MARK RECAPTURE STUDY TO DETERMINE POPULATION SIZE OF CAPE FEAR RIVER STRIPED BASS

Prepared by

Chip Collier
Will Smith
Chris Stewart
Stephen Taylor

North Carolina Division of Marine Fisheries

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ABSTRACT

The Cape Fear River had very low levels of striped bass prior to new management measures taking effect including: harvest moratorium in the Cape Fear River and its tributaries, using striped bass caught near historic spawning grounds on the Cape Fear River as broodstock for stocking striped bass, releasing stocked striped bass at phase II size, and constructing a rock arch ramp at Lock and Dam #1. All these management measures likely had a positive impact on the Cape Fear River striped bass population. However, there have been little data available to determine if the management measures were successful in enabling the striped bass population to rebuild to sustainable levels using traditional stock assessment methods.

A fishery independent double tagging striped bass program was used to track striped bass length composition, migration, trend in abundance, and population size from 2011 to 2013. The tagging was conducted by the North Carolina Division of Marine Fisheries, Cape Fear River Watch Striped Bass Invitational Tournament, a recreational fisherman near downtown Wilmington and by North Carolina Wildlife Resources Commission near the spawning grounds on the Cape Fear River. The number of striped bass tagged per year was 279 in 2011, 394 in 2012, and 421 in 2013. Fifty-nine percent of the striped bass tagged around Wilmington and 76% of the fish tagged near the spawning grounds were greater than the 475 mm fork length, which is the predicted size at maturity for female striped bass in North Carolina. The number of striped bass increased from 2011 to 2013 based on a zero inflated negative binomial model used to estimate catch in an electrofishing survey. Other factors significant in predicting catch included water temperature, salinity, conductivity, and sample area. The factors that were used to estimate the probability of zero catch included salinity and tidal stage (ebb or flood). The population model based on the mark-recapture data in the fishery independent study indicated the abundance of striped bass has not significantly changed from 2011 to 2013 but the estimated abundance increased yearly. The population abundance was estimated to be 15,209 striped bass (greater than 250 mm total length) in 2013.

The management measures enacted to protect and enhance Cape Fear River striped bass are having a positive impact. The percent of striped bass greater than the size of maturity, the number of striped bass greater than 28 inches FL, and trend in catch based on the electrofishing survey were all positive and indicated increasing spawning stock biomass in the Cape Fear River. However, the number of adult fish remains well below the target of 100,000 recommended by the Cape Fear River Partnership and more time is needed to determine if the juvenile production is increasing as a result of the management measures.

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GRANT INFORMATION

Project No: 2F40 F010

Project Title: **Mark Recapture Study to Determine Population Size of Cape Fear River Striped Bass**

Grant Duration: Start Date: 1 Aug 2010 End Date: 31 July 2018

Period Covered by This Report:
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Project Costs:

Proposed	CRFL: $xxx,xxx	Grantee:	Total: $xxx,xxx
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Study/Job Title: **Mark Recapture Study Cape Fear River Striped Bass**

INTRODUCTION

Striped bass (*Morone saxalitis*) are an important recreational and commercial fish in North Carolina. The importance of striped bass has a long history and records of landings go back into the 1800s (Chestnut and Davis 1975). Over this time period, the stock has declined in the Cape Fear River due to a combination of factors including: overfishing, poor water quality, and dams. Low stock size in the Cape Fear River led managers to establish a harvest moratorium in 2007 (NCDMF and NCWRC 2011). Currently, there is no management target for population size to reopen the fishery. However, the Cape Fear River Partnership suggested that 100,000 spawning adults in the Cape Fear River would be a target for rebuilding the population.

Within North Carolina, there are several stocks of striped bass typically isolated by river systems (Winslow 2010). Striped bass in the Cape Fear River system are rarely observed outside of the system although a few have been reported. Additionally, few fish are recaptured within the Cape Fear River system tagged from the ocean or other river systems. Since there is little mixing among river systems, rebuilding the Cape Fear River striped bass required management targeted to that particular system.

As mentioned above, the moratorium was the first action to rebuild the stock. The second action was changing the method used to stock and rear juvenile striped bass. The North

Carolina Wildlife Resources Commission (NCWRC) changed from using striped bass broodstock from other systems and began using broodstock caught near the lock and dams in the Cape Fear River to rebuild the populations. NCWRC also started stocking the Cape Fear with phase two striped bass which are six to eight inches (152 – 203 mm TL). The third action taken was the modification of Lock and Dam #1 to a rock arch ramp to allow passage of diadromous fishes. This rock arch ramp is the first of its kind on the Atlantic Coast and has the potential to increase access to historic spawning grounds for diadromous fishes. Prior to the construction of the rock arch ramp, anadromous fishes were locked upriver three times per day using a set protocol developed by NCWRC and US Army Corps of Engineers (USACOE). Research is underway to determine the passage efficiency of the rock arch ramp.

Estimates of population size and trends in population abundance are not available for the Cape Fear River system. In the most recent review of Cape Fear River striped bass data, there were not sufficient data to conduct a stock assessment or catch curve analysis (NCDMF and NCWRC 2011). Prior to 2012, recreational data were not collected on an annual basis. Since 2008, there has been a moratorium on harvest and there are not sufficient surveys to estimate discards. There is also no independent index of abundance based on the NCWRC spawning area survey on the mainstem of the Cape Fear River near the three locks and dams. However, there are two other large tributaries of the Cape Fear River that can contribute to egg and juvenile production: Black and Northeast Cape Fear rivers. This tagging study was initiated to estimate the population size of striped in the Cape Fear River and determine trends in abundance. A tagging study was the preferred method to estimate the population size of striped bass in the Cape Fear River due to potential problems with more traditional stock assessment methodologies. Prior to 2012, annual recreational landings were not reported and this missing component of the harvest would hamper methods that condition stock size on removals. The stock is also enhanced through the NCWRC stocking program, thus impacting the stock recruitment relationship. To avoid these problems, a double tagging program was selected as the method to estimate the population size. The program used fishery independent tagging and recapturing as the primary method to estimate abundance and supplemented with tagging and recapturing from the Cape Fear River Watch Striped Bass Invitational (CFRWSBI) as well as one recreational fisherman.

SAMPLING PROCEDURES AND ANALYSIS

Sample Area (Excerpt from Cape Fear River Hurricane Grant)

“The Cape Fear River is the longest river (325 km) that flows entirely in North Carolina (Figure 1). It originates above Greensboro (as the Haw River) and empties into the Atlantic Ocean near Southport. A minimum flow of 200 cubic feet per second is released to the Cape Fear River from Lake Jordan Reservoir, which is approximately 60 miles downstream of Greensboro (Dan Emerson, [USACOE], personal communication). The depth of the more coastal portion of the Cape Fear is controlled by three lock and dams that were created from 1915 to 1935 by the USACOE between Wilmington and Fayetteville. The locks were created to enable barge traffic up and down the river. There has been no commercial traffic for a number of years and the fate of the dams is currently undergoing a General Re-evaluation Report by the USACOE. Below the lock and dams, the lower mainstem Cape Fear River is characterized by turbid water and contains high levels of inorganic nutrients. It is fed by two large blackwater rivers (the Black and Northeast Cape Fear rivers) that have low levels of turbidity, but highly tannin-stained water, with less inorganic nutrient content than the mainstem (Mallin et al. 2002).” (Collier et al. 2007)

In 2011 and 2012, a rock arch ramp was constructed by the USACOE at Lock and Dam #1 to enable better fish passage to historic spawning grounds. The rock arch ramp has a gradual decline from the top of the dam out 200 feet. The rocks were designed to have pools in between large rock features to give fish a chance to rest as they migrate through the flowing water. Striped bass were known to pass this structure in 2012 when it was partially completed and 2013 when it was completed.

Methods

Sampling was divided into six sampling periods based on year and area sampled. Sampling around Wilmington included samples collected on the Northeast Cape Fear River and its tributaries, Cape Fear River below Black River and its tributaries, and Brunswick River. Sampling on the spawning grounds was conducted at the base of the three lock and dams by NCWRC in the spring (Figure 1). Electrofishing was the primary method used to catch and tag striped bass because of the gear's higher efficiency catching striped bass compared to hook and line and gill netting. Electrofishing was conducted from an 18' SeaArc boat, equipped with a Smith-Root, Inc. 7.5 Gas Powered Pulsator (GPP) Electrofisher. Sampling was generally conducted in waters with salinities less than five parts per thousand (ppt).

Additional gears included gill nets and hook and line. Striped bass captured in North Carolina Division of Marine Fisheries (NCDMF) independent gill net surveys were tagged and released. Hook and line gear was used during the CFRWSBI and a recreational fishermen, Jot Owens. Sampling using these additional gears was only conducted around Wilmington.

All fish collected by NCDMF on a sampling trip were recorded for entry into Program 311. Fork length and number of fish collected was recorded for recreationally important species. Fish condition and if hook and line was used hook type, bait type, and hook location were recorded for released striped bass. Only striped bass were recorded by NCWRC, CFRWSBI, and Jot Owens and entered into Program 311.

Striped Bass Abundance Trends

The catch of striped bass was zero-inflated based on a score test: therefore, a zero inflated model was used to track trends in abundance (Flynn and Francis 2009). A generalized linear model was used to estimate trends in abundance based on parameters included in the model and distribution of the catch data (Poisson or negative binomial). The model included a two-stage model: the first stage estimated zero or greater than zero and the second stage estimated the catch greater than zero. River section was split between the Northeast Cape Fear River, Cape Fear River, and Brunswick River. This split was done to standardize the effort among sampling sites. Tide was categorized as either rising or falling to reduce the degrees of freedom included in the mode. Model selection was based on Akaike's information criterion (AIC) and Pearson residual distribution. Statistical analyses were conducted using SAS 9.3.

