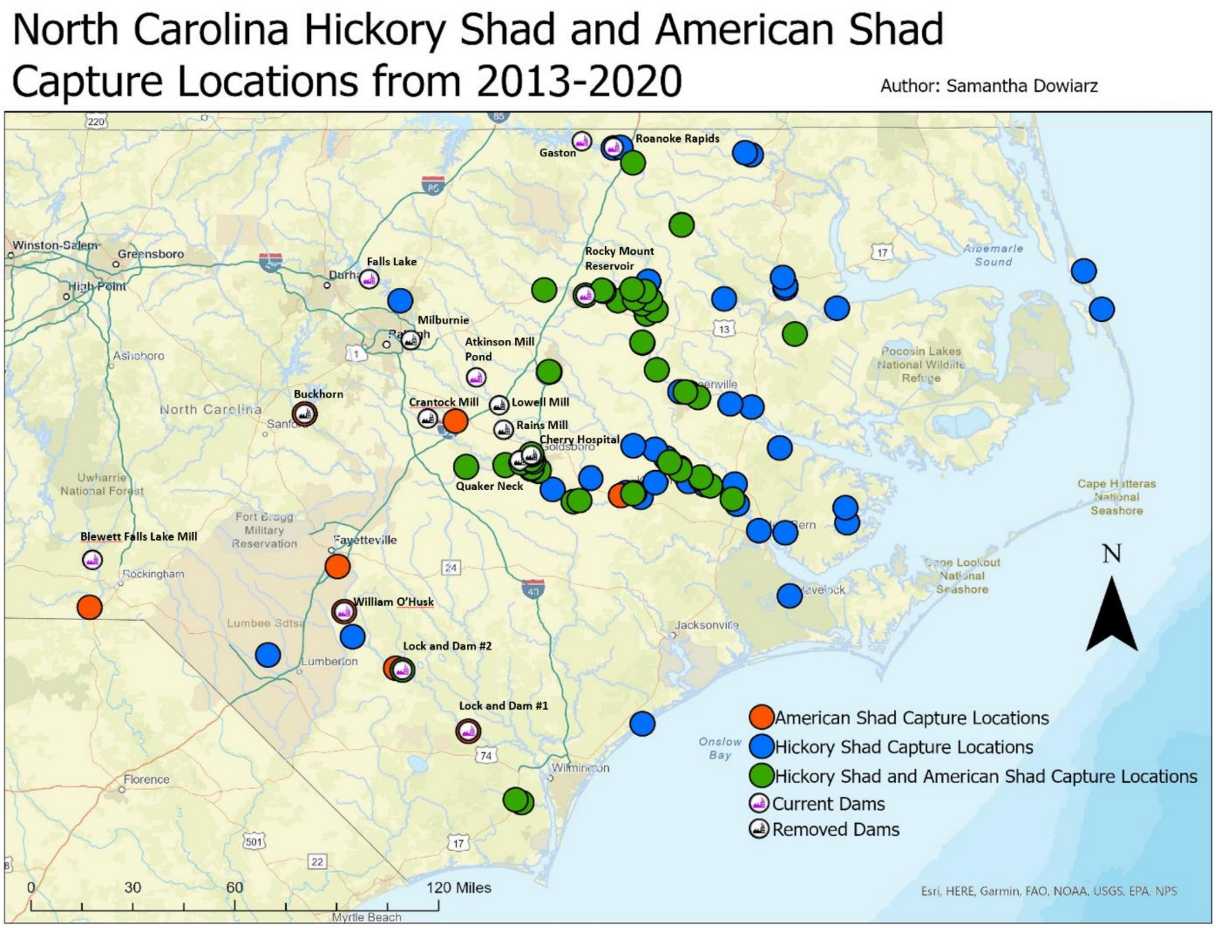

Figure 3-11. Locations where at least one Hickory Shad and/or American Shad were captured and reported from "NC-Shad" posts (n=1398) along with current and removed locks and dams. Orange circles are locations where only American Shad were captured, blue circles are where only Hickory Shad were captured, and green circles indicated locations were both Hickory Shad and American Shad were caught from 2013-2020. Currently constructed and active locks and dams are marked in fuchsia, and locks and dams that have been removed are in black.

