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A simulation-based evaluation of commercial port sampling programs for the Gulf and Atlantic Menhaden fisheries

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Running head: Menhaden Port Sampling Evaluation

[A]Abstract

Biological data collected in commercial port sampling programs are a critical component of the assessment and management of Gulf Menhaden *Brevoortia patronus* and Atlantic Menhaden *Brevoortia tyrannus*. The menhaden port sampling program represents one of the longest, continuous commercial sampling efforts in the U.S; however, this sampling program has not been evaluated recently to determine if the program adequately characterizes size and age structure of the catch despite significant changes in the spatial extent and magnitude of the fisheries in the last three decades. We conducted a simulation study to evaluate current menhaden fishery sampling targets and to examine relative performance of a suite of alternative targets. To simulate data collection, we conducted a bootstrap analysis of the observed port sampling data. These observations were resampled with replacement across a range of current and alternative combinations of number of trips and fish sampled per trip. At current target sampling intensity and allocation, the mean sample weight and proportions at age for ages 2-3 are well characterized in both the Gulf and Atlantic Menhaden fisheries. Proportions of age-1 fish in the catch differed by stock and region with samples from the northern Atlantic regions displaying the greatest uncertainty overall. Proportions of age-4 and older fish were poorly characterized in both fisheries likely due to their rarity in the population (Gulf) and lack of spatial overlap between the fishery and the stratified distribution of menhaden by age along the coast (Atlantic). Our results indicate that reducing the number of fish sampled per trip from the current target of 10 to as few as 4 would have minimal impact on estimates of mean size and proportions at age in the catch. Increasing the number of trips sampled will not greatly improve characterization of catch size or age composition. [A]Introduction

The goal of commercial port sampling programs is to collect life history information that can be used to characterize the catch (e.g., age and size composition) for use in stock assessment and management (Cotter and Pilling 2007; Thorson and Haltuch 2018). Individual fish weight is often collected from a subset of the catch to enable conversion of landings in biomass (t) to numbers of fish landed. In addition, fishery-dependent age and length composition data can provide information about year class strength and age- or size-specific fishing pressure that allows for the estimation of selectivity and fishing mortality by age or length, gear, and sector (Quinn and Deriso 1999).

Biological data collected in commercial port sampling programs are a critical component of the assessment of menhaden, which represent the second largest component of U.S. wild capture commercial fisheries by weight with total annual landings of more than 1.4 billion pounds in 2017 (National Marine Fisheries Service 2018). Regionally, the Gulf Menhaden *Brevoortia patronus* stock supports the largest commercial fishery in the Gulf of Mexico, and the Atlantic Menhaden *Brevoortia tyrannus* stock supports the largest commercial fishery on the

East Coast of the U.S. (National Marine Fisheries Service 2018). Each fishery is composed of a purse seine reduction sector and a mixed-gear bait sector. In the Gulf of Mexico, the reduction sector accounts for the majority (approximately 99%) of landings (SEDAR 2018). In contrast, the bait sector comprises a larger and increasing portion of the Atlantic Menhaden fishery on the East Coast, accounting for approximately 24% of coastwide landings in recent years (ASMFC 2017).

The port sampling programs for Atlantic and Gulf Menhaden represent two of the longest, continuous commercial data collection efforts in the U.S. (Smith 1991; Smith et al. 1987). The reduction fishery port sampling program began in 1955 for Atlantic Menhaden and in 1964 for Gulf Menhaden; both programs are conducted by the National Marine Fisheries Service Beaufort Laboratory (ASMFC 2017; SEDAR 2018). Port sampling of menhaden catch is conducted throughout the fishing season and across all ports of landing to account for seasonal growth (i.e. length-at-age) and migration patterns. A two-stage cluster sampling scheme is employed in which the primary sampling unit is the last set of each fishing trip intercepted (hereafter, "trip") and the secondary sampling unit is the individual fish (Chester 1984; June and Reintjes 1959). Agents randomly select vessels dockside and retrieve a bucket of fish from the top of the hold (SEDAR 2015). A subset of fish is then selected by the agent at random from the bucket. Each fish is measured (fork length in mm), weighed (grams), and a collection of scales (n=6 for Atlantic Menhaden, n=10 for Gulf Menhaden) are removed, cleaned, and mounted on a glass microscope slide for ageing (June and Roithmayr 1960; Nicholson and Schaaf 1978).

Sampling targets for the menhaden reduction fishery port sampling program have changed over time as understanding of menhaden biology and ecology has improved. Soon after port sampling of the Atlantic Menhaden reduction fishery began, June and Reintjes (1959) evaluated adequacy of the sampling design. Given menhaden purse seine fisheries operate by surrounding and capturing all or portions of a single school, each set represents samples collected from the same school. June and Reintjes (1959) found that Atlantic Menhaden port samples collected in the same set were shown to be highly homogeneous with regard to both size and age and that variability in length, weight, and age among trips was much greater than within a trip. In the 1980s, the Atlantic Menhaden port sampling program was re-examined (Chester 1984; Chester and Waters 1985), and it was determined that a sample size of 20 fish per trip provided adequate precision of the mean length of Atlantic Menhaden in a purse seine set to within ±2%. The sampling target was changed in 1971 from a minimum of 10-15 trips per port every week (hereafter, "port/week") with 20 fish sampled per trip to a new target of 20-25 trips per port/week and 10 fish per trip to better capture the among-trip variance. Chester (1984) conducted an updated analysis of the Atlantic Menhaden port sampling program in the 1980s and suggested that the minimum number of trips sampled should be 10 per port/week to adequately characterize the size and age composition of the catch by port and week. At present, a minimum target of 10-15 trips per port/week and 10 fish per trip has been used on both coasts. However, the reduction fishery port sampling program has not been evaluated in recent decades to determine if the sampling program still adequately characterizes mean size and age structure of the catch despite significant declines in the spatial extent and magnitude of both the Gulf and Atlantic Menhaden reduction fisheries (SEDAR 2015; SEDAR 2018).

Over the history of both Gulf and Atlantic reduction fisheries, achieved sampling effort often differed from target levels. Sampling levels in the Gulf Menhaden fishery increased from an average of 5 trips sampled per port/week at the start of the program to 10 from the 1980s to present (Figure 1). The average number of trips sampled per port/week in the Atlantic Menhaden fishery sometimes exceeded target levels; however, as the number of reduction plants and fleet size declined on the East Coast, sampling declined to minimum target levels (Figure 1). For both Gulf and Atlantic Menhaden, the target number of fish sampled per trip shifted from 20 to 10 in 1971. However, the appropriateness of applying Atlantic Menhaden sampling targets to the Gulf Menhaden fishery has never been evaluated even though Gulf Menhaden typically live only to age 4, while Atlantic Menhaden can live to approximately age 10 (June and Reintjes 1959; SEDAR 2018).

The Atlantic Menhaden bait fishery port sampling program has experienced large changes over time as well. Port sampling for Atlantic Menhaden harvested for bait began in 1985 using 10 fish per trip as a target for sampling individual fish but with no established target for the number of trips per state or gear type (Figure 2; Smith and O'Bier 2011). As the magnitude of the bait fishery increased in the late 2000s, a power analysis was conducted to determine the number of trips that should be sampled across the species' range using the limited number of samples collected to date (McNamee 2012). The results of this analysis were used to set minimum port sampling requirements for each state based on state-specific annual bait landings from 2012 onward (ASMFC 2012). However, adequacy of the new bait fishery port sampling requirements has not been evaluated since the number of trips sampled increased in 2012.