Tagging

Most fish were implanted with two tags: internal anchor tag and electronic passive integrated tag (PIT). Standard striped bass tags issued by the United States Fish and Wildlife Service were used as an external marker for the mark recapture model and were inserted in the belly of the fish on the left side. PIT tags were used to estimate tag retention of the internal anchor tags and inserted in the left operculum of the fish. PIT tag retention was assumed to be 100%.

Tagged fish were measured to the nearest millimeter for fork and total length and weighed to nearest one hundredth in kilograms. Some fish did not have either fork (FL) or total length (TL) recorded. The missing length was estimated by: TL= 5.01 + 1.06*FL or FL= 0.94*TL – 3.05. The r^2 for both regression equations was greater than 0.995 and included fish from 200 to 800 mm.

Mark-Recapture Model

Mark-recapture data were modeled using the Bayesian multistate model described by Kery and Schaub (2010), which simultaneously estimated capture probabilities, instantaneous mortality rate, and movement probabilities between three areas, the lower Cape Fear and Northeast Cape Fear Rivers (LCF), the Cape Fear River above Lock and Dam One and the Black River (UCF), and the upper Northeast Cape Fear River (UNE). By simultaneously modeling both mortality and movement parameters, the multistate model accounted for uncertainty in these parameters when estimating capture probabilities. Accurate estimates of capture probabilities were required to estimate population size, which was estimated using a Jolly-Seber model (catch per time period / capture probability).

The Kery and Schaub (2010) model is a hierarchical, individual-based version of the multistate model that separates state (mortality and movement) probabilities from observation (capture) probabilities, allowing stochasticity in each sub-model. A matrix of state transition probabilities (Ω) was a function of survival (φ) at time t:

$$\varphi_t = \exp(-Z_t),$$

where Z was the instantaneous rate of mortality in time period t, and transition probabilities $\psi_{r,s}$ between areas r in t and s in t+1. Rows of Ω corresponded to states at t and columns corresponded to states at t+1:

$$\begin{array}{cc} & \underline{\text{State at } t+1} \\ & \begin{array}{cccc} \text{LCF} & \text{UCF} & \text{UNE} & \text{Unobserved} \end{array} \\ \Omega_t = & \begin{bmatrix} \varphi_t * \psi_{1,1,t} & \varphi_t * \psi_{1,2,t} & \varphi_t * \psi_{1,3,t} & 1-\varphi_t \\ \varphi_t * \psi_{2,1,t} & \varphi_t * \psi_{2,2,t} & \varphi_t * \psi_{2,3,t} & 1-\varphi_t \\ \varphi_t * \psi_{3,1,t} & \varphi_t * \psi_{3,2,t} & \varphi_t * \psi_{3,3,t} & 1-\varphi_t \\ 0 & 0 & 0 & 1 \end{bmatrix} \end{array} \begin{array}{c} \text{State at } t \\ \text{LCF} \\ \text{UCF} \\ \text{UNE} \\ \text{Dead} \end{array}$$

A matrix of observation probabilities (χ) was defined by time- and area- specific capture probabilities $r_{s,t}$:

$$\begin{array}{cc} & \underline{\text{Observation at t}} \\ & \begin{array}{cccc} \text{LCF} & \text{UCF} & \text{UNE} & \end{array} \\ \chi_t = & \begin{bmatrix} r_{1,t} & 0 & 0 & 1-r_{1,t} \\ 0 & r_{2,t} & 0 & 1-r_{1,t} \\ 0 & 0 & r_{3,t} & 1-r_{1,t} \\ 0 & 0 & 0 & 1 \end{bmatrix} \end{array} \begin{array}{c} \text{State at t} \\ \text{LCF} \\ \text{UCF} \\ \text{UNE} \\ \text{unobserved} \end{array} .$$

Rows of χ corresponded to states, and columns of χ corresponded to observations.

A latent variable, $z_{i,t}$, describing the true state of each individual i was estimated for each time interval, assuming a categorical distribution with probability Ω_t:

$z_{i,t}$ ~ dcategorical(Ω_t).

Observed data, $y_{i,t}$, were also categorically distributed, with probability χ_t conditional on $z_{i,t}$:

$y_{i,t}$ ~ dcategorical(χ_t).

Capture histories for each tagged individual were summarized in bi-monthly intervals and one eight-month interval (January-February, March-April, May-December). Most sampling occurred from January through May of each year. Time intervals were selected based on striped bass life history dynamics. Interval one (January−February) represented a winter period when striped bass are known to be relatively sedentary. Interval two (March−April) represented the early spawning season when mature striped bass are known to run upstream to spawning grounds. Interval three (May−December) represented the peak spawning season, and non-spawning summer and fall periods. Capture and movement probabilities were assumed to vary among time intervals and be consistent among years (i.e., $r_{s,1}$did not equal $r_{s,2}$, but $r_{s,1,2011}$= $r_{s,1,2012}$=$r_{s,1,2013}$), and mortality probabilities were assumed to vary based only on the length of the time interval (i.e., an individual was four times more likely to die in a eight-month interval than in a two-month interval). Annual instantaneous mortality probabilities were estimated by summing Z over time intervals.

Mortality and movement probabilities can be confounded in the multistate model, so auxiliary telemetry data was used in a joint likelihood to facilitate estimates of movement probabilities and thus aid in the separation of movement and mortality estimates. Telemetered individuals were assumed to be observed without error and with observation probability of one; therefore, the telemetry model consisted only of a state model (ω_t), analogous to Ω_t, in which only movement was modeled:

$$\omega_t = \begin{array}{c} \begin{array}{ccc} \text{LCF} & \text{UCF} & \text{UNE} \end{array} \\ \begin{bmatrix} \psi_{1,1,t} & \psi_{1,2,t} & \psi_{1,3,t} \\ \psi_{2,1,t} & \psi_{2,2,t} & \psi_{2,3,t} \\ \psi_{3,1,t} & \psi_{3,2,t} & \psi_{3,3,t} \end{bmatrix} \end{array} \begin{array}{c} \text{State at } t+1 \\ \text{LCF} \\ \text{UCF} \\ \text{UNE} \end{array} .$$

States of telemetered fish ($telz_i$) were categorically distributed with probability, ω_t:

$telz_{i,t}$~ dcategorical(ω_t).

Abundances in each area ($N_{s,t}$) were estimated with a Jolly-Seber model ($N_{s,t}$= $\text{catch}_{s,t}/r_{s,t}$). Total abundance in each time period was the sum of $N_{s,t}$ over all areas. Finally, annual estimates of abundance were estimated by taking the average of total abundance during all time intervals for each year (2011−2013). Abundance estimates were interpreted as representative of the entire Cape Fear system, including the Cape Fear, Northeast Cape Fear, and Brunswick rivers.

All model parameters were given uninformative prior distributions (Table 2), with the exception of Z. Preliminary model runs indicated that a lower bound was required on the prior for Z for the model to converge. A burn-in period of 10,000 was followed by 100,000 Markov Chain Monte Carlo (MCMC) samples among two chains. Model convergence was assessed with the Gelman and Rubin diagnostic test (Gelman and Rubin 1992) and upper credible interval values for the

Gelman and Rubin statistic of 1.05 or less were assumed to indicate model convergence. Statistical software R (version 3.0.1; R Core Team) and JAGS (version 3.4.0; Plummer 2003) were used to fit the model.

RESULTS

A total of 451 samples were taken targeting striped bass in the Cape Fear River from January 2011 through June 2013 (Table 2). The samples were collected by the NCDMF, NCWRC, CFRWSBIT, and a recreational angler. Most of the samples were collected around Wilmington in the mainstem of Cape Fear River and Northeast Cape Fear River (NECFR). During the winter (January- March), this area had a relatively high concentration of striped bass compared to other areas in the Cape Fear River Complex and salinities were low enough for electrofishing gear to work successfully.

Environmental Data

Striped bass targeting occurred when mean water temperatures ranged between 7.9°C and 27.5°C (Table 3). Most of the samples around Wilmington (NECFR and Downtown Wilmington) and Brunswick River occurred when maximum water temperatures were below 20°C. Mean water temperature during the NCWRC spawning grounds survey ranged from 12.1 to 27.5°C. The temperatures in the spring of 2013 on the spawning grounds were cooler than the two previous years for most locations.

The mean salinities ranged between 0.1 and 10.3 ppt. All sample means were below 5.7 ppt with the exception of the downtown Cape Fear River in January 2012 (Table 3). Samples collected during this time came from CFRWSBIT, hook and line, and gillnetting. Striped bass occur in salinities greater than 5 ppt, but sampling was generally limited to low salinity areas because the electrofishing gear was less effective at higher salinities.

The mean dissolved oxygen (DO) ranged between 4.2 and 13.8 mg/L with most samples ranging from 5.0 and 10.0 mg/L (Table 3). The lowest minimum DOs observed occurred on the Brunswick River in March 2013 (5.8 mg/L), the NECFR in March 2012 (3.2 mg/L) and April 2013 (3.5 mg/L), the downtown Cape Fear River in April 2013 (2.1 mg/L), and the spawning grounds in May 2012 (4.6 mg/L) and May 2012 (4.3 mg/L). The highest maximum DOs observed occurred on the Brunswick River in January (10.7 mg/L), the NECFR in February 2012 (10.6 mg/L), the downtown Cape Fear River in February 2013 (12.4 mg/L), and the spawning grounds in March 2013 (16.4 mg/L).