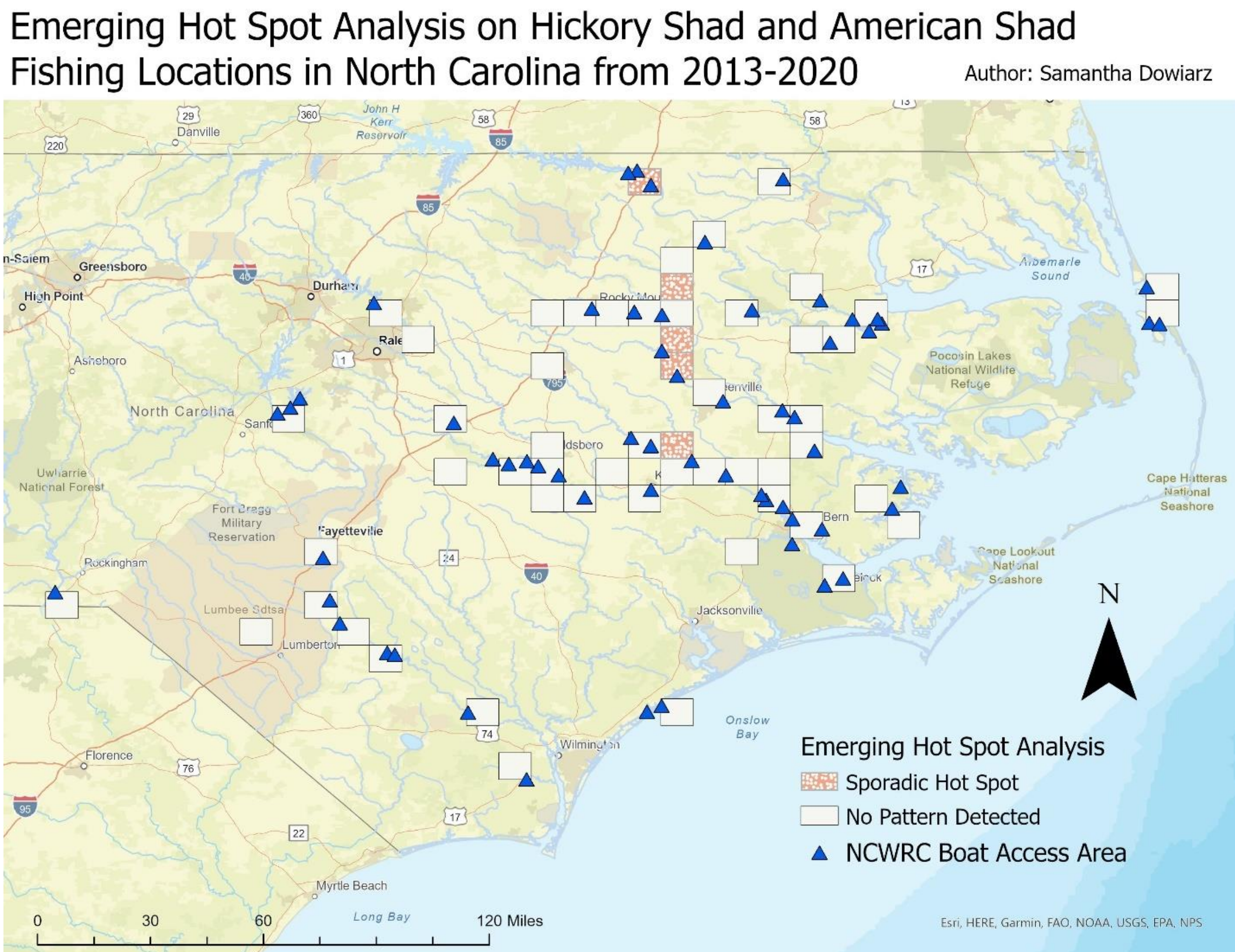

Figure 3-12. Emerging Hot Spot Analysis indicating significant hot spot trends based on fishing location from 2013-2020. Significant hot spot trends were based on the number of times a fishing location was mentioned from the "NC-Shad" Facebook posts (n=1398).

