**RESEARCH PROPOSAL**

# Characterizing Reservoir Fish Assemblages and Population Dynamics of Striped Bass in North Carolina

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## INTRODUCTION

Lentic aquatic environments created by the construction of dams on rivers and streams provide numerous essential functions (e.g., irrigation, power generation, fish and wildlife habitat) and have been important components of human civilizations for over 5000 years (Schnitter 1994). Abundance estimates of lake and artificial lentic habitats (hereafter reservoirs) greater than a hectare in surface area exceed 24 million (Downing et al., 2006). These waterbodies are necessary to support municipal water supply demands, maintain navigable waterways for interstate and international commerce, and provide invaluable security in times of extreme fluctuations in water availability by mitigating the effects of drought, power failure, and devastating floods. Although reservoir construction peaked in the 1960's (i.e., 20,257 dams completed from 1960-1969; 2017 Hydropower Market Report, Uría-Martínez et al., 2017) and are ubiquitous across most of the developed world, understanding of biology of reservoirs has received substantially less attention compared to riverine habitats.

Reservoir construction can have varying effects on the composition and distribution of aquatic organisms, such as altering the physical and chemical processes of lotic habitats and limiting passage and occurrence of migratory freshwater and diadromous species. Additionally, reservoirs are also commonly stocked with ubiquitous sport fish species that can provide numerous recreational opportunities, but are often non-native (Gozlan et al., 2010). As such, research on reservoir fishes has often focused on recreationally and economically important species and reservoirs have received little attention from community ecologists (Miranda et al., 2008; Irz et al., 2002) relative to natural lakes (Jackson et al., 2001; Tonn and Magnuson, 1982) despite the potential for similar species and management. Reservoir fish assemblages warrant further investigation to better understand their ecological role in continually changing environmental conditions (e.g., land use change, urbanization, water demands) and to optimize management and conservation strategies for species or populations that reside within, or are influenced by, reservoir presence.

Striped Bass (*Morone saxatilis*) is a diadromous fish species that has been widely introduced into reservoirs across the U.S. and particularly the Southeast. Striped Bass naturally occurred in estuaries and rivers from the St. Lawrence River in Canada through the Gulf coast of Louisiana during annual spawning migrations from marine environments. Although they were introduced into California estuaries by 1879 (Raney et al. 1952), the 1941 impoundment of the Santee and Cooper rivers in South Carolina inadvertently created the first reproductively successful population by isolating adult Striped Bass during spawning migration (Scruggs and Fuller 1955; Whitehurst and Stevens 1990). Kerr Lake, located in North Carolina and Virginia, became the second self-sustaining population via dam construction on the Roanoke River in 1952 (Coutant 2013). Fisheries management agencies were tasked with determining the degree of future supplementation to sustain Striped Bass after initially establishing reservoir populations (Van Horn 2013). Management agencies in the Southeastern U.S. also discovered that many reservoir Striped Bass populations failed reproductively in absence of necessary water currents that prevent their semibuoyant eggs from suffocating on the bottom (Barkuloo 1970; Gustaveson and Blommer 2013). However, following a hatchery experiment, Bayless (1968) asserted it was of greater importance to a successful hatch that eggs not be threatened by poor water quality or suffocation by silt than be suspended by water current. In reservoirs where Striped Bass were found to be reproductively successful, stocking remained a tool by which to further thriving populations (Bulak et al. 1995). Introducing these new sport fish populations in systems that commonly lacked pelagic predators achieved the primary objective of establishing new recreational fisheries.

The resulting recreational fisheries and perceived potential from these new land-locked populations led to widespread development of hatchery and stocking techniques for Striped Bass and their hybrids during the peak of reservoir construction (i.e., 1950-1960) throughout the United States. By 1981, they were established in at least 279 reservoirs in 34 states (Axon and Whitehurst 1985). Recreational fisheries for Striped Bass, White Bass (*M. chrysops*), and their hybrids proved economically valuable, particularly in inland waterbodies with thriving hatchery-maintained populations (e.g., US$ 24.6 billion expended in 2006 ; U.S. Department of Interior 2006). Therefore, understanding Striped Bass populations are necessary for successful propagation and management of these introduced sportfish.

Striped Bass introductions in reservoirs were endorsed by fisheries managers as an opportunity to utilize an “empty niche” by occupying unused open-water habitat in these newly constructed reservoirs and curbing the number of Gizzard Shad (*Dorosoma cepedianum*) that were too large to consume by other reservoir sport fish such as Largemouth Bass (*Micropterus salmoides*) (Axon and Whitehurst 1985; Coutant 2013; Van Horn 2013). A survey of fisheries agencies conducted by Axon and Whitehurst (1985) showed reductions of up to 90% in Gizzard Shad following an intentional stocking of hybrids to utilize and check this forage species. Widespread introductions of Striped Bass in reservoirs successfully established new fisheries and made use of abundant and often underutilized prey populations. However, increased mortality, slow growth, and poor body condition were observed in reservoir populations that failed to produce trophy-sized fish. For example, condition of Striped Bass in reservoirs across the southeastern United States was inversely related to age suggesting slower growth of older individuals (Wilson et al. 2013) as a potential result of limited prey resources (Gustaveson 1999; Gustaveson and Blommer 2013).