The objectives of our study were to 1) provide a quantitative evaluation of the current commercial port sampling programs' ability to characterize size and age composition of menhaden catch, and 2) examine the relative performance of a suite of potential alternative two-stage sampling targets. Previous studies of the sampling program design were limited to analytical approaches prior to the widespread availability of high speed computing (Chester 1984; Chester and Waters 1985; June and Reintjes 1959). Here, we adopted a simulation-based approach to examine the combined effects of alternative sampling targets for both the number of trips sampled and the number of individual fish sampled per trip in the Gulf Menhaden reduction fishery and the Atlantic Menhaden reduction and bait fisheries.

[A]Methods

We conducted a simulation study to evaluate current menhaden reduction and bait fishery sampling targets and to examine relative performance of a suite of alternatives targets. To simulate port sampling data collection, we conducted a non-parametric bootstrap analysis in which existing data were resampled with replacement across a range of current and alternative sampling schemes (i.e., combinations of number of trips and fish sampled). This approach allowed us to account for both random sampling error and systematic error due to differences in schools caught among trips. By comparing the coefficient of variation of the bootstrap distribution of size and proportions at age among different sampling schemes, we were able to examine tradeoffs between sampling intensity and uncertainty in current estimates of catch size and age compositions (Manly 2007).

[C]*Biological port sampling data*.—We focused our analyses on the two most recent years for which commercial port sampling data were available at the start of this study (2015 and 2016) because extensive changes have occurred in both Gulf and Atlantic Menhaden fisheries and management plans during 1955-2012 (ASMFC 2017; SEDAR 2018). Thus, 2015-2016 data were assumed to most closely reflect current and future fishery conditions. Analysis of data from both 2015 and 2016 allowed us to examine the impact of interannual variability in catch composition on our conclusions. We also analyzed historical Atlantic Menhaden port sampling data from 1969, prior to the reduction in sampling targets, for comparison with more recent years in which fewer samples were taken.

During the 2015 and 2016 fishing seasons, Gulf Menhaden reduction plants were operational at three ports in the Gulf of Mexico: Moss Point, MS, Empire, LA, and Abbeville, LA. In the stock assessment model used for management of Gulf Menhaden, inputs derived from port sampling data were prepared at the port level. Therefore, we conducted simulation analyses on a port-by-port basis.

In the stock assessment used for management of Atlantic Menhaden, both the reduction and bait sectors are divided into northern and southern regional fleets to account for spatial changes in both fisheries over time relative to the extent of the coastwide stock (ASMFC 2017). Therefore, we analyzed performance of various two-stage sampling schemes at the regional (North vs South) scale for each Atlantic Menhaden sector to provide results that would be most informative to future stock assessments. The North region extended from Maine to coastal Maryland, and the South region included Chesapeake Bay and the coastal regions of Virginia to Florida. During 2015-2016, only one menhaden reduction plant was operational, in Reedville, VA. Therefore, reduction samples are assigned to a region based on set location information collected in Captain's Daily Fishing Reports (SEDAR 2015). Bait samples were assigned a region based on port of landing as in the assessment given Atlantic Menhaden bait operations typically operate over a much smaller geographic range than that of reduction purse seines.

[C]*Evaluation of Sampling Targets*.—We evaluated the performance of various sampling targets on metrics important to assessment and management of menhaden, namely accuracy of mean size and the age composition of fish landed. Mean weight of fish collected in port samples from both the Gulf and Atlantic reduction fisheries in a given port/week is used to convert landings (t) to number of fish landed at the port/week level to account for growth and migration effects across the fishing season (SEDAR 2015; SEDAR 2018). Therefore, our simulation study evaluated the impact of sampling targets (i.e., number of trips and number of fish sampled per trip) on mean weight of the reduction catch at the port/week level by year and region. For the Atlantic Menhaden bait fishery, mean weight of fish sampled is calculated after pooling samples by gear and year because of differences in gear selectivity and the small number of samples collected from the bait fishery in most years (SEDAR 2015). Thus, we evaluated the impact of sampling targets on mean weight of the bait catch by gear, region, and year. Fork length data were treated similarly to weight for both regions and sectors. When generating catch-at-age estimates for the statistical catch-at-age (SCAA) assessment model used for each stock, catch age composition data are pooled annually by port for the Gulf Menhaden reduction sector, by port and region for the Atlantic Menhaden reduction fishery sector, and by region for the Atlantic Menhaden bait sector. Thus, our evaluation of sampling targets on estimation of menhaden catch age composition was conducted at the port and year level for Gulf Menhaden, and at the sector, year, and region level for both the Atlantic Menhaden reduction and bait sectors given only one reduction plant was operational in recent years.

To assess the two-stage cluster sampling design employed in the menhaden port sampling program, we examined the combined effects of both the number of trips sampled and the number of individual fish sampled from each trip using menhaden port sampling data collected in 2015-2016. For the reduction fishery, port/weeks with <8 trips and fish collections with <8 fish per trip were not used in the simulation study to ensure sampling data were representative and adequate for resampling. Failure to meet the target number of trips per port/week is typically due to weather or plant logistics, whereas unreadable scales are the typical reason for failing to meet the target number of fish sampled per trip. Using the remaining data, we first evaluated the effect of current Gulf and Atlantic Menhaden reduction sector sampling targets on estimated size composition of the catch at the port/week level. The first stage of the two-stage cluster sampling design was simulated such that between 2 and 20 trips were randomly selected with replacement in each port/week. We then simulated the random selection with replacement of between 2 and 20 individual fish from each trip selected. Thus, our simulated sample target combinations spanned 20 trips per port/week with 2 fish sampled per trip to 2 trips per port/week and 20 fish per trip. This resampling procedure for each trip/fish sample size combination was then repeated 1,000 times (Efron 1979), and the coefficient of variation for the distribution of mean weight and fork length of fish caught per port/week was calculated for the reduction fishery. The same procedure was used for the Atlantic Menhaden bait sector with the exception that data were pooled across gears within a year instead of by port/week.

Next, we evaluated the effect of sampling targets on estimated annual age composition of the catch by port for the Gulf Menhaden reduction fishery, and by region and sector for the Atlantic Menhaden fishery using the same data inclusion criteria described above for size. In the first stage, a subset of trips per year was selected with replacement; the range of trips selected for resampling was chosen based on reasonable fishery performance expectations for each port, sector, and region, as appropriate, spanning approximately 50% fewer to approximately 25%

more trips sampled in recent years. From each trip selected, we then simulated the random selection with replacement of 2 to 20 individual fish. This resampling procedure for each trip/fish sample size combination was then repeated 1,000 times (Efron 1979), and the coefficient of variation for the distribution of proportions at age in the catch was calculated.