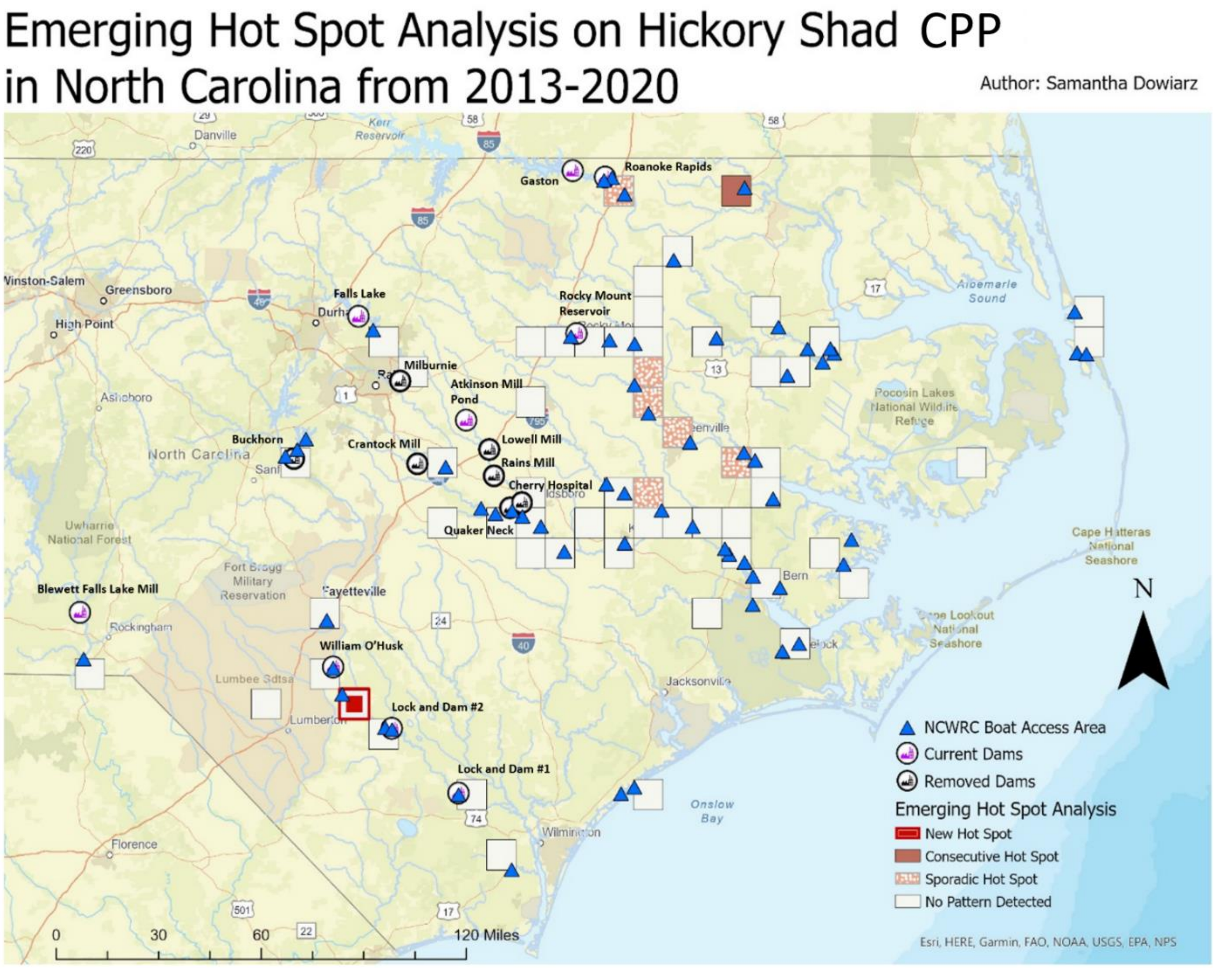

Figure 3-13. Emerging Hot Spot Analysis indicating significant hot spot trends based on Hickory Shad CPP from 2013-2020. Significant hot spot trends were based on the average Hickory Shad CPP for each date at each location mentioned from the "NC-Shad" Facebook posts (n=1088).

