An evaluation of sampling adequacy for the Gulf Menhaden reduction fishery

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The Gulf Menhaden (*Brevoortia patronus*) stock supports the largest commercial fishery by volume in the Gulf of Mexico and the second largest in the US (National Marine Fisheries Service 2017). In order to characterize the size and age composition of landings for use in stock assessment, data are collected through an extensive port sampling program. Biological samples allow for conversion of landings from weight to numbers caught by age class and provide critical information about the stock that allows the assessment model to track year class strength and estimate fishing mortality by age and fleet.

The reduction fishery port sampling program for Gulf Menhaden was modeled after that of Atlantic Menhaden (*Brevoortia tyrannus*) on the East Coast. In applying the Atlantic Menhaden fishery port sampling design and targets to Gulf Menhaden, it is assumed that the species and fisheries are similar enough that the same sampling program appropriately characterizes the size and age structure of the Gulf Menhaden landings. To date, the validity of this assumption has not been examined. Therefore, the goal of this study was to evaluate the adequacy of current and potential alternative port sampling targets in their ability to characterize the size and age composition of the Gulf Menhaden reduction fishery catch. Our objectives were to:

1. Assess the ability of the current reduction fishery sampling programs to characterize the size and age composition of the catch.
2. Examine the relative performance of a suite of alternative two-stage sampling targets.
3. Simulate the potential impact of ageing error on accuracy of sample age composition.

Methods

We conducted a simulation study to evaluate the adequacy of the current reduction fishery sampling targets and to examine relative performance of a suite of alternative targets. We conducted a bootstrap analysis in which we extensively resampled the existing data, with replacement, across a range of current and alternative sampling schemes (i.e., combinations of number of trips and fish sampled). 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 the estimated size and age composition of the catch. We evaluated the potential impact of ageing error on accuracy of catch age composition estimates by multiplying the age composition of the resampled collections by two different ageing error matrices.

Results

Current sampling targets appear adequate for characterizing mean weight and fork length of fish caught. Reducing the number of fish sampled per trip had a very small impact on estimating the mean size of the catch, indicating that length composition is well characterized and implying that fish caught in the same school are highly homogenous with regards to size. Current sampling intensity appears to be adequate for characterizing annual catch proportions at age for most age classes, particularly ages 1-2 y. However, proportions of age 4 fish were poorly characterized in the fishery and across all plants possibly due to either their rarity in the population or a lack of spatial overlap between age 4 fish habitat and current fishing activities. Thus, we urge caution when interpreting apparent fluctuations in the commercial age composition for ages 4 Gulf Menhaden.

We found that increased sampling above current target levels will not greatly improve the precision of estimates of catch age composition. In addition, increased sampling may not improve estimation of proportions of age 4 fish in the catch. Our results also indicate that reducing the number of fish sampled to as few as 4 per trip would have little impact on estimating the proportions at age in the catch. Thus, it may be possible to increase efficiency of the sampling program by sampling fewer fish per trip.

We observed a lack of trend in the impact of ageing error with increased sampling intensity, indicating that increased sampling will not alleviate issues with ageing fish ages 3+ and that including fish ages 4 in the SCAA model used for stock assessment may result in the model chasing noise rather than tracking good year classes. In addition, consistency in the results of age composition analyses in this study between 2015 and 2016 suggest that changes in the primary scale reader at the NOAA Beaufort Laboratory during that time period did not result in directional (consistent over or under ageing) bias.

Management impact

Prior to this study, the assumption that Atlantic Menhaden sampling targets could be reasonably applied to the Gulf Menhaden fishery was untested. Our results indicate that the Gulf Menhaden reduction port sampling program is adequate for characterizing the size composition of the catch, which is required for converting weight to number of fish landed for the stock assessment. Also, we found that efficiency of the sampling program may be increased by sampling fewer fish per trip (minimum 4) without negatively impacting estimation of catch proportions at age. The Gulf States Marine Fisheries Commission's Menhaden Advisory Committee (MAC) will be presented with the results of this study and will use our results to decide if the sampling program achieves an adequate level of precision when characterizing the age composition of the catch, a critical input in the statistical catch-at-age model used for management. Upon reviewing the results of this study, the MAC may recommend future changes to the stock assessment model or to port sampling targets.