Species Composition

A total of 4,876 individual fish from 38 different species were caught in the NCDMF electrofishing survey (Table 4). In 2011 the five most abundant species were as follows: striped mullet (*Mugil cephalus*; n = 767, 55.0%), striped bass (n = 429), gizzard shad (*Dorosoma cepedianum*; n = 171, 7.7%), largemouth bass (*Micropterus salmoides*; n = 111), and spot (*Leiostomus xanthurus*; n = 60). By frequency of occurrence striped bass was the highest (78.7%) followed by striped mullet (55.0%), blue catfish (*Ictalurus furcatus*; 15.4%), bluegill (*Lepomis macrochirus*; 12.4%), and largemouth bass (11.2%).

In 2012 the five most abundant species were as follows: striped bass (n = 451), striped mullet (n = 440), blue catfish (n = 122), longnose gar (*Lepisosteus osseus*; n = 65), and red drum (*Sciaenops ocellatus*; n = 45). By frequency of occurrence striped bass was the highest (86.7%) followed by striped mullet (38.9%), blue catfish (29.2%), red drum (19.5%), and American eel (*Anguilla rostrata*; 10.6%).

In 2013 the five most abundant species were as follows: striped mullet (n = 636), striped bass (n = 480), red drum (n = 177), gizzard shad (n = 172), and longnose gar (n = 100). By frequency of occurrence striped bass was the highest (96.5%) followed by striped mullet (55.3%), blue catfish (42.1%), red drum (27.2%), and largemouth bass (15.8%).

For striped bass, there was an increasing frequency of occurrence as well as an increase in the number of fish collected per sample (total number/total number of samples) from 2011 (78.7%, 2.5 fish/sample) to 2013 (96.5%, 4.2 fish/sample). Most red drum captured in this study were tagged and released.

NCWRC's survey data includes only data for striped bass. Information on other species can be found in NCWRC's annual survey report for the Cape Fear River.

Striped Bass

A total of 1,360 striped bass was caught during the study and 1,094 were tagged (Table 5). The fish ranged in size from 108 mm fork length (FL) to 806 mm FL (Table 6). Both NCDMF and NCWRC were recommended to tag fish greater than 250 mm TL (232 mm FL) due to potential differences in natural mortality. Each agency did tag four striped bass under the recommended tagging size.

The size distribution of tagged fish was very different for fish caught around Wilmington by NCDMF, CFRWSBI, and the recreational fisherman compared to fish caught near the spawning ground by the NCWRC fish (Figure 2). The average size of fish was 500 mm FL for fish caught by NCDMF with a maximum size of 806 mm FL, 492 mm FL for fish caught by CFRWSBI with a maximum size of 774 mm FL, and 491 mm FL for fish caught by a recreational fisherman with a maximum size of 765 mm FL (Table 6). There were two modal sizes for the fish caught around Wilmington in the winter (January through April). One peak ranged from 350 mm FL to 370 mm FL and a second peak at 490 mm FL to 510 mm FL (Figure 2). After the second peak, the percent of fish by category decreased in size gradually.

Striped bass caught on the spawning grounds by NCWRC averaged 529 mm FL with a maximum size of 717 mm FL (Table 6). The percent of fish less than 475 mm FL was much less on the spawning grounds compared to Wilmington tagging (Figure 2). The modal range was from 490 mm FL to 650 mm FL. There were few fish greater than 650 mm FL (8.8%) compared to striped bass caught around Wilmington (12.0%).

Trends in Striped Bass Abundance

The model with the lowest AIC was a two-stage zero-inflated negative binomial model that included salinity and tide as the predictor for the probability of zero and predictors for the catch data year, conductivity, river section, salinity, and temperature. The two parameters for predicting the probability of zero, salinity and tide, can be correlated on a given day but over

several samples the model was able to predict the influence of the two parameters. The median of the probability of zero striped bass was higher on a rising tide (11.4%) compared to a falling tide (1.6%). The probability of catching zero striped bass increased with increasing salinity (Figure 3).

The estimate of catch depended on several variables including: year, sample location, conductivity, salinity, and temperature. The catch of striped bass (number of fish/sample) was estimated to be increasing from 2011 to 2013 (Figure 4). Catch was estimated to be highest in the Northeast Cape Fear followed by the Cape Fear around Wilmington and Brunswick River. Conductivity and temperature had a positive effect on catch rates (Figure 5). Salinity had a slightly negative effect on catch rates.

Recaptures

There were 65 striped bass recaptured (5.9%) that were tagged during the study (Table 7). Fish were at large from 0 to 721 days (Table 8). Fish that were out from 0 to 123 days were recaptured within the same year. Fish that were recaptured from 264 to 486 days were recaptured in the subsequent sampling year. Fish recaptured after 600 days were tagged in the first sampling year and recaptured in the last sampling year.

Fish were recaptured in all sampling areas (NECFR, CFR, Brunswick River, and Spawning Grounds). Only one fish was recaptured outside of the Cape Fear River and recaptured in New York (Winslow 2010). The largest majority of recaptured fish (89%) were tagged around Wilmington (Table 9). This was also where a majority of the tagging occurred (81%). Interestingly, only three striped bass that were tagged on the spawning grounds have been recaptured outside of the original tagging season.

The average growth varied by time at large (Figure 6) and size (Figure 7). In general, the fish that were recaptured within the first 150 days had very little growth. Fish that were recaptured after 250 days had a change in length ranging from -8 mm to 163 mm FL. Growth was also correlated with the length of fish at tagging. The smallest fish typically grew more than the largest fish. The largest fish recaptured in the study was reported to have decreased 3 mm in length after being out for almost one year (356 days). Striped bass that were released at similar sizes grew at similar growth rates (mm/day) regardless of the number of days at large (Figure 8).

Mortality and Population Estimate

A total of 1,094 tagged individuals and 61 recaptured individuals (some fish were recaptured more than once) were included in the model to estimate mortality and population size. The upper credible interval of the Gelman and Rubin statistic was 1.05 or less for each model parameter, indicating that model convergence was reached. An annual Z of 0.24 (95% CI: 0.02−0.59) was estimated by the multistate model, and no movement probabilities within anytime period were significantly different, indicating that the data used to fit the model were too sparse to estimate movement probabilities with sufficient confidence. Annual abundance estimates were not significantly different, and median annual abundance was 15,209 (Figure 10). Capture probabilities ranged from 0.03 to 0.01 among the three spatial strata and three annual time intervals.

DISCUSSION

The striped bass population appears to be improving based on the percent of fish greater than the size of 50% maturity (475 mm FL), presence of large females greater than 28 inches TL, and increasing trend in striped bass catches observed in the study. Most of the tagged fish were larger than the size where 50% of striped bass are mature around Wilmington (59%) and near the spawning grounds (76%). Additionally, the number of striped bass greater than 28 inches TL (125 fish total, 11% of the tagged fish) was encouraging. Both of these values indicate there should be a growing spawning stock biomass in the Cape Fear River system.

However, most of the striped bass greater than 28 inches TL were caught around Wilmington (n=107) and not on the spawning grounds. There were only 18 striped bass greater than 28 inches TL observed on the spawning grounds over the three years of the study. It is not known if the large fish use the Cape Fear River spawning grounds, if they are missed in the spawning area survey, or if they use other tributaries of the Cape Fear River for spawning. More research is needed to determine where the largest, potentially best spawners are migrating. Telemetry data are being gathered to help answer this question.

The zero-inflated generalized regression models indicated that the catch of striped bass in the electrofishing survey around Wilmington was influenced by several variables but also included an excessive amount of zero catches. The percent of zero catches was influenced by salinity and tidal stage. The electrofishing gear is typically less efficient at higher salinities. Electrical current typically follows the path of least resistance and completely bypasses the fish when the dissolved salts and minerals in the water is more than that of the fish (Smith-Root, Inc. 2007). Tidal stage may also influence the distribution of striped bass as they prey on bait fish emptying from creeks on falling tides and indirectly as salinity gradients shift with the ebb and flow of water within the estuary.

Most of the zero-inflated generalized regression models for estimating positive catch included year as a significant factor and indicated a positive trend in abundance. The catch of striped bass was also influenced by the area of the river sampled, water temperature, salinity, and conductivity. The highest abundance of striped bass was observed on the Northeast Cape Fear River sampling stations. The main stem of the Cape Fear River tended to have fewer areas where the electrofishing gear was effective due to depth and salinity. It appeared the striped bass were in deeper water when temperatures were less than 10°C. As the water warmed in the spring, striped bass used shallow water to warm and forage. Salinity and conductivity impacted the electrofishing gear efficiency as described above and both restricted the areas and time when the electrofishing could be conducted. If the appropriate conditions were met for salinity and conductivity, then sampling was initiated to survey striped bass.

This two-stage model was important for estimating trends in abundance because factors other than year had a significant impact in estimating trends in catch. The predicted trends in abundance over time from the model were also observed by recreational fishermen (personal communication). However, the increasing trend in the catch model was not observed in the abundance estimate from the Jolly-Seber model. There was no significant difference among years in the abundance estimate (15,209 striped bass greater than 250 mm TL). As more mark-recapture data are gathered, a more precise abundance estimated may be developed.

An estimate of total mortality (*Z*=0.24) was also derived from the mark-recapture model. The total mortality observed on the Cape Fear River was slightly higher than the natural mortality (*M*=0.2) used in the most recent stock assessment for striped bass (NCDMF and NCWRC 2011). There was likely some fishing mortality induced by recreational catch and release fishing as well as bycatch in commercial fishing gear. The overall fishing mortality for Cape Fear River striped bass was expected to be low due to the harvest moratorium.