[A]Results

Our simulation results demonstrated a low amount of interannual variability, indicating that the same general conclusions could be drawn regardless of the year (2015 or 2016). Therefore, summarized results generated using 2016 data are presented here for brevity. More extensive 2016 and complementary 2015 results can be found in Supplemental Materials (Table S1 and Figures S1-S23). Also, simulation results were largely similar across all three ports of menhaden landings in the Gulf of Mexico; therefore, results for the Abbeville, LA port are presented here, and additional results for the Moss Point, MS and Empire, LA plants can be found in Supplemental Materials. Simulation results generated at sampling levels of n = 2, 10 (current target), and 20 fish per trip are presented to demonstrate the range of estimated CVs. A complete set of simulation results generated at all sampling levels explored can be found in the Supplemental Materials.

[B] Size

At current sampling target levels, mean length and weight are well characterized on both coasts, at all plants, and in all sectors and regions. Across all simulations, the CV of the bootstrap distribution of mean weight was about 2-3 times higher than that of the CV of mean fork length; however, the overall pattern of decline in CV with increasing sample sizes for both variables was similar. Therefore, only simulation results for mean weight are displayed here for brevity; the results of the simulation of fork length can be found in the Supplemental Materials.

At current target sampling levels of 10 trips per port/week and 10 fish sampled per trip, the average bootstrap distribution coefficient of variation (CV) for mean weight of Gulf Menhaden sampled across port/weeks at the Abbeville, LA reduction plant was approximately 3% (Figures 3, S1). Increasing the number of simulated trips sampled generally resulted in small improvements in the form of slightly lower average CVs in the range of 1-2%. Decreasing the number of simulated trips below target levels resulted in higher average CVs in the range of 4-7%. Increasing the number of fish sampled per trip above 10 had little effect, whereas decreasing the number of fish to as low as 2 increased the average CV to 4-11% across the range of number of trips sampled.

At current target sampling levels, the average bootstrap distribution coefficient of variation (CV) for mean weight of Atlantic Menhaden sampled across port/weeks (reduction) or gears (bait) was approximately 6-7% for the reduction sector and 2-3% for the bait sector in both the North and South regions (Figures 4, S4-S7). Increasing the number of simulated trips sampled above current levels generally resulted in small improvements in the form of slightly lower average CVs in the range of 4-5% for the reduction sector and 2-2.4% for the bait sector. Decreasing the number of simulated trips below target levels resulted in higher average CVs in the range of 6-14% for the reduction sector and 3.5-4% for the bait sector. Increasing the number of fish sampled per trip above 10 had little effect in both sectors and regions. In general, decreasing the number of fish to as low as 2 increased the average CV by 1-2% across the range of number of trips sampled. However, in the bait sector, reducing the number of fish sampled per trip had a larger impact on estimated CVs for pound net gear than purse seine or cast net (Figure S8-S9).

[B]Proportions at age

At 2016 target sampling levels, the bootstrap distribution CV for proportions at age of Gulf Menhaden sampled in 2016 at the Abbeville, LA reduction plant (n=199) was low for ages 1-3 (3-9%) relative to age 4 (39%; Figures 5 and S8). Increasing the number of simulated trips sampled generally resulted in small reductions in CVs, whereas decreasing the number of simulated trips below current levels resulted in higher CVs in the range of 3-13% for ages 1-3 and 39-45% for age-4 fish. Increasing the number of fish sampled per trip above 10 had little effect, whereas decreasing the number of fish to as low as 2 increased the CV to a range of 7-20% for ages 1-3 and 30-70% for age-4 fish across the range of number of trips sampled.

At 2016 target sampling levels, the CVs for proportions at age of Atlantic Menhaden sampled in the northern reduction sector (n=70) was high for ages 1 (30%) and 4 (25%) relative to ages 2 (13%) and 3 (11%) (Figures 6, S11). At 2016 target sampling levels, the CVs for proportions at age sampled in the southern reduction sector (n=180) was high for age 4 (40%) relative to ages 1 (10%), 2 (5%), and 3 (11%). In both regions, increasing the number of simulated trips sampled resulted in small reductions in CV. Decreasing the number of simulated trips sampled in the southern reduction sector had little impact on CVs for proportions of age-2 fish; in contrast, CVs increased from 13% to between 14% and 30% in the northern reduction sector. In contrast, decreasing the number of trips in the northern reduction sector resulted in CVs for age-1 fish ranging as high as 70%. Decreasing the number of simulated trips below current levels for both sectors resulted in moderate increases in CVs to between 12-29% for age 3 and 25-75% for age-4 fish in the north and 10-14% for age 3 and 45-60% for age-4 fish in the south. Both increasing and decreasing the number of fish sampled per trip from the current target of 10 generally had little effect with the exception of increasing the CVs for ages 3 and 4 in the south to between 12-18% and 60-100%, respectively. Although fish older than age 4 were encountered by the fishery, there were insufficient samples to provide reliable simulation results.

At 2016 target sampling levels, the CV for proportions at age of Atlantic Menhaden sampled in the northern bait sector was relatively high for ages 1 (30%), 4 (30%), and 5 (75%) relative to ages 2 (7%) and 3 (7%) (Figures 7, S12). At 2016 target sampling levels, the CVs for proportions at age sampled in the southern bait sector was relatively high for ages 4 (25%), and 5 (50%) relative to ages 1 (15%), 2 (7%) and 3 (10%) (Figures 7, S12). In both regions, increasing the number of simulated trips sampled resulted in minor reductions in CVs. Decreasing the number of simulated trips sampled resulted in slight increases in the CVs for proportions at age in both regions. In contrast to the reduction fishery, though, decreasing the number of fish sampled per trip in the bait sector increased CVs noticeably, in particular for ages 4 and 5 fish in both regions; for example, CVs for age 5 in the northern bait sector (where they are most likely to be encountered by any fishery) increased from a range of 60-90% at 10 fish sampled per trip to 90-150% at 2 fish sampled per trip. Increasing number of fish sampled per trip above the current target of 10 had little effect. Although fish older than age 5 were encountered by the fishery, there were insufficient samples to provide reliable simulation results.

[A]Discussion

This study evaluated the ability of current and alternative port sampling targets to characterize the size and age composition of the Gulf and Atlantic Menhaden commercial fishery catch. Current sampling targets appear to be adequate for characterizing mean weight and fork length of fish caught in both the Gulf and Atlantic fisheries and across all Atlantic Menhaden sectors and regions (Figures 3-4, S1-S7). Our results demonstrated similar performance of sampling program targets for overlapping ages (1-4), indicating that applying Atlantic Menhaden targets to Gulf Menhaden is appropriate. Also, both Gulf and Atlantic Menhaden reduction purse seine sets sampled (representative of schools sampled) were found to be highly homogeneous with regard to size, confirming historical Atlantic Menhaden studies (Chester 1984; Chester and Waters 1985; June and Reintjes 1959). Given our simulations generated consistently low CVs for the bootstrap distribution of fork length compared with weight or age (Figures S1-S7), our results also suggest that both Gulf and Atlantic Menhaden school primarily by length rather than age. This conclusion is supported by the fact that there is considerable overlap in length among ages for both species (Schueller et al. 2014). Also, menhaden sets can contain a mixture of ages which is likely due to a combination of multiple ages schooling together and ageing error.