Rationale

The Gulf Menhaden (*Brevoortia patronus*) stock supports the largest commercial fishery by volume in the Gulf of Mexico and the second largest in the US (National Marine Fisheries Service 2017). The fishery is primarily composed of a purse seine reduction fleet; landings for bait generally comprise less than 2% of the total (SEDAR 2018). In order to characterize the size and age composition of the reduction landings for use in stock assessment, data are collected through an extensive port sampling program. Biological samples allow for conversion of landings records from weight to numbers caught by age class. In addition, biological samples provide critical information about the stock that allows the assessment model to track year class strength and estimate age-specific fishing mortality.

The reduction fishery port sampling program for Gulf Menhaden has been conducted since 1964 by the National Marine Fisheries Service (SEDAR 2018). The program was modeled after that of Atlantic Menhaden (*Brevoortia tyrannus*) on the East Coast. A two-stage cluster sampling scheme is employed in which the primary sampling unit is the fishing trip sampled and the secondary sampling unit is the individual fish (June and Reintjes 1959; Chester 1984). Reduction plant employees randomly select vessels dockside and retrieve a bucket of fish from the top of the vessel's hold, which is representative of fish collected during the last set of the day (SEDAR 2018). A subset of fish is then selected by the agent at random from the bucket and provided to the NOAA Fisheries port sampler. Each fish is measured (fork length in mm), weighed (grams), and a collection of scales (n = 10) are removed, cleaned, and mounted on a glass microscope slide for ageing. Given the schooling nature of Gulf Menhaden, each trip sampled is assumed to be an independent sampling event. Sampling is typically conducted throughout the fishing season and across all ports of landing to account for seasonal growth (i.e. length-at-age) and movement patterns. In applying the Atlantic Menhaden fishery port sampling design and targets to Gulf Menhaden, it is assumed that the species and fisheries are similar enough that the same sampling program appropriately characterizes the size and age structure of the Gulf Menhaden landings. To date, the validity of this assumption has not been examined.

Sampling targets determined by previous studies of the Atlantic Menhaden fishery were applied to the Gulf Menhaden fishery. Both the Atlantic and Gulf Menhaden port sampling program design was modified with increased scientific understanding of Menhaden biology and as both the nature of the fishery and financial support for the program changed over time. Soon after implementation of the Atlantic reduction fishery port sampling program, June and Reintjes (1959) conducted a study of the homogeneity of the Atlantic reduction fishery catch and determined that a sample size of 20 fish per trip was adequate to estimate mean length of fish in a purse seine to within +-2% (Chester 1984). Variability among trips was also found to be much greater than within a trip. Therefore, sampling protocols were changed in 1971 from a target of 10-15 trips per port and 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. Actual sampling achieved in the Gulf was higher, ranging from an average of 40-70 trips sampled per port/week (Figures 1); however, the adoption of 10 fish per sample was largely consistent in the Gulf from 1971 onward (Figure 2). As the number of active reduction plants and fleet size declined (Figure 3), the average number of trips sampled per port/week (Figure 1) and total number of trips per year (Figure 4) decreased. Chester (1984) conducted an in-depth analysis of the Atlantic Menhaden port sampling program 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 at the port/week level. At present in the Gulf, a target of 10-15 trips per port and week (hereafter, “port/week”) and 10 fish per trip has been used with an informal goal of reaching approximately 300 samples per plant in a given year. Although even greater declines in the spatial extent and magnitude of both the Gulf and Atlantic reduction fishery have occurred since Chester’s 1984 study (SEDAR 2015), the reduction fishery port sampling program has not been recently re-evaluated to determine if the sampling program is meeting its goals.