Due to the low population size of striped bass little information has been gathered on the basic life history characteristics for Cape Fear River striped bass. The average maximum predicted size of striped bass based on von Bertalanffy growth curve was over 1,000 mm in the Roanoke River stock (Boyd 2011). The largest striped bass observed in this study (806 mm TL) was much smaller than the predicted maximum size and could be a result of habitat availability, environmental conditions (Brandt and Kirsh 1993), or a truncated size structure. The growth of Cape Fear River striped bass may asymptote at a smaller length than other populations based on the growth of fish greater than 600 mm FL (26 inches) being slower than for striped bass less than 600 mm FL (Figure 7). Brandt and Kirsch (1993) noted that fish growth integrates both natural variability and anthropogenic causes of ecosystem change, not only influencing the overall health of an ecosystem but a fish's maximum growth potential and ultimate survival. Further research is needed to determine how growth rate influences the reproductive potential of striped bass in the Cape Fear River system.

Growth rate and size also have an influence on the migratory patterns of striped bass (Dorazio et al. 1994; Secor and Piccoli 2007). Past studies of migration have reported minimal emigration from the Cape Fear River system and the stock appeared to be isolated (Winslow 2010; Smith and Hightower 2012). However there were few fish tagged greater than 28 inches TL, which is the size at which oceanic migration has been observed in other systems (Dorazio et al. 1994). Wingate et al. (2011) noted that striped bass showed varying degrees of residency in natal estuaries and exhibited diverse seasonal migration patterns. In the Chesapeake Bay, Secor and Piccoli (2007) noted that a substantial portion of striped bass remained residents of estuarine habitats throughout their lives regardless of age or size. At the low population size currently in the Cape Fear River, estuarine residency seems to be the most common pattern for striped bass in the Cape Fear River (Smith and Hightower 2012); however, a longer time series is needed to determine if there is a gradual shift to ocean habitats as the population increases and more larger fish are present in the population. Additionally, the large females produce more and larger eggs than smaller striped bass (Montelone and Houde 1990) which should enable the stock to rebound more quickly. The lack of larger females on the spawning grounds may further explain the low egg production observed by Dial Cordy and Associates, Inc. (2006) and Smith (2009). As more fish are tagged and recaptured using a combination of traditional and acoustic tags, we will develop a better understanding of striped bass migration patterns in and out of the Cape Fear River and how the management measures may affect migration patterns and reproductive potential.

Based on the preliminary findings of this study, the management measures taken since 2007 have been successful at increasing the abundance of striped bass in the Cape Fear. Additional research will continue in the Cape Fear River to address hook and line mortality, estimate population abundance and trends using conventional tagging, and track individuals to determine the efficacy of the new rock arch ramp with acoustic tags. Future work should determine if the increase in mature adults is increasing the juvenile production compared to previous research conducted on the Cape Fear River when population levels were at low levels (Dial Cordy and Associates, Inc. 2006; Smith 2009) and if the new rock arch ramp at Lock and Dam #1 is

enabling better passage to historic spawning grounds than traditional locking methods. Additional work should be expanded to the Black and Northeast Cape Fear rivers to determine if population trends in those river systems mirror that of the mainstem of the Cape Fear River.

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Table 1. Prior distributions of all parameter estimates used in the Jolly-Seber tag return model.

Parameter	Distribution	Prior
$r_{s,t}$ (capture probability)	beta	(1,1)
Z_t(instantaneous mortality rate)	uniform	(0.05,10)
$\psi_{r,s,t}$ (movement probability)	beta	(1,1)

Table 2 Number of samples by year, month, and river area collected during electrofishing surveys in the Cape Fear River system targeting striped bass. NECFR= Northeast Cape Fear River. Downtown CFR=Cape Fear River from the confluence of the Cape Fear and Northeast Cape Fear River upstream to Sutton Power Plant. Spawning grounds CFR= Cape Fear River from just downstream of Lock and Dam #1 to Lock and Dam #3.

Year	Month	Brunswick River	NECFR	Downtown CFR	Spawning Grounds CFR	Total
2011	Jan	1	2			3
	Feb	10	6	28		44
	Mar	8	23	52	5	88
	Apr	2	7	11	8	28
	May				11	11
	Jun				2	2
	Dec	3	6	10		19
2012	Jan	3	14	20		37
	Feb		21	3		24
	Mar		22	11		33
	Apr		8	9	4	21
	May				11	11
	Dec		2			2
2013	Jan	4	19	12		35
	Feb		23	13		36
	Mar	4	16	10	3	33
	Apr		6	6	3	15
	May			1	8	9
Total		35	175	186	55	451

Table 3. Environmental data collected by month and area sampled during the striped bass tagging events from January 2011 to May 2013. NECFR=Northeast Cape Fear River. Downtown CFR=Cape Fear River from the confluence of the Cape Fear and Northeast Cape Fear River upstream to Sutton Power Plant. Spawning grounds CFR= Cape Fear River from just downstream of Lock and Dam #1 to Lock and Dam #3.

		Salinity (PPT)			Temperature (C)			Dissolved Oxygen (mg/L)		
Area	Mon-Yr	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Brunswick River	Jan-11									
	Feb-11	0.2	0.1	0.4	11.4	9.5	12.9	9.3	9.0	9.8
	Mar-11	1.9	0.3	2.8	15.0	14.2	15.7	7.5	6.3	8.3
	Apr-11	0.1	0.1	0.1	15.2	14.8	15.6	7.6	7.6	7.6
	Dec-11									
	Jan-12	5.7	4.4	7.1	10.3	9.5	10.9	10.1	9.3	10.7
	Jan-13									
	Mar-13	0.3	0.2	0.3	14.9	14.0	15.7	7.3	5.8	8.8
NECFR	Jan-11									
	Feb-11	0.1	0.1	0.1	7.9	7.7	8.1	8.6	8.0	9.3
	Mar-11	1.0	0.2	2.5	15.7	13.7	17.7	7.5	6.5	8.3
	Apr-11	1.6	0.1	5.2	17.2	12.4	23.6	7.9	6.6	9.3
	Dec-11	1.3	1.3	1.3	14.4	14.4	14.4	7.5	7.5	7.5
	Jan-12									
	Feb-12	0.9	0.1	2.1	12.9	10.8	14.6	9.3	7.2	10.6
	Mar-12	0.5	0.1	1.7	16.4	14.3	20.4	6.7	3.2	7.8
	Apr-12	0.9	0.1	2.1	18.1	17.1	18.9	6.4	5.4	8.6
	Dec-12	0.6	0.6	0.6	12.7	12.7	12.7	8.2	8.2	8.2
	Jan-13	0.5	0.1	1.2	9.5	7.4	12.1	8.9	6.5	10.1
	Feb-13	0.4	0.1	2.1	10.8	9.5	12.8	9.1	7.7	10.1
	Mar-13	0.2	0.1	1.0	11.6	8.2	15.1	8.7	7.3	10.4
	Apr-13	0.3	0.1	1.0	15.6	13.9	20.0	7.2	3.5	8.6

Table 3 (cont.)

Area	Mon-Yr	Salinity (PPT) Mean	Min	Max	Temperature (C) Mean	Min	Max	Dissolved Oxygen (mg/L) Mean	Min	Max
Downtown CFR	Feb-11	0.2	0.1	1.0	9.9	7.1	15.3	9.1	7.5	10.1
	Mar-11	1.2	0.1	5.1	14.7	6.2	17.2	7.6	6.1	9.1
	Apr-11	0.5	0.1	3.0	17.1	11.4	23.1	7.7	6.5	9.6
	Dec-11	.	.	.	.	.	.	.	.	.
	Jan-12	10.3	7.1	13.1	11.6	11.0	12.5	10.1	8.5	11.2
	Feb-12	.	.	.	.	.	.	.	.	.
	Mar-12	0.3	0.1	0.7	16.6	13.4	20.1	8.1	6.6	9.7
	Apr-12	0.2	0.1	0.7	18.7	17.9	20.1	5.6	5.1	6.0
	Jan-13	0.1	0.1	0.2	9.1	8.3	10.2	10.6	10.3	11.4
	Feb-13	0.1	0.1	0.2	9.8	8.7	11.4	10.7	8.2	12.4
	Mar-13	0.1	0.1	0.1	10.4	8.6	13.5	9.7	7.3	10.8
	Apr-13	0.1	0.1	0.1	19.2	19.0	19.4	4.2	2.1	6.2
	May-13	.	.	.	.	.	.	.	.	.
Spawning Grounds CFR	Mar-11	0.1	0.1	0.1	14.2	13.0	15.8	8.7	8.3	9.0
	Apr-11	0.1	0.1	0.1	18.2	15.0	21.2	7.2	6.2	7.7
	May-11	0.1	0.1	0.1	22.8	21.5	24.7	6.2	5.4	7.1
	Jun-11	0.1	0.1	0.1	27.5	27.4	27.5	6.1	6.0	6.2
	Apr-12	0.1	0.1	0.1	19.1	17.8	19.8	6.2	5.7	6.6
	May-12	0.1	0.1	0.1	22.8	20.2	26.1	7.6	4.6	10.7
	Mar-13	0.1	0.1	0.1	12.1	11.1	12.8	13.8	8.8	16.4
	Apr-13	0.1	0.1	0.1	17.1	12.6	19.9	6.5	5.7	7.9
	May-13	0.1	0.1	0.1	20.5	16.7	24.0	5.5	4.3	6.2

Table 3 (cont.)