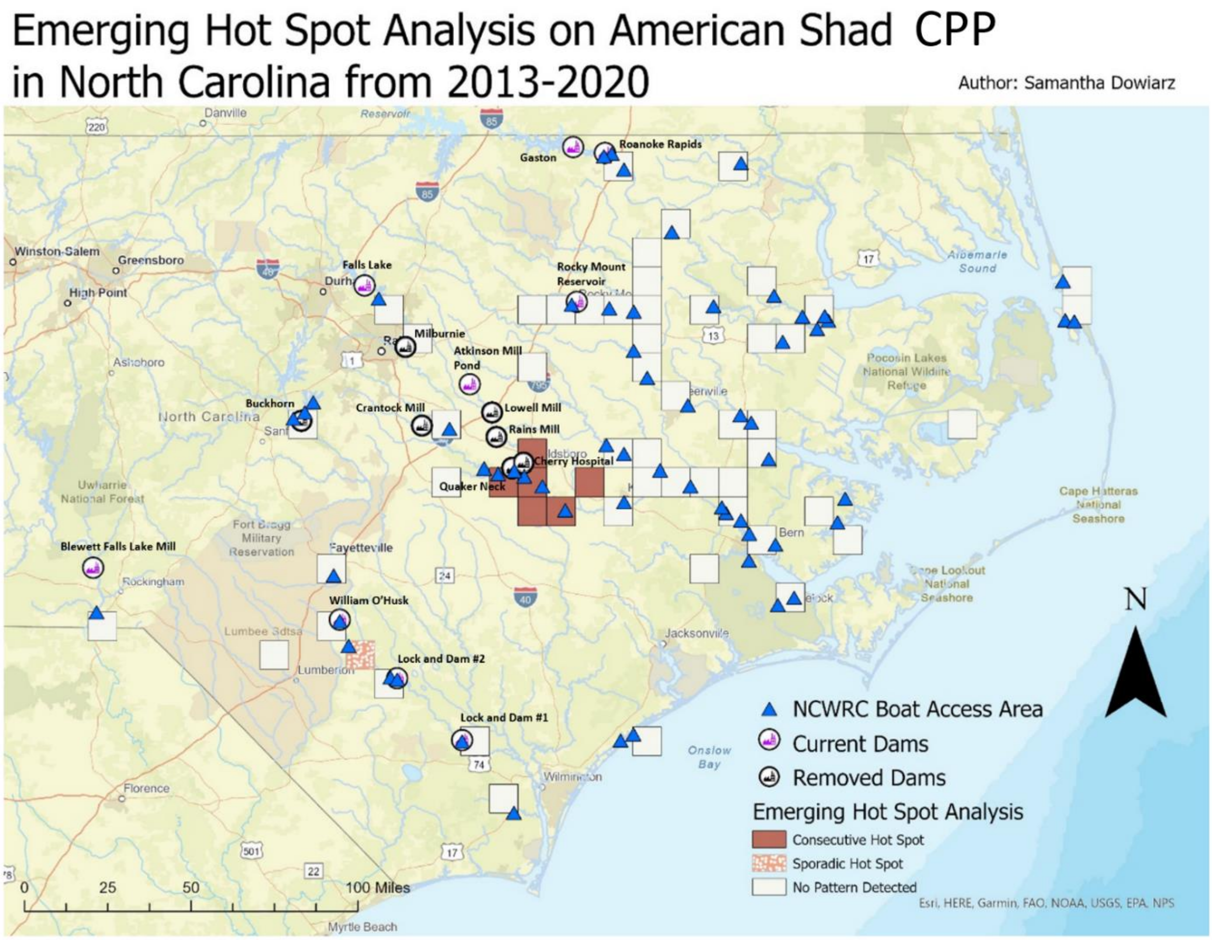

Figure 3-14. Emerging Hot Spot Analysis indicating significant hot spot trends based on American Shad CPP from 2013-2020. Significant hot spot trends were based on the average American Shad CPP for each date at each location mentioned from the "NC-Shad" Facebook posts (n=1088).

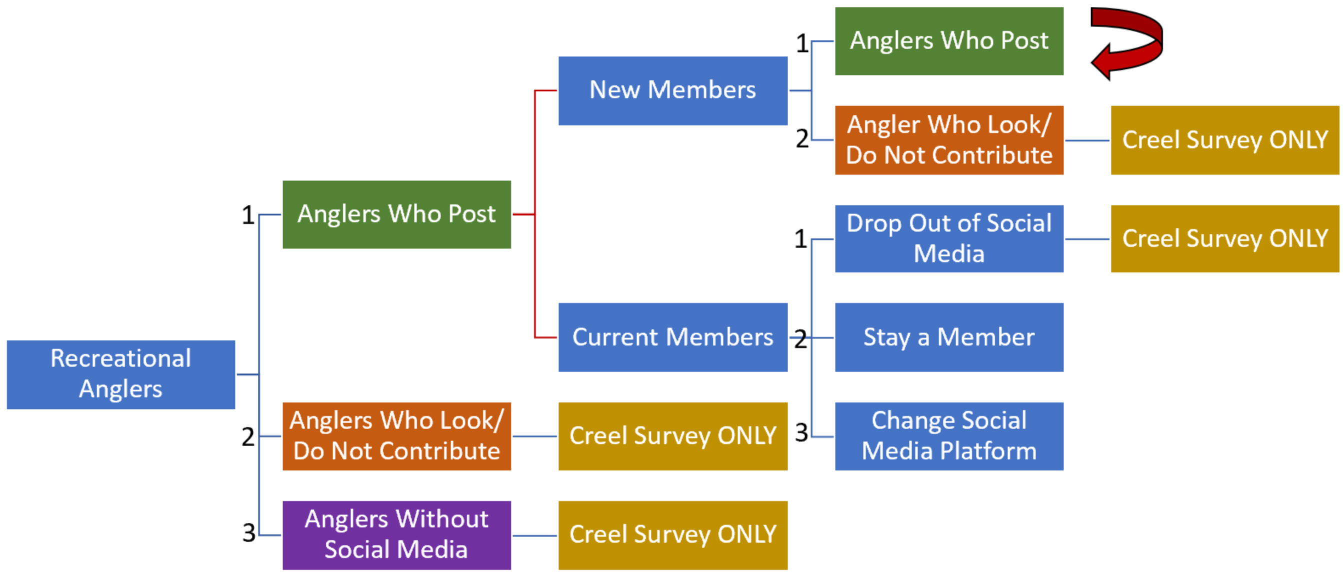

Figure 3-15. Flow chart grouping recreational anglers based on participation within the "NC-Shad" Facebook group. Anglers could either 1) post and comment within the social media platform, 2) look at the posts, but not contribute to the social media platform, or 3) not be on social media whatsoever. The route the angler takes depends on whether they could be assessed by data mining social media.