Simulation results indicate that sampling targets (both number of trips and fish per trip) could be lowered on both coasts if the primary goal was characterizing the mean size of fish in the catch (Figures 3-4). However, the models used to assess both stocks require catch-at-age information. Our results suggest that characterizing the age composition of both Gulf and Atlantic Menhaden catch requires higher sampling intensity than characterizing size alone (Figures 5-6), as initially suggested by Chester (1984) for the Atlantic Menhaden reduction fishery. In general, current fishery sampling levels achieved low CVs for the bootstrap distribution of annual catch proportions at age for ages 2-3 in both the Gulf and Atlantic Menhaden fisheries (Figures 5-6). Fish age 2 and 3 are an important component of these fisheries, and are thought to make up the majority of the catch in the Atlantic Menhaden northern reduction and bait sectors; in addition, age-2 fish are thought to comprise the majority of fish caught in the southern Atlantic Menhaden fisheries (ASMFC 2017; SEDAR 2018).

However, characterization of proportions of age-1 fish in the catch differed by plant, region, and sector (Figures 5-6). Across all sampling levels, CVs for proportions of age-1 Gulf Menhaden were lower at the more eastern Louisiana and Mississippi reduction plants than at the westernmost Abbeville, LA reduction plant, indicating a potential longitudinal effect of the availability of age-1 fish in the western Gulf of Mexico as suggested by Ahrenholz (1991) (Figures S19-S21). For Atlantic Menhaden, CVs for proportions of age-1 at current sampling levels were lower in the southern reduction and bait sectors compared with both sectors in the northern region (Figures 5-7). Given that Atlantic Menhaden exhibit age-based northward migration behavior that stratifies fish by age along the East Coast during the fishing season (Dryfoos 1973; Liljestrand et al. 2019; Nicholson 1978), higher CVs for proportions of age-1 fish in northern sector catches is likely due to the lack of overlap between location of fishing activities and location of high concentrations of age-1 Atlantic Menhaden. Proportions of age-1 Atlantic Menhaden were well characterized in the southern region where they are more likely to reside prior to migrating northward as they age (Liljestrand et al. 2019).

Proportions of fish ages 4 and older were characterized with much greater uncertainty than younger ages in both fisheries and across all sectors and regions. Both species exhibit dome-shaped selectivity (SEDAR 2018; SEDAR 2020), thought to be driven by a combination of fisher choice and annual migration patterns for both species. Gulf Menhaden have a shorter life span (max age 6; SEDAR 2018) than Atlantic Menhaden (max age 10; June and Reintjes 1959); thus, higher uncertainty in estimating proportions of fish ages 4+ in the catch is likely due to their rarity in the population. Proportions of age-4 and older fish in the Atlantic Menhaden fishery were poorly characterized by the sampling program likely due to their rarity in the catch, not in the population itself. It is possible that there is little spatial overlap between the location of older Atlantic Menhaden and the locations in which the fishery is prosecuted. Evidence from commercial sea samples indicates Age-4+ Atlantic Menhaden are typically encountered farther offshore and in more northerly portions of their range where they are not often encountered by most trips taken by the current reduction sector (SEDAR 2015). However, biological data collected from the very limited offshore directed midwater trawl and other offshore bycatch fisheries frequently encounter older Atlantic Menhaden (SEDAR 2015), indicating these fish exist but are not encountered by the majority of targeted menhaden fishing trips. In addition, ageing error may be contributing to higher uncertainty in the estimation of proportions of age-4 and older fish for both stocks given uncertainty in age determination for menhaden increases with age (ASMFC 2015; ASMFC 2017; SEDAR 2018). It is also possible that older menhaden have greater variability in size-at-age and thus schools of larger fish may be more heterogeneous in age composition, which would make estimation of proportions at age in the catch more uncertain.

Our results suggest that reducing the number of fish sampled per trip from the current target of 10 to as few as 4 would have minimal impact on estimating mean size or proportions at age (Figures 3-7, S1-S23). Thus, it may be possible to increase efficiency of the sampling program by sampling fewer fish per trip. Our results also indicate that increasing the number of trips sampled above current levels will not greatly improve characterization of age composition of the catch, particularly for age-4 and older fish. In some situations, such as the northern reduction sector for Atlantic Menhaden, port samplers are already sampling nearly all of the available trips per port/week. Given the limited number of trips taken in the northern region in both sectors of the Atlantic Menhaden fishery, increasing sampling may not be feasible. Also, it may not be possible to improve sampling for age-4 and older fish in the Gulf Menhaden fishery given their shorter life span. Similarly, it may not be possible to improve sampling for age-4 and older fish in the Atlantic Menhaden fisheries given the lack of spatial overlap between their locations and current fishing activities.

Conclusions drawn from this simulation study assume that port sampling data collected from the 2016 and 2015 Gulf and Atlantic Menhaden fisheries represent the full range of sizes and ages typically encountered by the fishery (Manly 2007). If current sampling levels are insufficient to fully characterize the size and age range of fish caught, our results could be biased. Therefore, we performed our resampling simulation procedures on Atlantic Menhaden reduction fishery data collected in 1969 prior to sampling effort reductions when the number of trips per port/week and fish per trip was approximately 20 (Figure 1). CVs for the bootstrap distributions of mean size and age composition in 1969 were largely similar to CVs generated using data collected in 2016 (Figure 8), demonstrating our results are not unique to recent years and the current sampling scheme is adequate to produce representative data for this resampling study. However, if significant shifts in the geographic distribution of the fish or fishery occur in the future, this analysis should be repeated to provide updated advice to menhaden scientists and managers. Unlike the Atlantic Menhaden port sampling program, which underwent a period of very high sampling effort prior to establishing current targets, the Gulf Menhaden sampling program does not have a comparable reference period during which both larger number of trips and fish sampled per trip were collected for comparison. That being said, all sizes and ages are likely represented in the 2016 port samples given the shorter life span of Gulf Menhaden. The bait fishery for Atlantic Menhaden, however, is not as closely monitored as the reduction fishery. Amendment 2 to the Atlantic Menhaden Fishery Management Plan recommends, but does not require, that port samples from the bait fishery be distributed among gear types. Without requirements to sample each bait gear in proportion to its landings, it is possible that port samples collected by the states are not truly representative of the size and age composition of the bait catch.

Large uncertainty in the proportion of age-4 and older menhaden in the Gulf and Atlantic commercial catch has implications for assessment of both stocks. The current stock assessments model tracks ages 0-4+ for Gulf Menhaden and ages 0-6+ for Atlantic Menhaden (ASMFC 2017; SEDAR 2018). If proportions of age-4 and older fish are as difficult to estimate well as our study suggests, the statistical catch-at-age models used in the Gulf and Atlantic Menhaden assessments may be chasing noise in the catch-at-age matrix rather than tracking real information about trends in older fish encountered. Thus, the adoption of a Dirichlet likelihood function (Thorson et al. 2017) for fitting proportions at age in the most recent Gulf (SEDAR 2018) and Atlantic Menhaden (SEDAR 2020) assessments appears warranted. In general, though, caution should be used in interpreting and fitting assessment models to menhaden catch-at-age data that include age classes 4 and older until the impact of plus group selection on both Gulf and Atlantic Menhaden assessments can be quantified with further simulation studies.