		Salinity (PPT)			Temperature (C)			Dissolved Oxygen (mg/L)		
Area	Mon-Yr	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Overall	Jan-11	.	.	.	.	.	.	.	.	.
	Feb-11	0.2	0.1	1.0	10.0	7.1	15.3	9.1	7.5	10.1
	Mar-11	1.1	0.1	5.1	14.9	6.2	17.7	7.7	6.1	9.1
	Apr-11	0.6	0.1	5.2	17.4	11.4	23.6	7.6	6.2	9.6
	May-11	0.1	0.1	0.1	22.8	21.5	24.7	6.2	5.4	7.1
	Jun-11	0.1	0.1	0.1	27.5	27.4	27.5	6.1	6.0	6.2
	Dec-11	1.3	1.3	1.3	14.4	14.4	14.4	7.5	7.5	7.5
	Jan-12	8.0	4.4	13.1	10.9	9.5	12.5	10.1	8.5	11.2

Table 4. Yearly species composition observed in the NCDMF electrofishing survey and percent occurrence (% Occur) based on total number of yearly samples.

		2011		2012		2013	
Species	Common Name	Total Number	% Occur	Total Number	% Occur	Total Number	% Occur
Lepisosteus osseus	longnose gar	8	3.6%	65	7.1%	100	10.5%
Amia calva	bowfin	19	4.7%	1	0.9%	13	5.3%
Anguilla rostrata	American eel	3	1.2%	25	10.6%	9	7.0%
Clupeidae	herrings			1	0.9%		
Alosa sapidissima	American shad	1	0.6%			2	1.8%
Alosa aestivalis	blueback herring	4	1.8%	1	0.9%	2	0.9%
Clupea harengus	Atlantic herring			1	0.9%		
Alosa mediocris	hickory shad	6	3.0%				
Brevoortia tyrannus	Atlantic menhaden	16	4.7%	1	0.9%		
Dorosoma cepedianum	gizzard shad	171	7.7%	2	1.8%	172	14.9%
Dorosoma petenense	threadfin shad					1	0.9%
Cyprinus carpio	common carp	8	4.7%	4	2.7%	18	7.0%
Notemigonius crysoleucas	golden shiner	2	0.6%			1	0.9%
Ctenopharyngodon idella	grass carp	1	0.6%			1	0.9%
Ameiurus catus	white catfish					1	0.9%
Ictalurus furcatus	blue catfish	59	15.4%	122	29.2%	153	42.1%
Ictalurus punctatus	channel catfish	1	0.6%	6	3.5%	10	5.3%
Pylodictis olivaris	flathead catfish	1	0.6%	1	0.9%	7	4.4%
Belonidae	needlefishes	1	0.6%				
Morone americana	white perch	3	1.8%	2	1.8%	2	1.8%
Morone saxatilis	striped bass	429	78.7%	451	86.7%	480	96.5%
Centrarchidae	sunfishes			8	0.9%		
Lepomis auritus	redbreast sunfish	2	1.2%			2	1.8%
Lepomis macrochirus	bluegill	42	12.4%	5	2.7%	4	3.5%
Lepomis gibbosus	pumpkinseed	1	0.6%	1	0.9%		
Lepomis microlophus	redear sunfish	5	3.0%	2	1.8%	1	0.9%
Micropterus salmoides	largemouth bass	111	11.2%	31	6.2%	46	15.8%
Archosargus probatocephalus	sheepshead			2	1.8%	18	6.1%
Bairdiella chrysoura	silver perch			5	0.9%		
Cynoscion nebulosus	spotted seatrout					1	0.9%
Leiostomus xanthurus	spot	60	10.7%	42	5.3%	2	1.8%
Pogonias cromis	black drum			3	1.8%		
Sciaenops ocellatus	red drum	1	0.6%	45	19.5%	177	27.2%
Mugil cephalus	striped mullet	767	55.0%	440	38.9%	636	55.3%
Mugil curema	white mullet			1	0.9%		
Paralichthys albigutta	gulf flounder	1	0.6%				
Paralichthys lethostigma	southern flounder	4	1.8%	19	9.7%	3	2.6%
Trinectes maculatus	hogchoker	1	0.6%				

Table 5. Yearly tagging totals for striped bass tagged by agency. NCDMF= North Carolina Division of Marine Fisheries, NCWRC= North Carolina Wildlife Resources Commission, CFRWSBI= Cape Fear River Watch Striped Bass Invitational, and Rec=Recreational fisherman.

Tagging Agency	2011	2012	2013	Total
NCDMF	175	246	314	735
NCWRC	68	84	52	204
CFRWSBI	16	30	38	84
Rec	20	34	17	71
Total	279	394	421	1,094

Table 6. Average, minimum, and maximum fork length (FL) of striped bass tagged in the tagging program.

Tagging Agency	Average	Minimum	Maximum
NCDMF	500	201	806
NCWRC	529	108	717
CFRWSBI	492	308	774
Rec	491	332	765

Table 7. Yearly recapture totals for striped bass tagged by agency. NCDMF= North Carolina Division of Marine Fisheries, NCWRC= North Carolina Wildlife Resources Commission, CFRWSBI= Cape Fear River Watch Striped Bass Invitational, and Rec=Recreational fisherman.

Recapturing Agency	2011	2012	2013	Total
NCDMF	19	19	12	50
NCWRC	3	4		7
CFRWSBI	2	1	1	4
Rec	2	2		4
Total	26	26	13	65

Table 8. Days at large for striped bass tagged during the survey.

Days Out	Number of Recaptures
0-25	12
26-50	8
51-100	6
101-200	1
201-300	5
301-400	23
401-500	4
501-600	0
601-700	4
>700	2

Table 9. Location of original tagging event and recapture location by year.

			Recapture Year and Location						
			2011		2012		2013		
Tagging Year	Number Tagged	Tagging Location	Wilmington	Spawning Grounds	Wilmington	Spawning Grounds	Wilmington	Spawning Grounds	Total Recaptured
2011	211	Wilmington	4	2	8	1	8		23
	68	Spawning Grounds		1		1	1		3
2012	310	Wilmington			2	3	16	1	22
	84	Spawning Grounds				3		1	4
2013	369	Wilmington					10	3	13
	52	Spawning Grounds							0

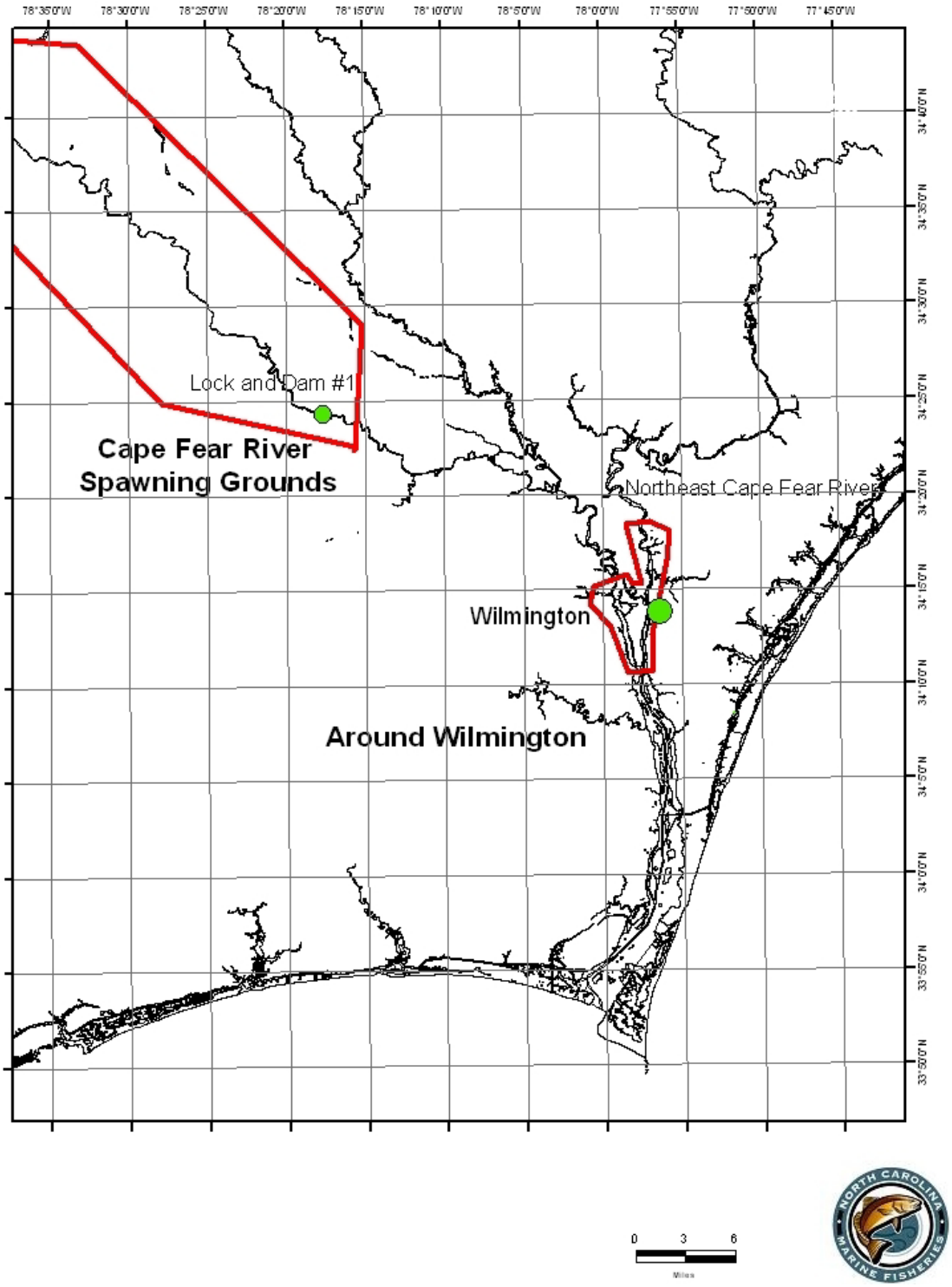


Figure 1. Map of the sampling areas.