The goal of this study was to evaluate the adequacy of current and potential alternative two-stage sampling targets in characterizing the size and age composition of Gulf Menhaden reduction fishery landings. Previous studies of Menhaden sampling program designs were limited to analytical approaches (June and Reintjes 1959; Chester 1984; Chester and Waters 1985). With the advent of high speed computing, a more complex and thorough simulation study can be conducted that examines the combined effects of sampling more or fewer trips and individual fish as well as the impact of ageing error on fishery catch composition estimates.

Objectives

The objectives of our study were to:

1. Assess the ability of the current reduction fishery sampling program to characterize the size and age composition of the catch.
2. Examine the relative performance of a suite of alternative two-stage sampling targets.
3. Simulate the potential impact of ageing error on accuracy of sample age composition.

Methods

We conducted a simulation study to evaluate the adequacy of the current reduction fishery sampling targets and to examine relative performance of a suite of alternatives targets. We conducted a bootstrap analysis in which we extensively and systematically resampled the existing data with replacement across a range of current and alternative sampling schemes (i.e., combinations of number of trips and fish sampled). 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 the estimated size and age composition of the catch (Manly 2007).

Biological sampling data

We focused our assessment on adequacy of the current port sampling program in the two most recent years for which data were available at the start of this project (2016 and 2015) to reflect current conditions in the fishery (SEDAR 2018). During 2015-2016, three Gulf Menhaden reduction plants were operational in Moss Point, MS, Empire, LA, and Abbeville, LA.

Biological sampling data used in the stock assessment for Gulf Menhaden are pooled across all plants. Therefore, we conducted coastwide simulations in which data from all plants were pooled. To explore the potential impact of longitudinal differences in catch composition, we also conducted plant-specific simulation studies to determine the impacts of sampling targets on our ability to characterize size and age composition of the catch by plant. A complete list of simulations conducted in this study are summarized in Table 1.

Simulation study

We evaluated the performance of various sampling targets on metrics important to the statistical catch-at-age (SCAA) stock assessment model used in Gulf Menhaden management, namely accuracy of the mean size and age composition of fish landed (SEDAR 2018). The SCAA models the population in terms of abundance, and thus requires that landings be converted from weight to numbers caught. Mean weight of fish collected in port samples from the reduction fishery in a given port/week is used to convert landings (t) to number of fish landed (SEDAR 2018). Therefore, our simulation study evaluated the impact of sample size on mean weight of the reduction catch at the port/week level by year. Fork length data were treated similarly to weight. When generating catch-at-age estimates for the SCAA, port sampling age composition data are pooled annually; thus, we mirrored this process in our simulation study and calculated age composition at the annual level.

In order to assess the two-stage cluster sampling design employed in the Gulf 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. 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. Using the remaining data, we first evaluated the effect of sampling targets on estimated size composition of the catch at the port/week level. The first stage of the sampling design was simulated such that between 2 and 20 trips were randomly selected with replacement in each port/week. From each trip selected, we then simulated the random selection with replacement of between 2 and 20 individual fish. 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, and the coefficient of variation for the distribution of mean weight and length of fish caught per port/week was calculated.

Next, we evaluated the effect of sampling targets on estimated age composition of the catch at the annual level. 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 expectations for the region or plant, spanning approximately 50% fewer to approximately 25% more trips sampled in recent years (2012-2016). 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, and the coefficient of variation for the distribution of proportions at age in the catch was calculated.