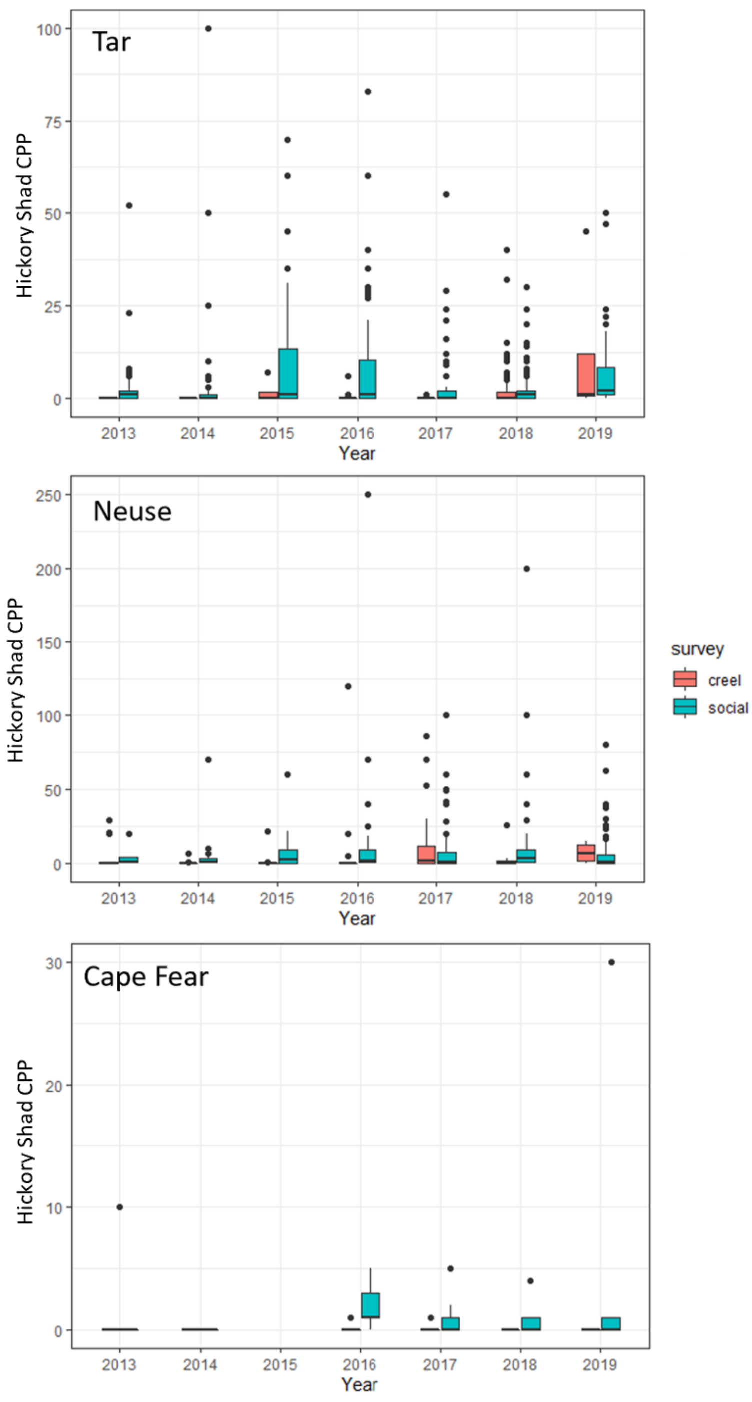

Figure 3-16. Boxplot of Hickory Shad CPP calculated from the CSMA creel survey (n=437) and the "NC-Shad" Facebook group (n=728) per year per river. The black bar within each box plot indicates the median. No outliers were removed. Note the difference in the y-axis for each river.