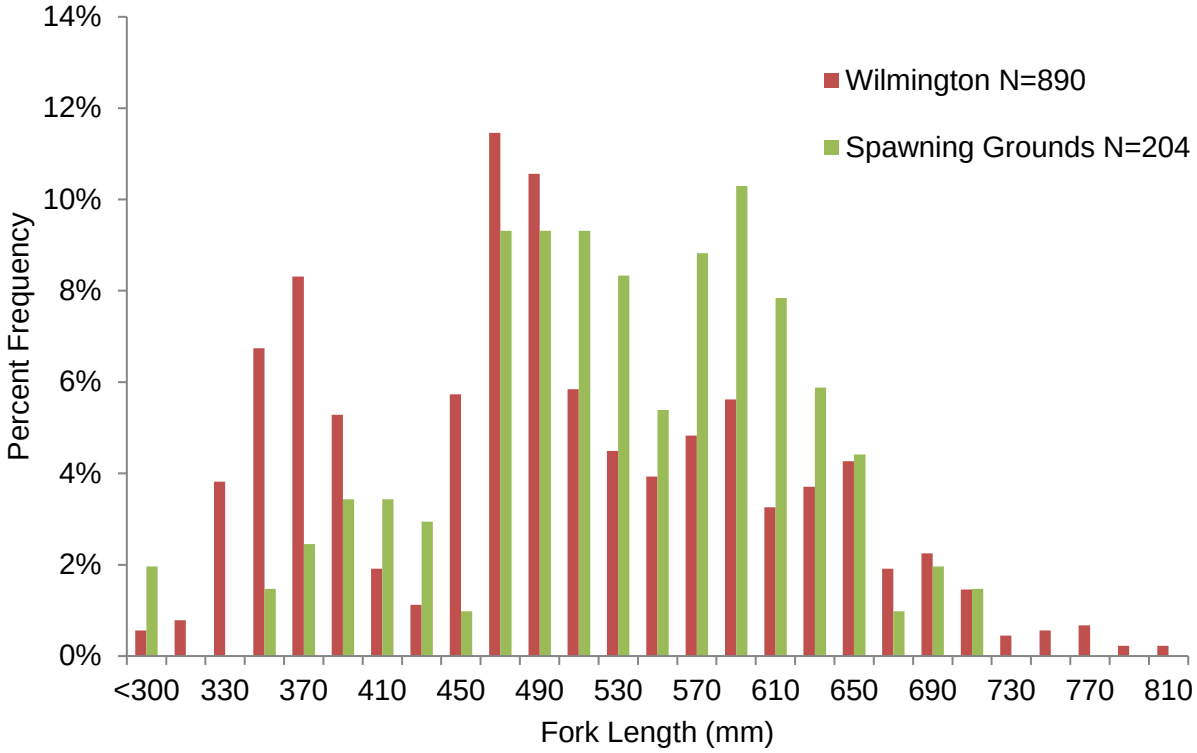
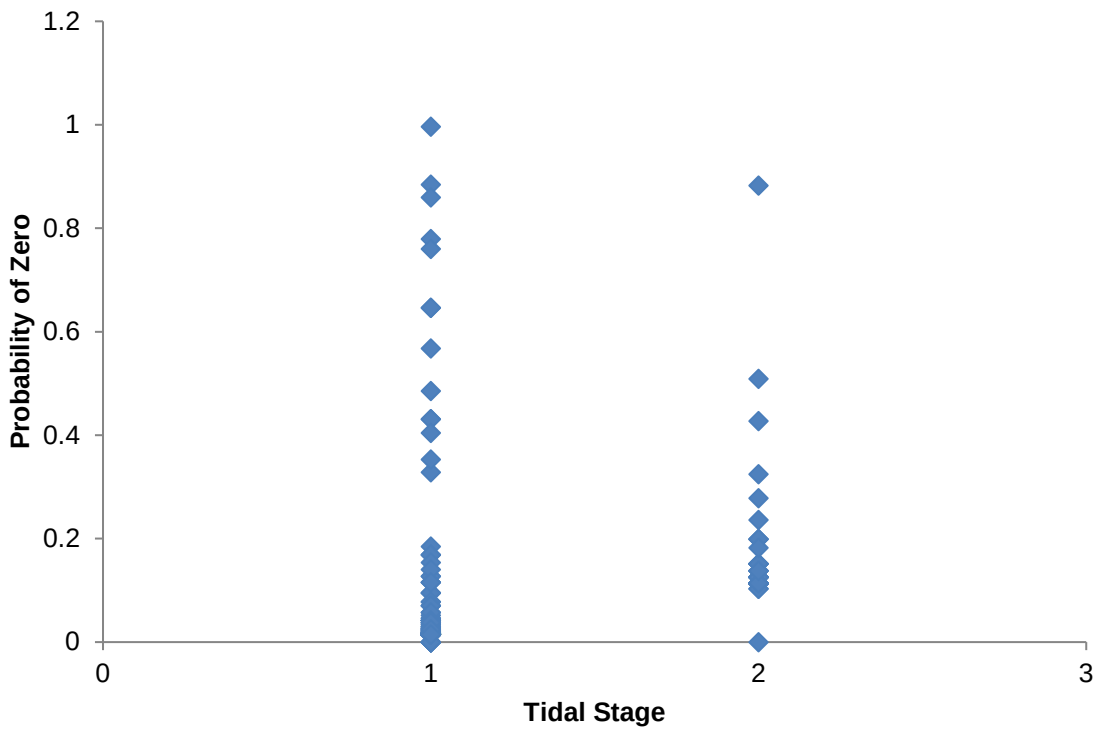


Figure 2. Length frequency distribution of fish tagged around Wilmington and on the spawning grounds of the Cape Fear River. Fish are grouped into 20 mm bins with midpoints on the graph.



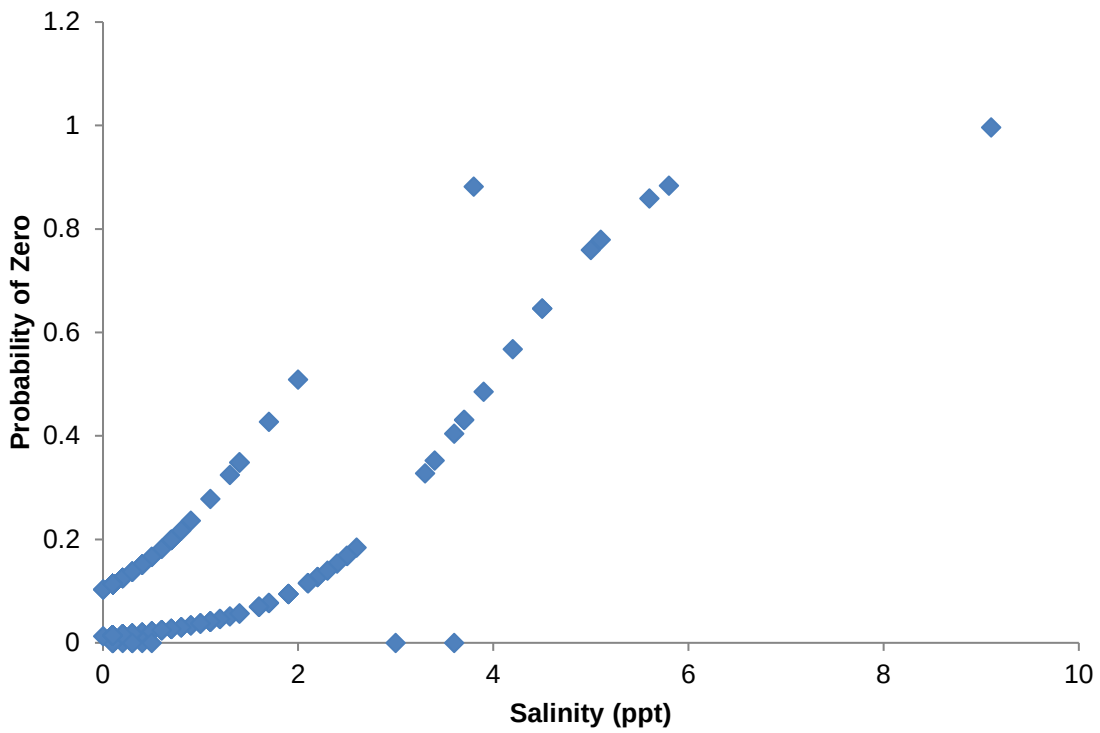
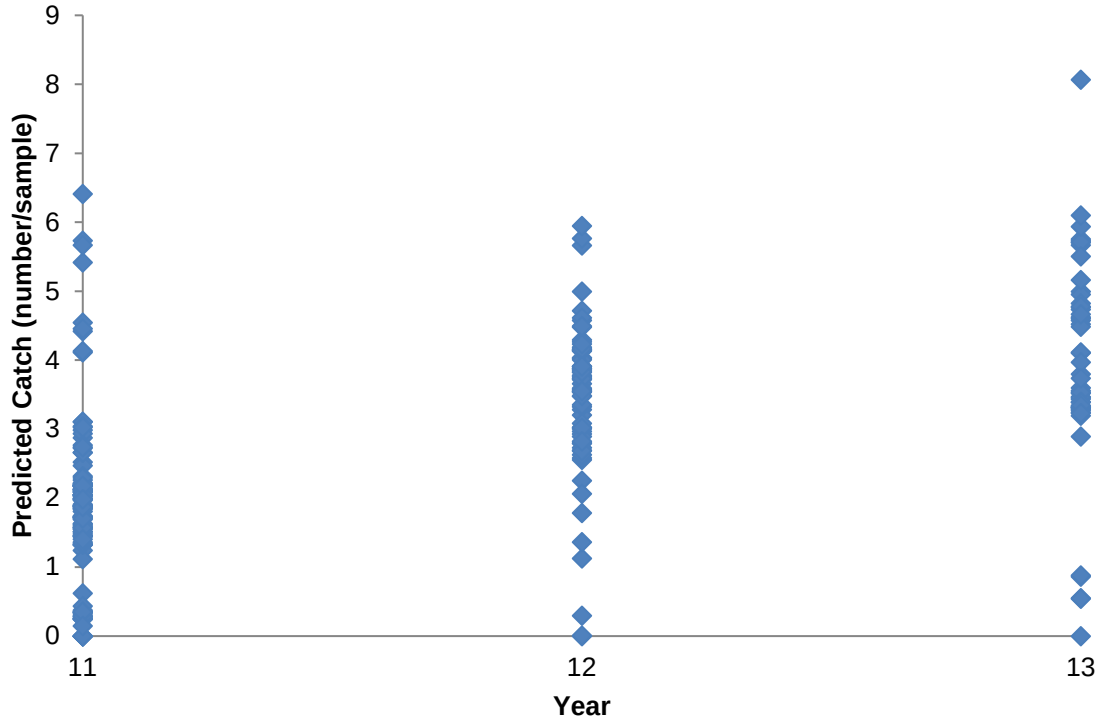


Figure 3. Probability of catching zero striped bass due to tidal stage (1= falling and 2= rising) and salinity (parts per thousand) estimated with the preferred model based on the lowest AIC value.