Our simulation study can be used to guide decisions regarding any proposed future changes to the port sampling programs for Gulf and Atlantic Menhaden. However, in order to examine the impact sampling has on model estimates and management, our resampled data sets would need to be passed through the complete data preparation and modeling processes unique to each stock assessment. Future research will include a full exploration of the potential impact that current and alternative sampling targets have on assessment model estimates and resulting management advice.

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FIGURES

FIGURE 1. Trends in Gulf and Atlantic Menhaden port sampling effort and number of reduction plants, 1955-2016.

FIGURE 2. Trends in port sampling effort for Atlantic Menhaden harvested for bait, 1985-2016.

FIGURE 3. Bootstrap distribution coefficient of variation for mean sample weight of Gulf Menhaden by resample size averaged across port/weeks for the Abbeville, LA reduction plant, 2016.

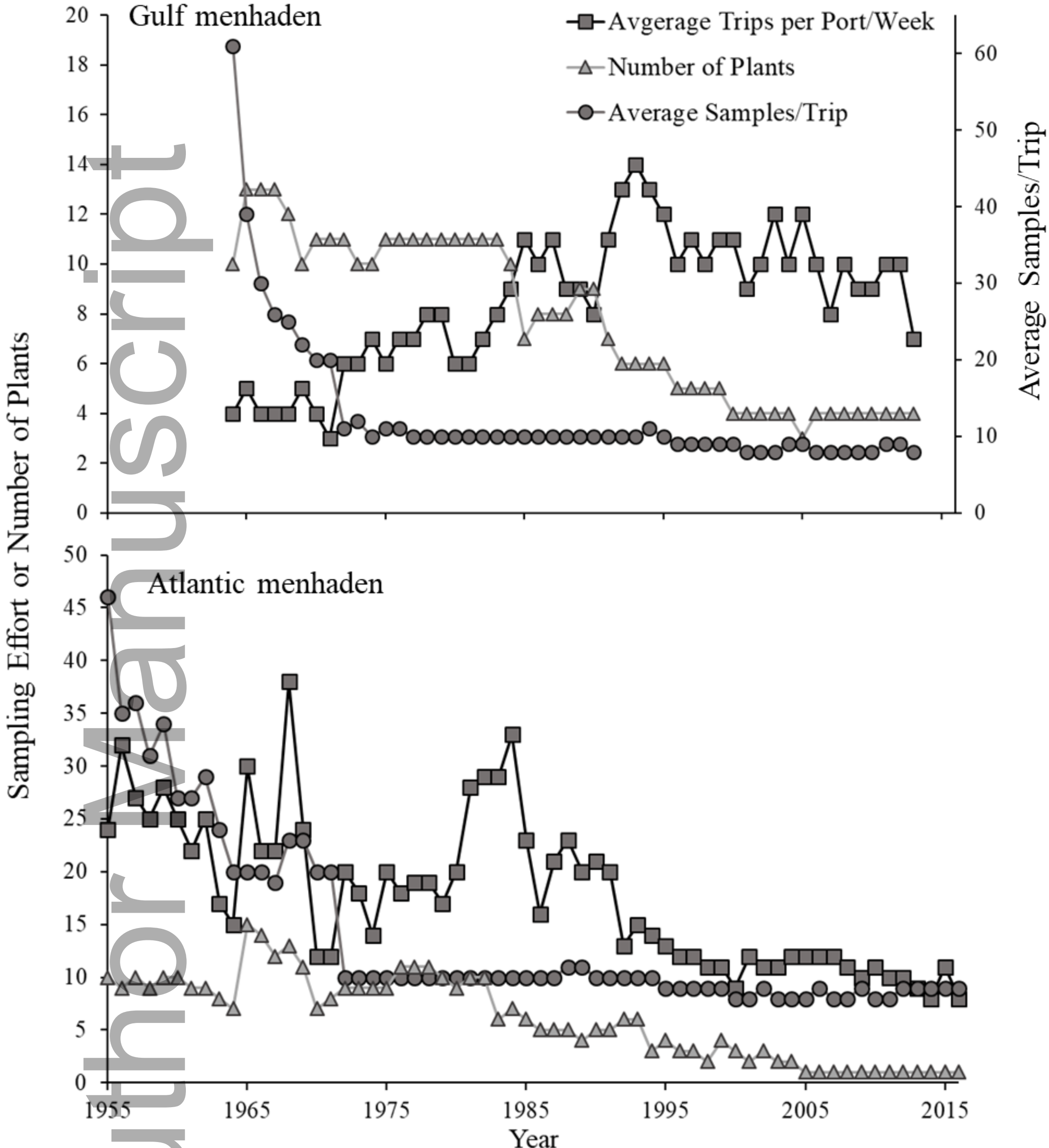
FIGURE 4. Bootstrap distribution coefficient of variation for mean sample weight of Atlantic Menhaden by resample size averaged across port/weeks by sector and region, 2016.

FIGURE 5. Bootstrap distribution coefficient of variation for Gulf Menhaden catch sample proportions at age by resample size for the Abbeville, LA reduction plant, 2016.

FIGURE 6. Bootstrap distribution coefficient of variation for Atlantic Menhaden reduction catch sample proportions at age by resample size and region, 2016.

FIGURE 7. Bootstrap distribution coefficient of variation for Atlantic Menhaden bait catch sample proportions at age by resample size and region, 2016.

FIGURE 8. Bootstrap distribution coefficient of variation for Atlantic Menhaden reduction catch sample size (left) and proportions at age (right) by resample size and region, 1969.



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520 plants, 1955-2016.