High mortality of Striped Bass, particularly during summer has also been problematic for many reservoir populations. Summer kills and stress to large reservoir fish that thermally stratify has been attributed to environmental conditions (i.e., high summer temperatures and low dissolved oxygen levels) that fail to meet physiological requirements of Striped Bass (i.e., thermal niche-dissolved oxygen hypothesis, Coutant 1985; Coutant 2013). Specifically, adult Striped Bass prefer cooler water temperatures and can become separated from prey populations when they are forced into deeper water with low oxygen concentrations (Coutant 1985; Coutant 2013; Thompson and Rice 2013). Availability of abundant shad *Dorosoma* spp. populations, however, may mitigate high energetic demands associated with poor summer habitat availability (Thompson et al. 2010; Thompson and Rice 2013). Population dynamic information is critical to understanding regulating factors of reservoir Striped Bass and necessary to effectively managing and optimizing stocking strategies, because growth and mortality of reservoir Striped Bass populations can differ substantially due to variety of both biotic (i.e., prey availability) and abiotic factors (e.g., summer oxygen-temperature dynamics).

## OBJECTIVES

The proposed research seeks to provide greater understanding of reservoir fish assemblages and associated environmental characteristics throughout North Carolina (Chapter 1) and to describe variation among Striped Bass reservoir population characteristics and their relationships to biotic and abiotic environmental conditions (Chapter 2). Specifically, I propose to; 1) conduct a survey of North Carolina reservoir fish assemblages using a combination of passive and active sampling methods, 2) estimate relative abundance, condition, and size structure for sampled fishes 3) relate assemblage characteristics to physical and chemical characteristics of reservoirs 4) estimate age, growth, and mortality of stocked Striped Bass populations using calcified bony structures (i.e., sagittal otoliths), 5) relate Striped Bass population dynamic rates to reservoir characteristics (e.g., prey species abundance, summer temperature and oxygen dynamics), and 6) develop hierarchical models of back-calculated annual growth to estimate variation among individuals, years, stockings, and reservoirs. Results of the proposed research will advance understanding of reservoir fish assemblages and provide information necessary to guide stocking strategies and refine management objectives of Striped Bass in North Carolina reservoirs.

## METHODS

### *Study Area*

The North Carolina Wildlife Resource Commission (NCWRC) has stocked over 25 million Striped Bass fingerlings among 17 North Carolina reservoirs since 1980. The Striped Bass stocking program in North Carolina began in the 1960s and is generally based on a 5 fish/surface acre (2.02 fish/ hectare) stocking rate. A total of 12 reservoirs currently stocked with Striped Bass will be sampled to provide a statewide assessment of reservoir Striped Bass populations and associated fish assemblages (Table 2). Reservoirs in this study exhibit a wide range of physical characteristics (e.g., size, depth, geographic region) which will allow relation of fish assemblage and Striped Bass catch data to potential indicators of ecological difference.

Fish sampling will be conducted using a systematic random sampling design used to reduce bias associated with physical and chemical gradients that exist within reservoirs (e.g., river to dam) and to ensure  samples are allocated throughout each reservoir. Sample reaches will be consistently spaced throughout each reservoir using shoreline segmentation with GIS applications.

Repeated sampling of reservoirs will be conducted to understand temporal influences on fish assemblage and Striped Bass population characterization. Specifically, three reservoirs (i.e., Jordan Lake, Lake Gaston, and Badin Lake) will be sampled in three consecutive years ( 2017, 2018, and 2019). Three reservoirs (i.e., High Rock Lake, Hickory Lake, and Lookout Shoals Lake) will be sampled in two years  (2018 and 2019). Tuckertown Reservoir, Lake Tillery, Roanoke Rapids Lake, W. Kerr Scott Reservoir, Lake Rhodhiss, and Hiwassee Lake will be sampled in a single year (2018 or 2019).

***Habitat***

In addition to physical characteristics recorded using geographic information system applications (e.g., watershed landcover) and reservoir bathymetric mapping (see Table 1), water quality will be measured from each reservoir to incorporate abiotic characteristics in future reservoir comparison analyses. Historical water quality data from the North Carolina Department of Environmental Quality will be compiled for each reservoir. Physicochemical water condition data (i.e., turbidity, conductivity, pH) and temperature and dissolved oxygen profiles will be related to observed trends in fish assemblage structure and Striped Bass population estimates.