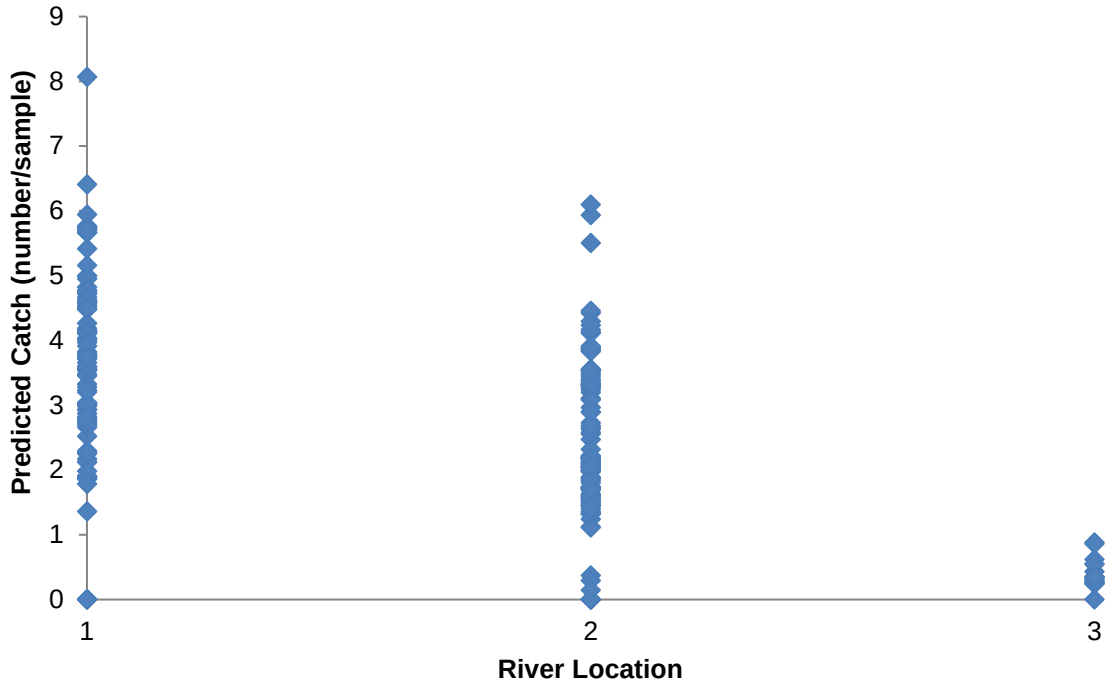


Figure 4. Year and river location, categorical variables, included in the model to predict catch (number/sample) of striped bass using a two stage zero inflated negative binomial model. 1= Northeast Cape Fear River, 2= Cape Fear River, 3= Brunswick River.

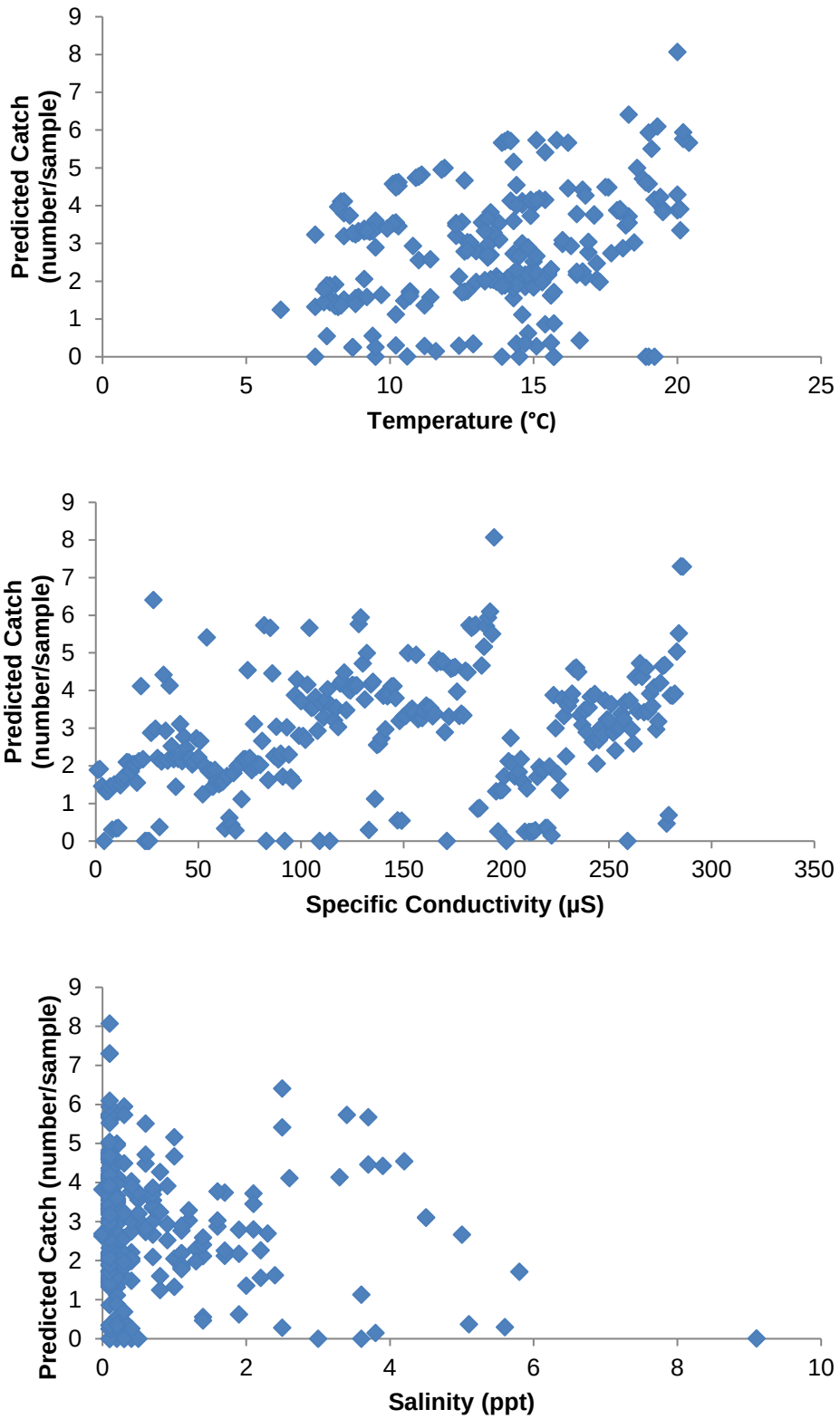


Figure 5. Temperature (°C), specific conductivity (µS), and salinity (ppt), continuous variables, included in the model to predict catch (number/sample) of striped bass using a two stage zero inflated negative binomial model.

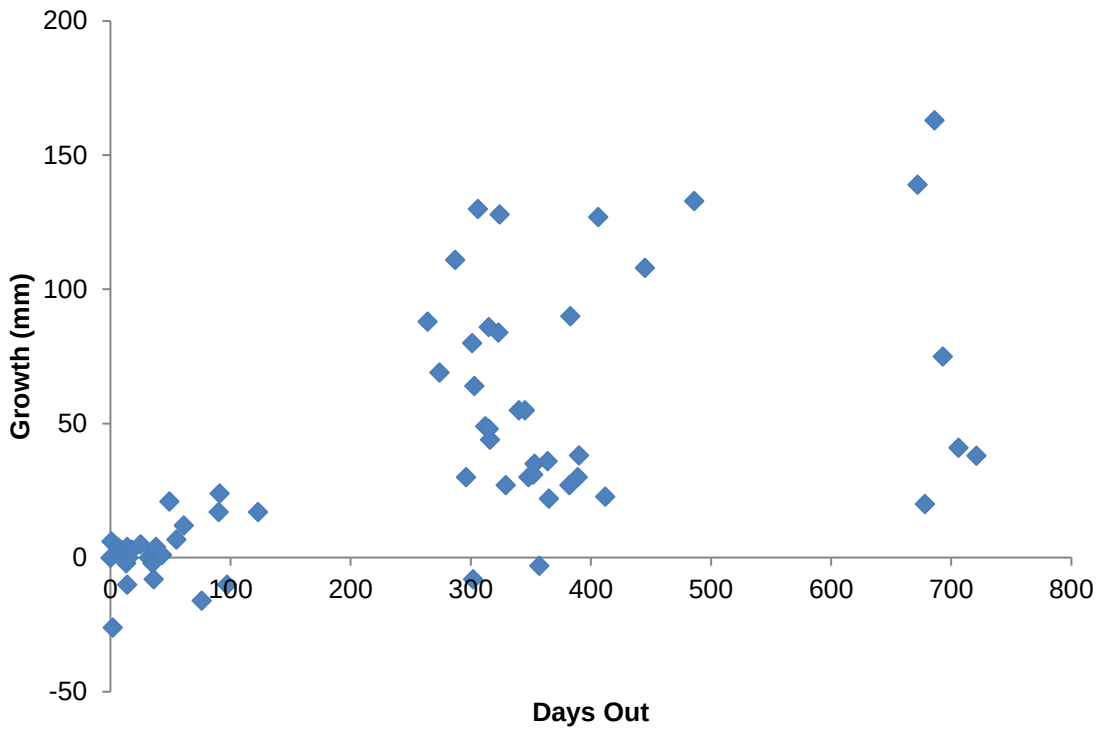


Figure 6. Growth of striped bass plotted with number of days out before recapture.