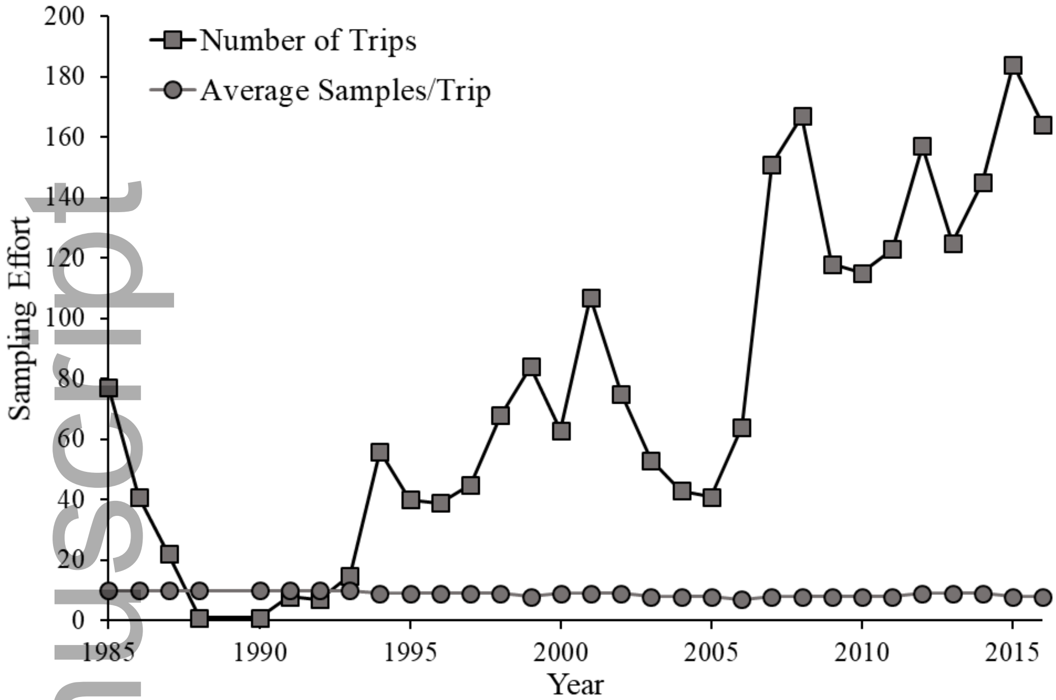
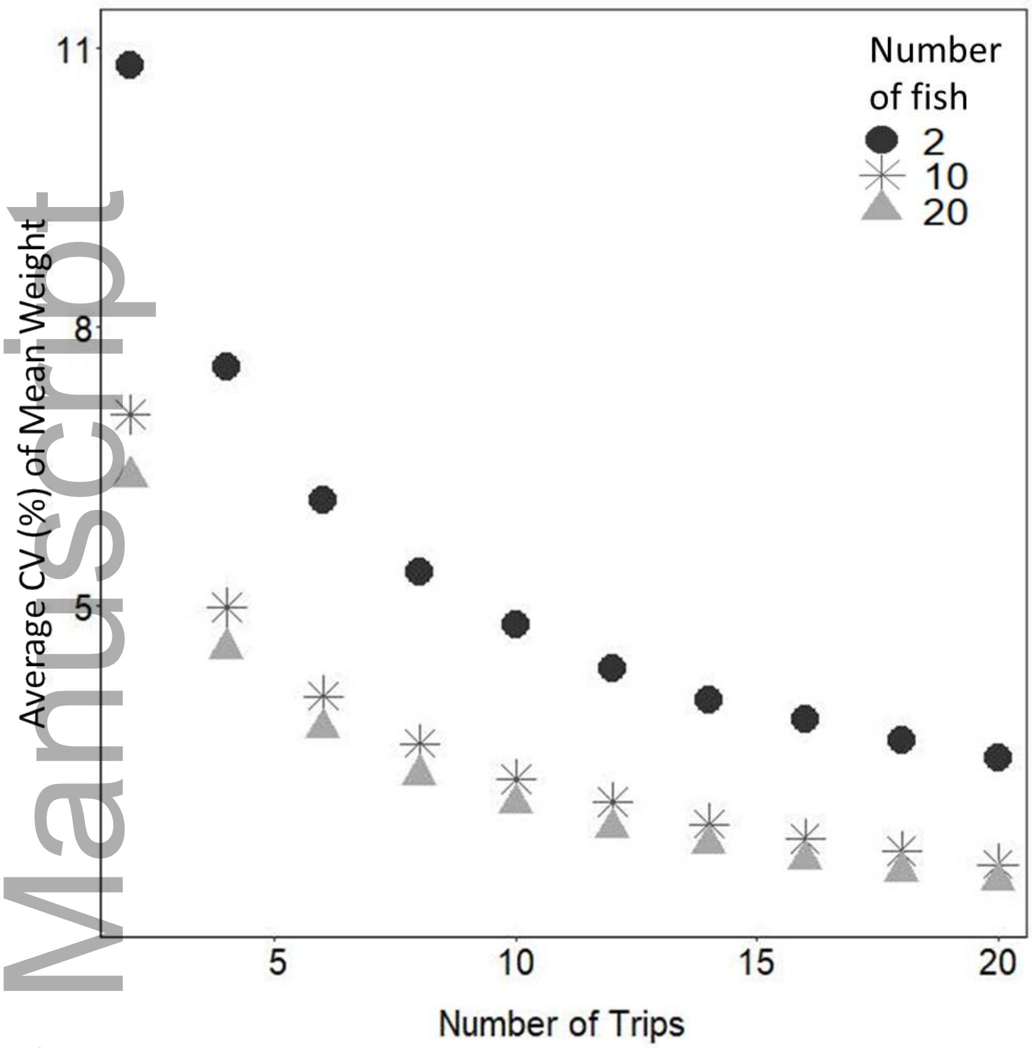


FIGURE 2. Trends in port sampling effort for Atlantic Menhaden harvested for bait, 1985-2016.



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526 FIGURE 3. Bootstrap distribution coefficient of variation for mean weight of Gulf Menhaden by

527 resample size averaged across port/weeks for the Abbeville, LA reduction plant, 2016.

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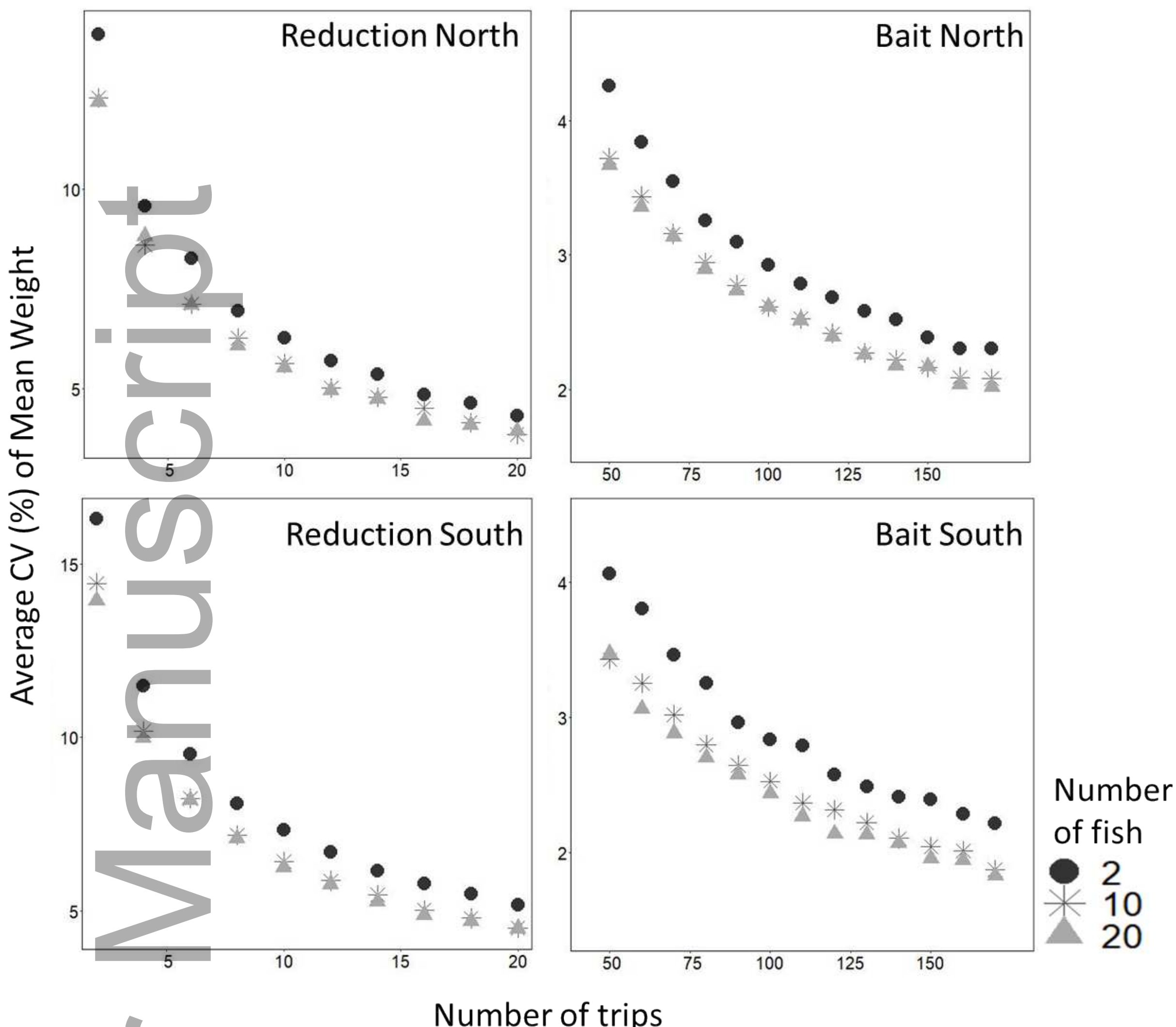