***Gill Netting***

Sinking experimental gill nets will be used to sample fish assemblages in North Carolina reservoirs because they are a common sampling method for shallow reservoirs with large littoral areas. They are also well-suited for studies of Striped Bass age and growth due to low bias associated with length-at-age data and mortality estimates (McRae et al. 2013). Gill nets are one of the most effective gears for pelagic and mobile species as Waters (2005) found 90% of surveyed reservoir Striped Bass managers in the southeastern United States used gill nets to monitor Striped Bass populations. Experimental gill nets will be 61.0 m (200 ft) long and consist of four 15.2 m (50 ft) long panels that were each 2.4 m (8 ft) in height of four mesh sizes arranged in a random order: 38 mm (1.5 in), 64 mm (2.5 in), 76 mm (3 in), 51 mm (2 in). Gill nets will be set at least an hour before sunset, bottom-deployed perpendicular to shore in water at least 3 m in depth, and retrieval initiated an hour after sunrise the following day. Shore-side mesh size will be randomized at each location and recorded. Total length (TL) will be measured to the nearest millimeter and weight will be measured to the nearest gram for all fish sampled on each reservoir. Catch rates will be estimated by determining the average number of a species caught per net night (NN) on each reservoir.

***Electrofishing***

Fish associated with the littoral zone in each reservoir will be sampled using pulsed DC electrofishing during fall/winter months (i.e., November-December) to index prey species (e.g., Gizzard Shad, Threadfin Shad *Dorosoma petenense*) and characterize fish assemblages in each reservoir. A total of 20 shoreline segments systematically located around each reservoir (see above) will be sampled using 5-minute night electrofishing runs conducted at night to increase catch rates and species encountered. Total length (TL) will be measured to the nearest millimeter and weight will be measured to the nearest gram for all fish sampled.

***Population Characteristics of Striped Bass and other focal species***

We will quantify the species composition of each reservoir by calculating the relative abundance for all fish species sampled based on sampling methods that best characterize populations. Size structure of populations will be calculated using proportional size distribution

(PSD; Gabelhouse 1984; Anderson and Neumann 1996) and body condition will be estimated using mean relative weight (Wr; Wege and Anderson 1978; Brown and Murphy 1991). Striped Bass otoliths will be viewed under a dissecting microscope coupled with image analysis software (Image Pro software; Media Cybernetics, Bethesda, MD, USA) to measure annular growth rings for age and growth estimates. Back-calculated length at age will be estimated and an age-length key will be used to assign ages to lengths of non-aged fish using methods detailed by Isermann and Knight (2005). Growth will also be estimated by fitting von Bertalanffy growth models to each population. Growth models will be fit using nonlinear regression techniques (Freund and Littell 1991) and modeled using a hierarchical framework to incorporate variation from repeated measurements of individual fish using incremental annual growth to estimate variation among individuals, years, stockings, and reservoirs. Mortality will be estimated using methods described by Miranda and Bettoli (2007), but the specific method of estimation (e.g., weighted catch curve adjusted for gill net selectivity) will largely depend on the structure of age data for each population.

## EXPECTED RESULTS

The proposed research approach is more than a simple characterization of reservoir Striped Bass populations and will offer greater understanding into the regulating factors of population dynamics of Striped Bass across a wide range of North Carolina reservoirs. Dynamic population rates, such as growth and mortality, are much more informative because rate functions provide temporally integrated assessments of physical and biotic environmental conditions (e.g., resource availability, thermal conditions, habitat suitability) and genetic factors that have direct and indirect effects on recruitment dynamics, trophic interactions, and survival

(DeVries and Frie 1996). Therefore, management and our understanding of fish ecology are often greatly enhanced with information on dynamic population rates (e.g., age structure, growth, mortality). Striped Bass stocking rates, associated fish assemblages (e.g., prey abundance and characteristics), and summer water conditions are likely the principle drivers of differences in Striped Bass success. However, other variables (e.g., water temperature, species rank order of abundance, etc.) will also be investigated and their strength of impact measured using ordination.

The process of evaluating and refining management strategies among reservoirs is often hindered by insufficient or inconsistently collected biological and physiochemical data. Differences among current sampling methods between reservoirs in North Carolina limits the ability to understand factors responsible for regulating important recreational fisheries such as Striped Bass. My approach will not only allow for the direct comparison of reservoirs but also supplement existing sampling regimes that will be critical for the assessment and adoption of statewide monitoring protocols. This project will provide a comparative framework capable of integrating historical and future information to guide stocking and management decisions.