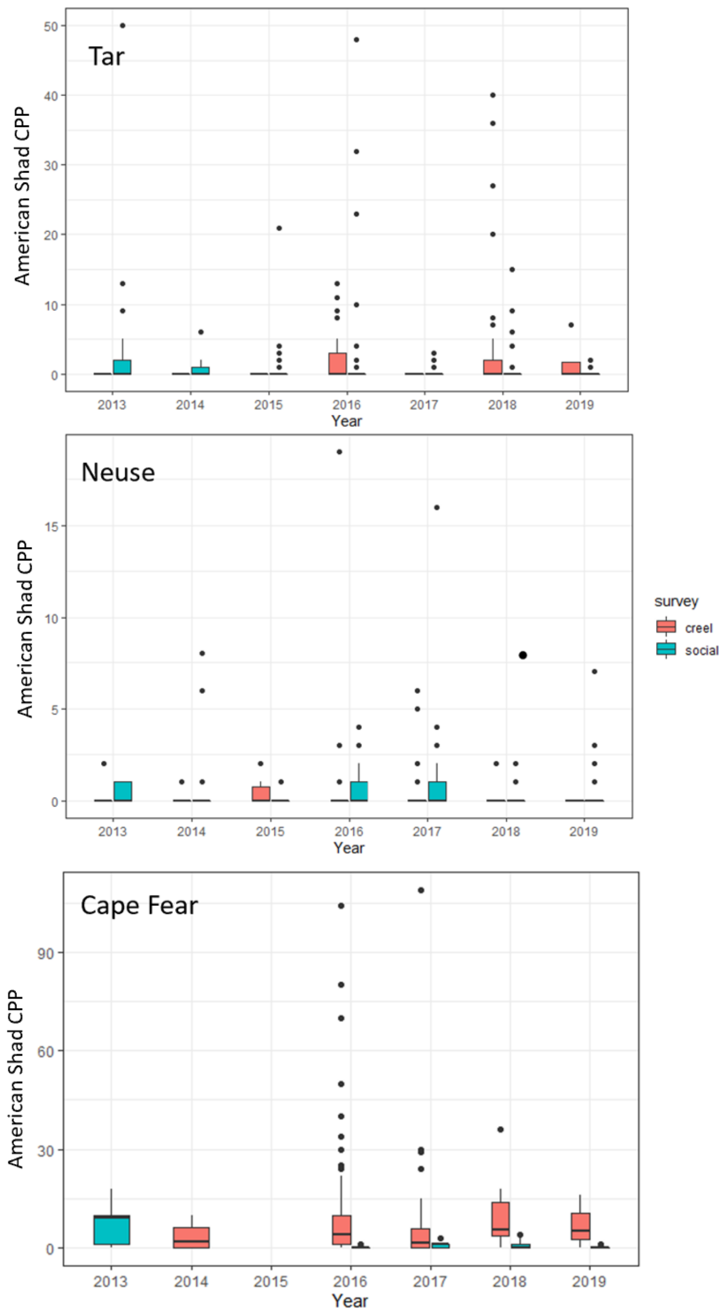

Figure 3-17. Boxplot of American Shad CPP calculated from the CSMA creel survey (n=437) and the "NC-Shad" Facebook group (n=728) per year per river. The black bar within each box plot indicates the median. No outliers were removed. Note the difference in the y-axis for each river.

CHAPTER 4: CONCLUSIONS AND RECCOMENDATIONS

Conclusions

The overall goal of this study was to compare aspects of Hickory Shad (*Alosa mediocris*) (Mitchell 1814) and American Shad (*Alosa sapidissima*) (Wilson 1811) life history and provide recommendations based on their current federal co-management under the Interstate Fishery Management Plan (IFMP) for Shad and River Herring. Because a coastwide stock assessment has never been completed for Hickory Shad, the first objective of this study was to provide supplemental information on the age and spawning composition of individuals captured in rivers along the eastern coast of the United States. Because no published protocol for ageing Hickory Shad scales and otoliths exists, a method was adapted from the Massachusetts Division of Marine Fisheries American Shad Ageing Protocol. Methods coincided for estimating Hickory Shad scale ages and assessing spawning marks, but one distinction between Hickory and American Shad otolith ageing was the start of the first annulus. Transversely sectioned otoliths paired with otolith microchemistry, specifically the strontium and barium profiles, support the theory that the first annulus should be counted earlier compared to the American Shad protocol. A level of uncertainty between the microchemistry levels and the subsequent annuli makes age validation tricky, which is why Hill (2020) urges that reasons for this odd pattern in barium should be explored in detail in future studies. Heimbrand et al. (2020) compared chemical ageing and traditional ageing methods for Eastern Baltic Sea cod (*Gadus morhua*) otoliths and not only found that chemical ageing was more precise between methods, but that trace element ratios related to metabolic activity (i.e., Mg:Ca and P:Ca) were most useful for estimating age. An alternative study in the future could pair otolith sections with otolith microchemistry from the trace elements incorporated from physiological processes instead of the ambient water like the current study did. This study did not include a validation technique because it is impossible to obtain known-age Hickory Shad without rearing them ourselves. A future tag-recapture study utilizing parentage-based tagged (PBT) larvae is most likely the best option for age validation, especially since oxytetracycline (OTC) marks have been found unreliable (ASMFC 2020).

Although Hickory Shad could be aged effectively with both scales and otoliths, otoliths were more precise between readers and appear to be more accurate for older fish. The use of both hard parts is needed to accurately assess an alosine population because, while otoliths might be the more precise and accurate ageing structure, scales display the spawning history of the individual. Based on ages from otoliths, mature Hickory Shad ranged from 2 to 7 years old, and most spawning individuals were ages 3 and 4. The truncated lengths and majority of younger ages seen in the Roanoke, Tar, and Neuse rivers suggests the Rosa Lee phenomenon, or the growth rate in fish populations is truncated due to size-selective fishing, or overharvesting may be occurring (Kraak et al. 2019). The spawning marks estimated from Hickory Shad scales revealed evidence of a latitudinal gradient of increased iteroparity from south to north like the life history of American Shad. Rulifson et al. (2020) utilized four methods (meristics and morphometrics, geomorphometrics, otolith shape, and otolith microchemistry) to test if Hickory Shad exhibit natal homing and found that all methods could discriminate unique Hickory Shad spawning populations by watershed, and sometimes by tributary, with a degree of wandering. The latitudinal iteroparity gradient compliments this finding, advocating for Hickory Shad to be managed as separate stocks along the Atlantic coastal spawning range. Future studies on differences in latitudinal fecundity between spawning populations of northern and southern Hickory Shad may show similarities in fecundity trends between the two shad species; northern American Shad have lower relative and absolute fecundity compared to southern populations attributed to the higher prevalence of repeat spawning of northern populations (Leggett and Carscadden 1978). The occurrence of skip spawning was exhibited in a portion of the geographical range; because of the gaps in Hickory Shad life history and the rare occurrence in our small sample sizes, this phenomenon may be more prevalent in future studies with larger samples over the full range of age classes. Wuenschel and Deroba (2019) used histological maturity classes to distinguish different stages of spawning, including skip spawning, for female Atlantic herring; this technique might be useful for developing a Hickory Shad spawning assessment.