FIGURE 4. Bootstrap distribution coefficient of variation for mean weight of Atlantic Menhaden by resample size averaged across port/weeks by sector and region, 2016. Sampling targets in 2016 were 10 fish sampled per trip with 10 trips per port/week for the reduction sector, and 10 fish sampled per trip with 83 and 90 total trips sampled for the North and South bait sectors, respectively.

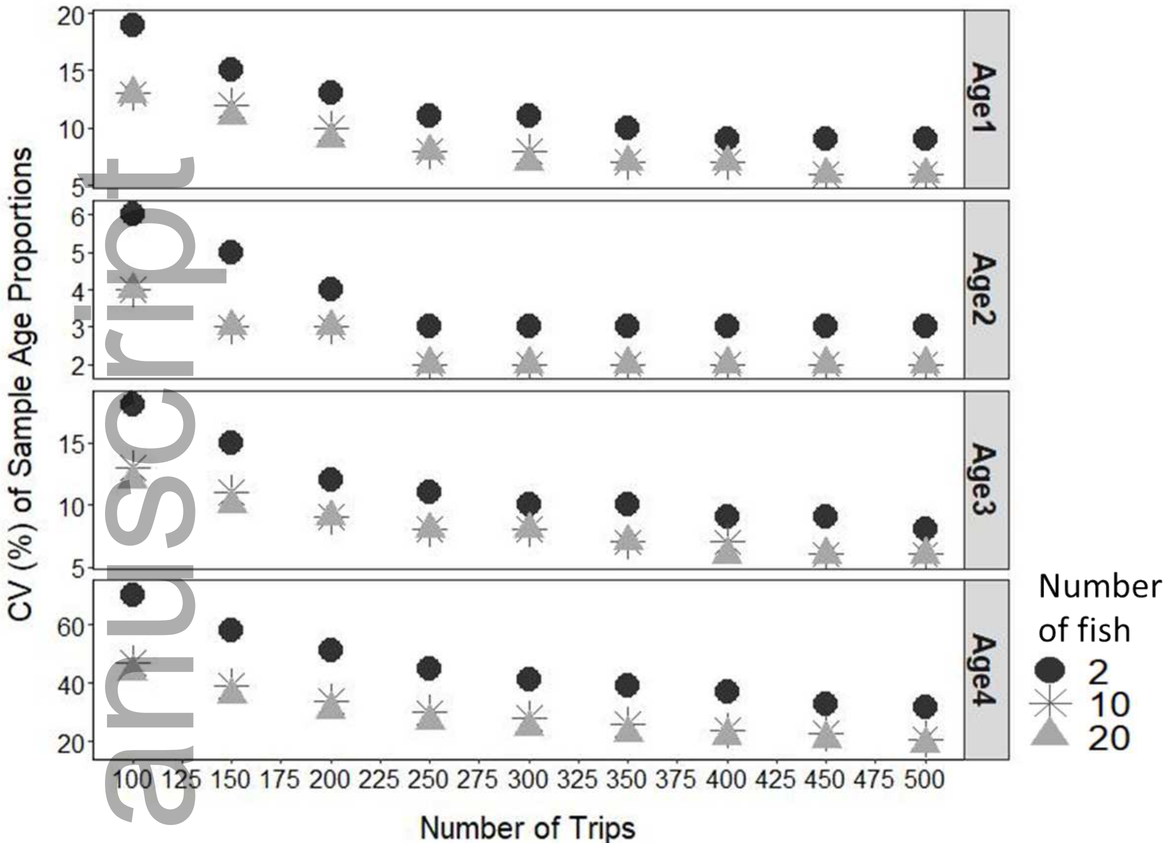

FIGURE 5. Bootstrap distribution coefficient of variation for Gulf Menhaden catch sample proportions at age by resample size for the Abbeville, LA reduction plant, 2016. Target sampling levels in 2016 were 10 trips per port/week (170 total trips) and 10 fish per trip.