We evaluated the potential impact of ageing error on accuracy of catch age composition estimates by multiplying the age composition of the resampled collections by an ageing error matrix. Two different ageing error matrices were employed. The first error matrix was derived from a study conducted by NOAA Beaufort Laboratory in which the same ageing technician conducted re-reads of a subset of scales collected in the 1970s, 1980s, 1990s, and 2000s (SEDAR 2018); ageing was informed by the length of the fish and date of capture. The second ageing error matrix was constructed by Rezek and Price (unpublished data) based on the comparisons done by two readers and incorporating blind reading with respect to fish length (SEDAR 2018). Assuming the simulated samples represented the true age composition of the catch, we calculated the percent relative error (RE) in age composition of the catch by age class (*a*), using the equation

$$RE_a = \frac{ACerror_a - ACsim_a}{ACsim_a} \times 100$$

for each ageing error matrix, such that *ACsim* was the simulated age composition and *ACerror* was the age composition with estimated ageing error applied.

Results

In general, low interannual variability in simulation results resulted in similar conclusions for both years. Therefore, for brevity, results using 2016 data are presented below. Results using 2015 data are available as supplemental materials[1].

Weight and fork length

At current target sampling levels of 10 trips per port/week and 10 fish sampled per trip, the bootstrap distribution coefficient of variation (CV) for mean weight of the catch by port/week was approximately 5-10% when analyzed either coastwide or on a plant-by-plant basis (Figures 5-8A). The same analysis for fork length resulted in lower bootstrap distribution CVs in the range of 2-6% (Figures 5-8B). As expected, increasing the number of simulated trips that were sampled resulted in a lower CV, and decreasing the number of simulated trips resulted in a higher CV. However, low to moderate reductions in CV were achieved with either increased or decreased number of fish sampled per trip.

When samples were pooled coastwide by port/week as in the stock assessment, the bootstrap distribution CV ranged from 3-20% for mean weight and 1-7% for mean fork length of fish in the catch (Figure 5). At the Moss Point plant, bootstrap distribution CVs for mean weight and fork length of fish in the reduction catch by port/week ranged from approximately 2-16% and 0.5-5%, respectively (Figure 6). At the Empire plant, bootstrap distribution CVs for mean weight and fork length of fish in the reduction catch by port/week ranged from approximately 3-23% and 0.5-6%, respectively (Figure 7). At the Abbeville plant, bootstrap distribution CVs for mean weight and fork length of fish in the reduction catch by port/week ranged from approximately 0.5-17% and 0.5-5%, respectively (Figure 8).

Proportions at age

The bootstrap distribution CV for proportions at age in the coastwide reduction fishery (Figure 9) was relatively high for age 4 (range ~20-60%). A lower bootstrap distribution CV was observed for proportions at age 1 (range ~2-4.5%), age 2 (range ~3-7%) and age 3 (range ~10-20%). The number of fish sampled per trip had a greater impact on bootstrap distribution CV for proportions at age 4. At the Moss Point plant, the bootstrap distribution CV for proportions at age (Figure 10) was relatively high for both ages 3 (range ~50-175%) and 4 (range ~100-350%). A lower bootstrap distribution CV was observed for proportions at ages 1 (range ~1-4%) and age

[1] Additional materials available online at http://bit.ly/2UTI0gh.

2 (range ~5-13%). At the Empire plant, the bootstrap distribution CV for proportions at age (Figure 11) was relatively high for age 4 (range ~20-100%). A lower bootstrap distribution CV was observed for proportions at ages 1 (range ~1-7%), age 2 (range ~3-10%), and 3 (range ~10-35%). At the Abbeville plant, the bootstrap distribution CV for proportions at age (Figure 12) was slightly larger for ages 1 (range ~5-20%) and 4 (range ~20-70%). A lower bootstrap distribution CV was observed for proportions at age 2 (range ~2-6%) and 3 (range ~7-17%).

Ageing error

The impact of applying estimated ageing error to bootstrapped proportions at age for the coastwide reduction fishery differed by age class and ageing error matrix (Figure 13). Relative error generated by the ageing error matrix based on blind reads (BR) was larger and in the opposite direction compared to that of the ageing error matrix based on informed reads (IR) for age 1 fish (~-13% vs. 6%). However, BR-based relative errors were lower for age 2 (~-2% vs. -20%) and 4 fish (~74% vs. 193%). Both ageing error matrices produced similar relative error for age 3 fish (~43% vs. 41%). The number of fish sampled per trip did not impact relative error in proportions at age.