The otolith ages from North Carolina watersheds were used to create a sex-specific age-length key that was then applied to the NCDMF Creel Survey data, NCWRC Creel Survey data, and the NCWRC Electrofishing Survey data to estimate ages from total length (TL). Age-length keys reduce costs by estimating a subsample of fish, and they are especially important for overfished or data-poor species. Mean age and mean total length (TL) were evaluated between capture years for select rivers. Some tributaries, for example Contentnea Creek and Pitchkettle Creek of the Neuse watershed, showed a large drop in both average age and TL between sampling years perhaps due to an increase in fishing pressure, especially for the largest individuals. When the largest individuals are taken out of the gene pool, smaller, quick to mature individuals are left to contribute to the next generation. Over time, this causes the age and size structure of a mature population to get younger and smaller. Another interesting aspect is the majority of negative slopes (i.e., decrease in mean age and mean length over time) for females, and majority of positive slopes (i.e. increase in mean age and mean length over time) for males. Hickory Shad are sexually dimorphic --females are usually larger-- so they may be selectively taken out of the population more often because of their size. This study supports the idea that these life history parameters may be why females seem to be decreasing in average age and TL at maturity, and males are increasing. The results presented here of the more recent surveys (2012-2019) by the NCWRC and NCDMF should be compared to those from the 1980s and 1970s to look for long-term shifts in age-length relationships and in repeat spawning.

The last goal of this study was to utilize social media, specifically the Facebook group “NC-Shad” as a novel tool to obtain supplemental information on angler demographics and Hickory and American shad spatiotemporal distributions, and compare the Catch Per Post (CPP) calculated from social media and the Central Southern Management Area (CSMA) anadromous creel survey data. This study did not try to accurately assess a cross-section of the angler population, and it was assumed from the beginning that the methods used would not reflect all demographics equally. Because “NC-Shad” began in January of 2013, a very small number of members were responsible for the posts. Over time and as membership grew, so did the number of posts, and this trend must be taken into consideration for all analyses, because obviously a higher number of members means a higher probability of more posts.

One result of examining the social media data was a glimpse of how locks and dams block Hickory and American shad from reaching historical spawning grounds; removal of dams has shown to enhance the migration of these anadromous fish and provide many miles of additional spawning habitat (ASMFC 2020). In my study, before the Milburnie Dam on the Neuse River was removed, only one Hickory Shad was captured above it, but after the removal in 2017, a total of seven Hickory Shad were caught in 2018 and two in 2020. This increase in captured Hickory Shad could be a result of dam removal, which allowed Hickory Shad to access spawning habitat available up to the Falls Lake Spillway below the Falls Lake Dam. The remaining dams continue to block upstream migration, and they may have forced some individuals to pool below the most upstream dam. This may explain why out of the four main rivers in North Carolina, the Roanoke River had the highest Hickory Shad CPP. Because a bulk of the individuals were caught between Weldon, NC and upstream, the Roanoke Rapids Dam restricting upstream migration could make them more susceptible to recreational fishing pressure. The 2020 American Shad Stock Assessment indicated that both dam passage efficiency and the percentage of the population that spawns downstream of dams needs to be estimated to determine if fish passage should be implemented (ASMFC 2020). Cape Fear River surveys have documented evidence of American Shad successfully utilizing the Rock Arch Ramp at Lock and Dam #1 (White and McCargo 2018), so it could be hypothesized that Hickory Shad also follow that passage since both species were found above that obstruction in my study. For areas where dam passage will provide substantial spawning habitat and obstruction removal is not feasible, fish lifts, fish locks, fishways, and navigation locks should be installed (ASMFC 2020).

As for American Shad, the Tar River had the highest overall American Shad CPP, suggesting that the Cape Fear River may not provide the bulk of the American Shad fishery as once thought. When comparing the CPP between years for each river, only the Cape Fear River was found to have statistically significant differences between Hickory Shad CPP per year. The significant difference between 2020 and all other sampling years could be due to the small post sample size from the years 2013-2019, and the large increase in postings for 2020. Along with the large increase in posts for 2020, the number of members posting for the Cape Fear greatly increased, which could explain the dramatic increase in Hickory Shad catch. Although CPP was calculated where one post = one unit of effort, future studies may be able to incorporate CPP based on time spent fishing and angler number.