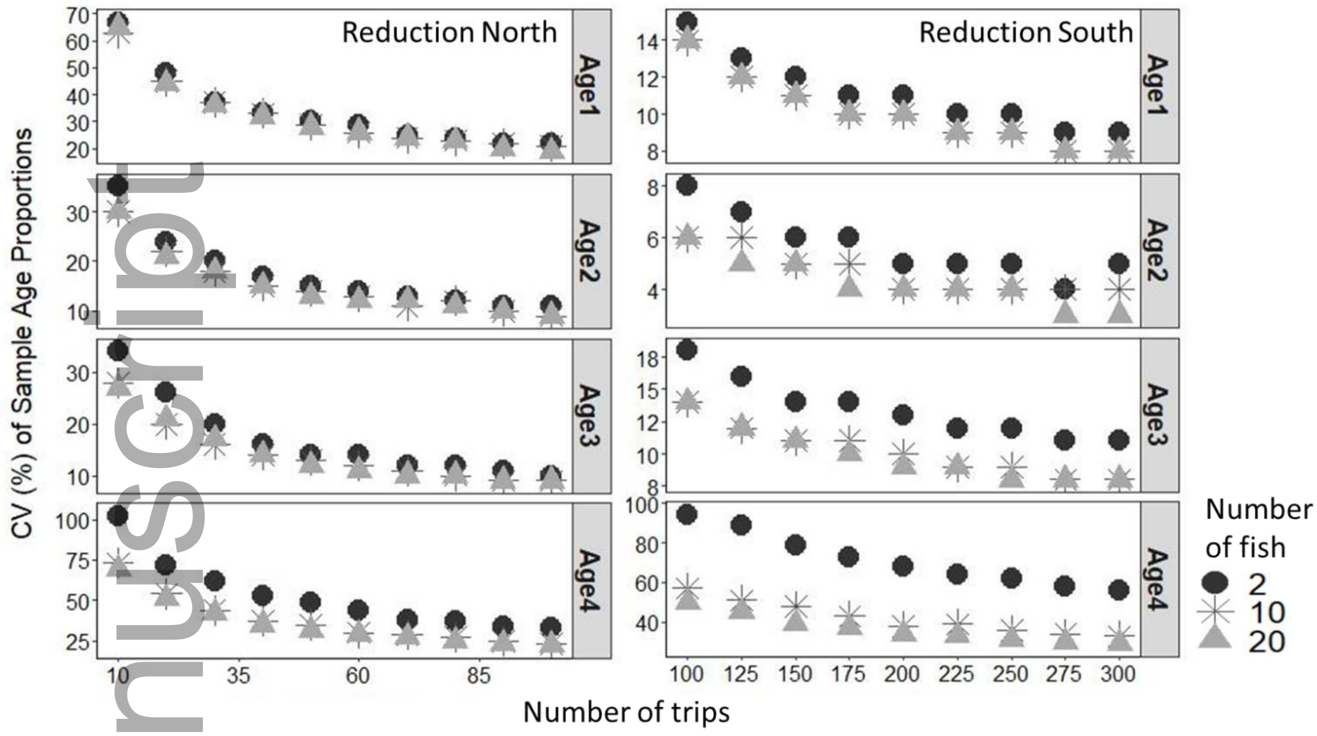

FIGURE 6. Bootstrap distribution coefficient of variation for Atlantic Menhaden reduction catch sample proportions at age by resample size and region, 2016. Sampling targets in 2016 were 70 (North) and 180 (South) trips per year and 10 fish per trip.

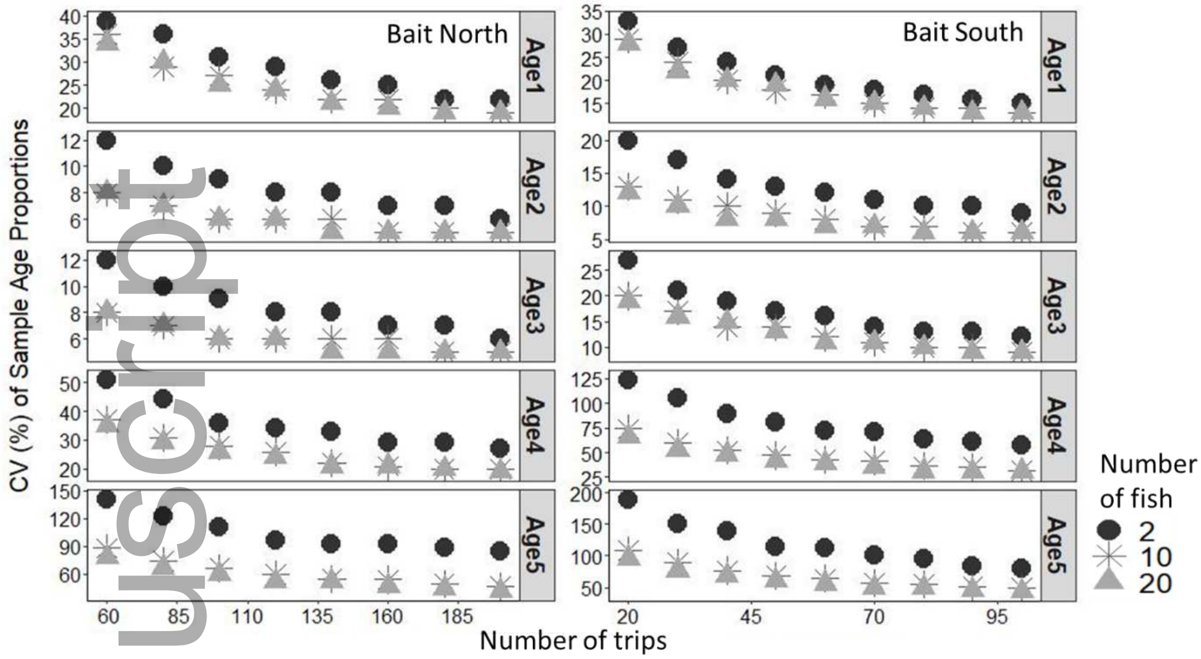

FIGURE 7. Bootstrap distribution coefficient of variation for Atlantic Menhaden bait catch sample proportions at age by resample size and region, 2016. Sampling targets in 2016 were 10 fish sampled per trip with 83 and 90 total trips sampled for the North and South bait sectors, respectively.

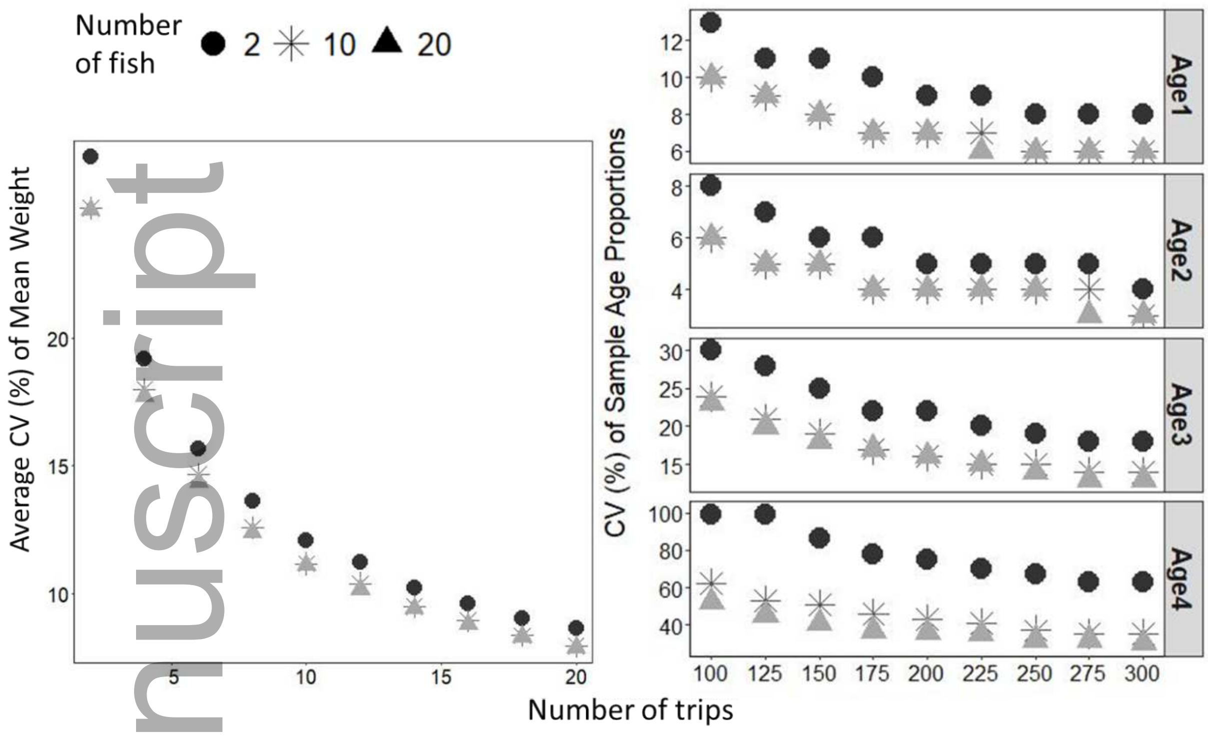

FIGURE 8. Bootstrap distribution coefficient of variation for Atlantic Menhaden reduction catch sample size (left) and proportions at age (right) by resample size and region, 1969.