Discussion

This study evaluated the ability of current and alternative port sampling targets to characterize the size and age composition of the current Gulf Menhaden commercial fishery catch. In general, current sampling targets appear to be adequate for characterizing mean weight and fork length of fish caught (Figures 4-7). Our results confirm that, like Atlantic Menhaden, Gulf Menhaden schools are highly homogeneous with regards to size (June and Reintjes 1959; Chester 1984; Chester and Waters 1985). Fewer fish per trip could be sampled if we were only concerned with characterizing the mean size of fish in the catch (Figure 5). However, this study demonstrated that characterizing the age composition of the catch requires higher sampling intensity than characterizing size alone, particularly if age 4 fish are present (Figures 9-12). Whether this is due to ageing error (Figure 13) or fish of similar sizes but different ages schooling together is unknown.

Weight and fork length

Although current sampling targets of 10 trips per port/week and 10 fish per trip achieved low CVs for the bootstrap distribution of mean weight and fork length of the catch, it should be noted that the number of trips actually sampled on average per plant in 2016 was 9 trips per port/week (Figure 14). This slight shortfall in number of trips sampled may be due to a combination of fewer trips conducted per port/week than in previous decades when the fishery was larger (Figure 1), sampling program coordination issues, or weather complications. The CV for mean weight and fork length of the catch actually achieved is only slightly larger than the target in some port/weeks (Figures 5-8). Overall, the difference in CVs is very small such that sampling slightly less than the target number of trips per port/week likely had very little effect on catch composition estimates. The average number of fish sampled per trip was 9 (Figure 15), which is likely less than the target of 10 due to damaged or otherwise unreadable scale collections. Reducing the number of fish sampled per trip had a very small impact on estimating the mean size of the catch, indicating fish caught in the same school are highly homogenous with regards to size.

Proportions at age

The total number of trips sampled in 2016 was 674 coastwide, 269 at Moss Point, 206 at Empire, and 199 at Abbeville (Figures 3 and 16). There are no established total annual target number of trips for characterizing the age composition of the Gulf Menhaden reduction fishery. However, current sampling levels appear to have achieved reasonably low CVs for the bootstrap distribution of annual catch proportions at age for most age classes, particularly ages 1-2 (Figures 9-12). The CVs for the bootstrap distribution of annual catch proportions of age 3 fish at sampling levels achieved in 2016 was approximately 10% at the coastwide level and at the Abbeville plant, but approximately 17% at Empire and 60% at the Moss Point plant. The CVs for the bootstrap distribution of annual catch proportions of age 4 fish at sampling levels achieved in 2016 was approximately 30% at the coastwide level, but approximately 30% at the Abbeville plant, 40% at Empire, and 140% at the Moss Point plant. Higher CVs for age 3+ proportions may be due to either their rarity in the population or a longitudinal gradient in Gulf Menhaden by age such that the easternmost reduction plant at Moss Point encounters far fewer age 3+ fish than more westerly plants (Nicholson 1978). However, analysis of data collected in 2013 at the Cameron, LA reduction plant before it closed resulted in relatively high CV for the distribution of proportion of age 4 fish (~100%; Figure 17)[2]. Proportions of age 4 fish were poorly characterized by the sampling program likely due to their rarity in the commercial fishery.

As expected based on sampling theory (Manly 2007), increasing the number of trips sampled per port/week (reduction) resulted in a lower CV for the distribution of proportions at age. However, our results indicated that increased sampling above current target levels will not greatly improve characterization of catch age composition. In addition, increased sampling may not improve estimation of proportions of age 4 fish in the catch if there is little spatial overlap between their locations and current fishing activities. Our results also showed that reducing the number fish sampled per trip to as few as 4 would have little impact on estimating the proportions at age in the catch (Figure 9). Thus, it may be possible to increase efficiency of the sampling program by sampling fewer fish per trip.