My study demonstrates that mining data posted on a social media network on fishing location, catch, and gear from 13 different rivers over eight years could provide a large amount of supplementary information on a relatively data-poor fishery. Geographic Information Systems (GIS) mapped the spatiotemporal patterns of both Hickory and American Shad CPP and fishing location, and although a significant overall trend was not found, hot spots for each species suggest aggregation patterns within North Carolina river systems. Multiple Consecutive Hot Spots near Goldsboro, North Carolina for American Shad CPP suggests that the Neuse River stocking program than began in 2012 may have successful natal homing individuals. A New Hot Spot for Hickory Shad CPP and a Sporadic Hot Spot for American Shad CPP in the Cape Fear River implies that Hickory Shad may be outcompeting American Shad for spawning habitat over time; this may be due to the American Shad stock of the Cape Fear being the most semelparous of their North Carolina range, whereas Hickory Shad are iteroparous throughout North Carolina.

The 2020 American Shad Stock Assessment indicated that a major weakness of the data is due to a lack of recreational fisheries catch, and although it is thought that the recreational fishery has declined in recent decades, the potential impact of this fishery is not well quantified besides the limited scope of the RRMA and CSMA creel surveys. The RRMA creel survey focuses on Striped Bass whereas the CSMA survey is comprehensive, so one recommendation would be for the RRMA to create a comprehensive creel survey, especially with the high volume of these species caught. These consistent methods would make future creel survey comparisons easier. The CSMA creel survey and “NC-Shad” comparison found multiple years with significant differences in mean Hickory and American shad CPP per river. One caveat in this comparison is that the CSMA creel surveys do not collect information from bank anglers, but many posts from “NC-Shad” were from bank anglers, which may explain some of the CPP differences. On the other hand, many of the years were not significantly different between the two data sources, demonstrating that similar inferences could be made from either of the two methods. It is assumed the all posts in "NC-Shad" were targeting Hickory and/or American shad, and although over 25,000 recreational angler interviews were completed from 2012-2019, only a fraction were compared with the posts from "NC-Shad" for the sake of consistent methodology. Although the method of fishing (bank or boat) was not quantitatively analyzed for this survey, a future study may be able to include this metric, recalculate the CPP, and then compare both the method and survey type (social media and creel survey) to determine if similar conclusions can be made on the recreational fishery. Because budgetary restrictions only allow the creel surveys to interview boat anglers, this novel approach for obtaining both boat and bank recreational angler data should be considered for future stock assessments and fishery management plans.

This study only provides a portion of what could be analyzed from the information obtained from the "NC-Shad" Facebook group. Analyses on the immigration, emigration, and seasonality of both Hickory Shad and American Shad may be possible with the use of GIS and the Space-Time Cube Toolbox, especially to detect shifts that may be a result of climate change. It would also be possible to estimate the number of discards (or released fish) from these posts, as many members specified if they kept or released fish, and some even specified the number released. Future studies similar to that described herein can take that into consideration. The number of fish used for bait can also be counted. It was mentioned many times that Hickory Shad and American Shad were being targeted for use as cut bait for catfish, so this metric could be taken into consideration and analyzed in the future.

Information posted on social media represents an extensive resource that could support epidemiological studies within certain circumstances. Social media sites such as Facebook increase the number of participants within certain situations, thus increasing the likelihood of obtaining data on short-lived events, such as the spring spawning run, over a larger geographical area, which in most cases are not possible to access with limited funding available. Although the information is already in the public domain, it is important to ensure that this innovative approach to collect social media data continues to protect the privacy and anonymity of participants and that confidentiality is upheld. While the information on "NC-Shad" may not accurately reflect the fishing activity by each member, there may be potential to form a network of anglers willing to participate in monitoring programs or take part in controlled citizen science studies. Some members explicitly stated whether they practiced catch and release and kept the allotted creel limit, suggesting the members want the recreational fishery to be sustainable as much as the fisheries agencies. A future co-management approach to implement management proposals that incorporates both epistemological knowledge systems of Local Ecological Knowledge (LEK), possibly using social media to crowdsource data, and Conventional Scientific Knowledge (CSK) regarding Hickory Shad and American Shad spawning migration and distribution, would increase the effectiveness of natural resource management in the river systems of North Carolina.

The IFMP addresses four species: Alewife (*Alosa pseudoharengus*), Blueback Herring (*Alosa aestivalis*), Hickory Shad, and American Shad (ASMFC 1985). Amendment 2 introduced new management practices for Alewife and Blueback Herring and Amendment 3 required similar management and monitoring for American Shad (ASMFC 2009, ASMFC 2010), but limited management is in place for Hickory Shad. Throughout the IFMP and the consecutive amendments, Hickory Shad are consistently compared to American Shad most likely due to a lack of Hickory Shad biological data available in published literature. With Hickory Shad populations vulnerable to pollution, habitat degradation, and overfishing, more research on their life history, especially to find evidence supporting or refuting the management of river-specific stocks, would benefit fishery managers. The results of my study described herein should provide a good baseline and impetus for starting those future critical studies.

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