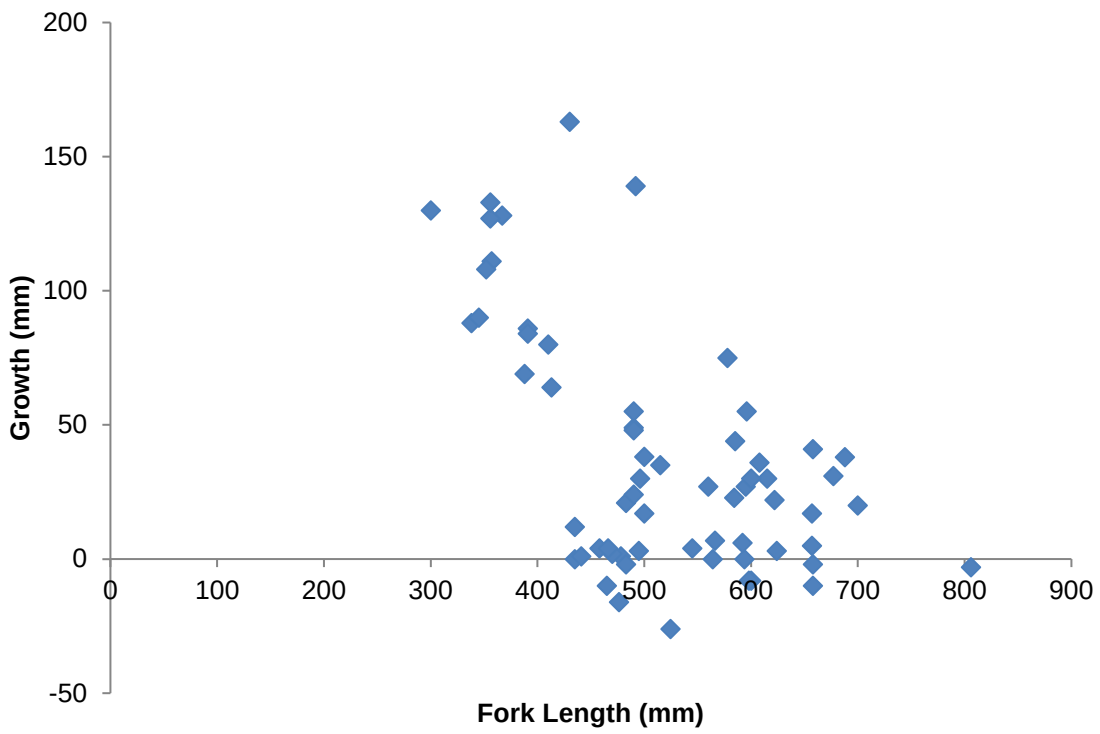


Figure 7. Growth of striped bass plotted with fork length at original tagging event.

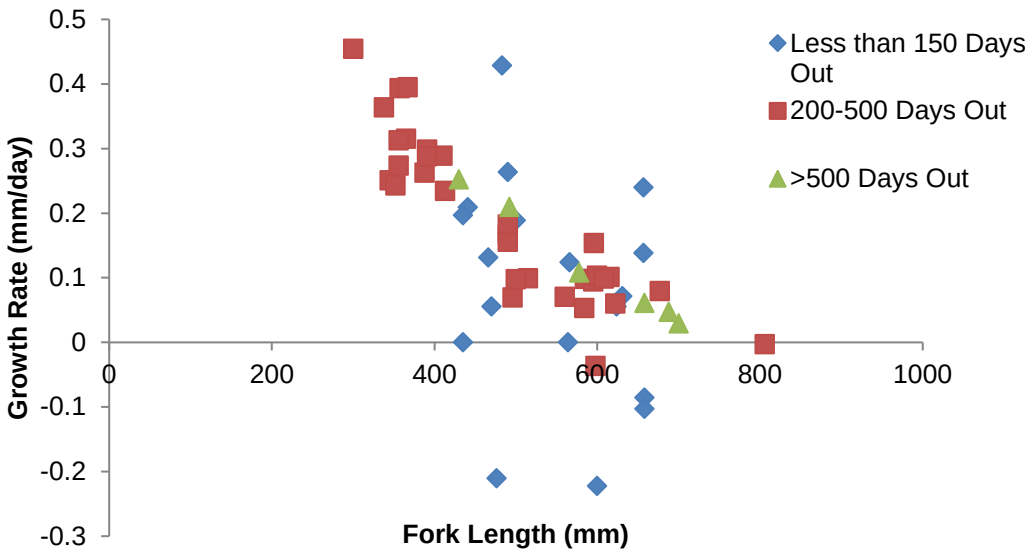


Figure 8. Growth rate (mm/day) of striped bass plotted over fork length at tagging grouped based on number of days released. Fish that were out less than 20 days were not included.

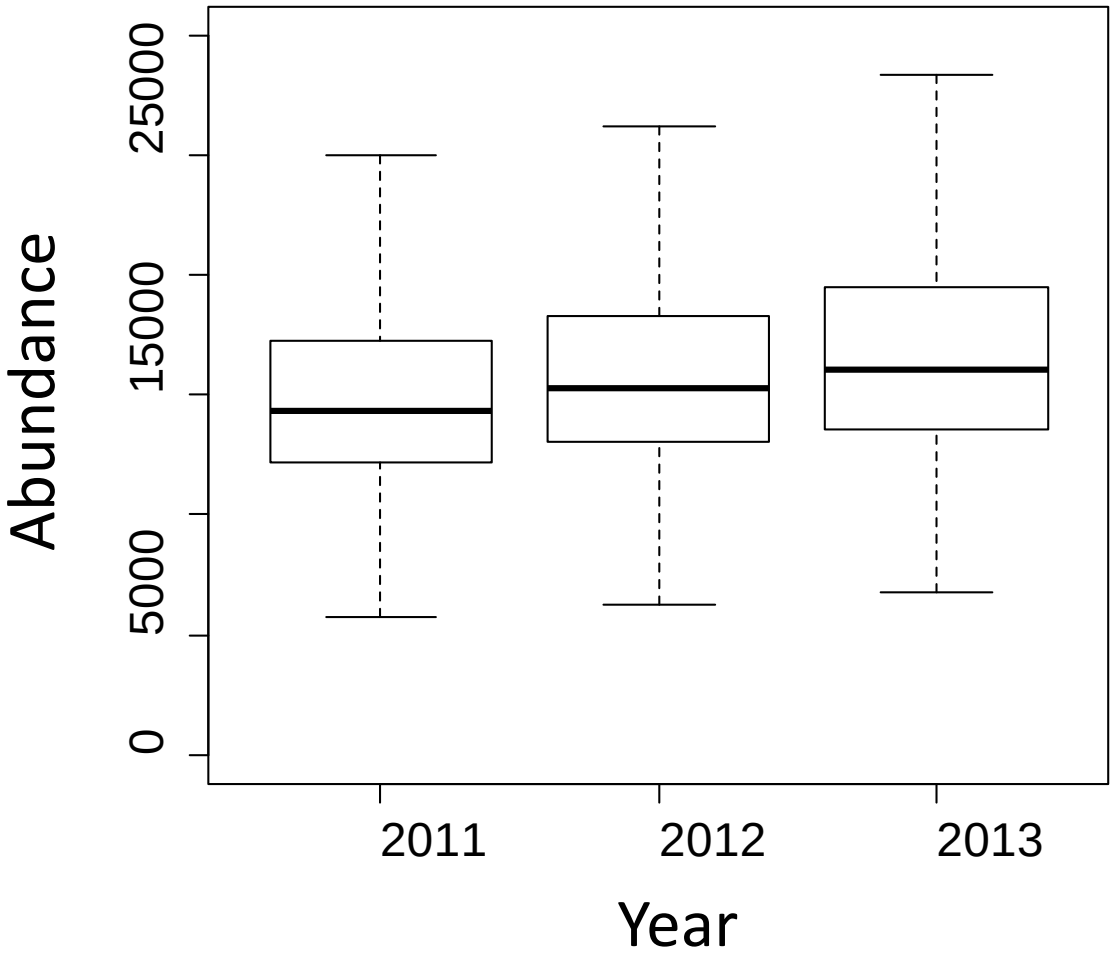


Figure 9. Posterior distributions of annual abundance estimated using a Jolly-Seber model and capture probabilities estimated by the multistate model. The whiskers of the boxplots indicate 95% credible intervals of the estimates; boxes of the boxplots represent 50% credible intervals, and the bolded lines of each boxplot represent abundance estimates.