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**Table 1.** Reservoirs included in the proposed research framework to characterize reservoir Striped Bass population dynamics from 2017-2019.

| Reservoir | Surface Area (hectares) | Shoreline Length (km) | Avg Depth (m) | Max Depth (m) | Elevation (m) | Completion Year | Drainage Area ($km^2$) | Water Volume ($m^3$) |
|---|---|---|---|---|---|---|---|---|
| Badin | 2,165 | 185 | 27 | 58 | 155 | 1917 | 10826 | 1.59e+08 |
| Gaston | 8,215 | 563 | 12 | 28 | 61 | 1963 | 21601 | 5.55e+08 |
| Hickory | 1,659 | 169 | 10 | 26 | 284 | 1927 | 3393 | 1.70e+08 |
| High Rock | 6,143 | 587 | 5 | 16 | 200 | 1928 | 10290 | 2.90e+08 |
| Hiwassee | 2,539 | 262 | 43 | 94 | 464 | 1940 | 2507 | 2.54e+08 |
| Jordan | 5,641 | 322 | 4 | 12 | 66 | 1982 | 4377 | 2.65e+08 |
| Lookout Shoals | 514 | 63 | 9 | 21 | 255 | 1916 | 3753 | 3.08e+07 |
| Rhodhiss | 1,422 | 145 | 6 | 16 | 303 | 1925 | 2823 | 8.67e+07 |
| Roanoke Rapids | 1,862 | 76 | 5 | 30 | 40 | 1955 | 21481 | 9.51e+07 |
| Tillery | 2,130 | 190 | 10 | 22 | 85 | 1928 | 12520 | 2.07e+08 |
| Tuckertown | 1,036 | 121 | 5 | 17 | 172 | 1962 | 10904 | 8.26e+06 |
| W. Kerr Scott | 597 | 89 | 9 | 20 | 314 | 1962 | 951 | 5.06e+07 |

**Figure 1.** Conceptual diagram of shoreline segmentation and sample allocation.

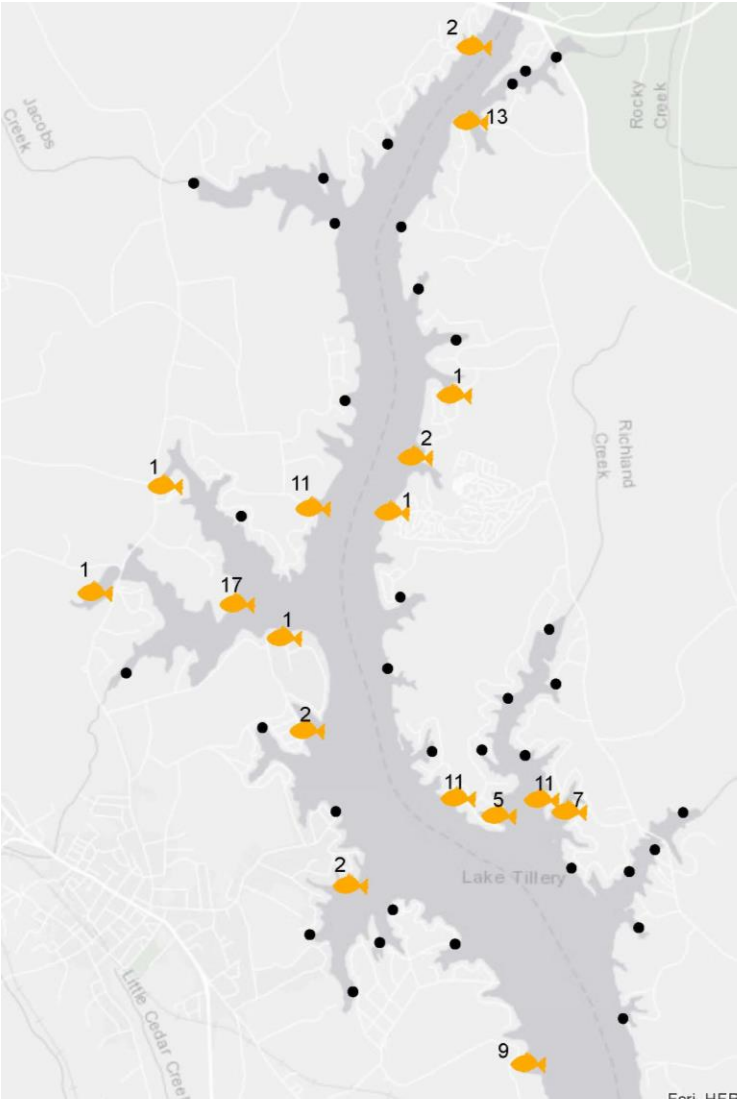

Figure 2. Map of study reservoir locations with yellow icons indicating potential gill net sampling frequencies (i.e., 3 years, 2 years, and 1 year)