Ageing error

When ageing error was applied to bootstrap distributions of Gulf Menhaden proportions at age in the catch, we observed a lack of trend in relative error with increased sampling intensity (Figure 13). This lack of relationship indicates that increased sampling will not alleviate issues with ageing fish ages 3+. More accurate ageing techniques will be required to improve age composition estimation for the commercial catch.

Overall, relative error was low for fish age 1 (~6-13%), low to moderate for age 2 (~2-20%), moderately high for age 3 (~40-44%), and high for age 4 (~68-197%). With the exception of age 1, blind reads produced the same (age 3) or lower (ages 2 and 4) relative error than informed reads, suggesting that blind reading of Gulf menhaden scales may reduce ageing error

[2] Additional analyses for the Cameron, LA reduction plant are available online at http://bit.ly/2UTI0gh.

for age 4 fish. However, this may come at the cost of increased error in reading age 1 fish, which comprise the majority of the catch in recent years (SEDAR 2018). Our results suggest that including age 4 fish (based on informed reads) in the SCAA model used for stock assessment may result in the model chasing noise rather than tracking good year classes. In addition, consistency in the results of age composition analyses in this study between 2015 and 2016 suggest that changes in the primary scale reader at the NOAA Beaufort Laboratory during that time period did not result in obvious patterning or bias.

Study limitations

This study assumed that the available port sampling data from the Gulf Menhaden reduction fishery represented the full range of sizes and ages in the commercial catch. 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 with current resampling analyses. However, if Atlantic Menhaden results can be applied to Gulf Menhaden, it may be safe to assume that the current sampling program is capturing the full range of ages and sizes caught as evidenced by resampling of Atlantic Menhaden data from 1969 (Nesslage and Leaf 2019).

This study provides guidance on the ability of the current Gulf Menhaden port sampling program to characterize the size and age distribution of the commercial catch. This catch composition information is used to generate inputs to the stock assessment model such as the catch-at-age matrix. To determine the ultimate impact of these results on the SCAA assessment model outcomes, these resampled data sets would need to be passed through the data preparation and modeling processes in order to quantify the impact of the sampling program on model estimates. This is a natural next step and will be pursued in future studies.

Management impact

Prior to this study, the assumption that Atlantic Menhaden sampling targets could be reasonably applied to the Gulf Menhaden fishery was untested. Our results indicate that the Gulf Menhaden reduction port sampling program is adequate for characterizing the size composition of the catch, which is required for converting weight to number of fish landed the stock assessment. Also, we found that efficiency of the sampling program may be increased by sampling fewer fish per trip (minimum 4) without negatively impacting estimation of catch proportions at age. The Gulf States Marine Fisheries Commission's Menhaden Advisory Committee (MAC) will be presented with the results of this study and will use our results to decide if the sampling program achieves an adequate level of precision when characterizing the age composition of the catch, a critical input in the statistical catch-at-age model used for management. Upon reviewing the results of this study, the MAC may recommend future changes to the stock assessment model or to sampling targets requirements for future amendments to the Gulf Menhaden Regional Fishery Management Plan.

Acknowledgments

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Tables

Table 1. Summary of regions and plants evaluated in this simulation study.

Year	Sector	Region	Plant
2016	Reduction	Coastwide	All active
2015	Reduction	Coastwide	All active
2016	Reduction	Plant-specific	Moss Point, MS
2015	Reduction	Plant-specific	Moss Point, MS
2016	Reduction	Plant-specific	Empire, LA
2015	Reduction	Plant-specific	Empire, LA
2016	Reduction	Plant-specific	Abbeville, LA
2015	Reduction	Plant-specific	Abbeville, LA
2013	Reduction	Plant-specific	Cameron, LA
2012	Reduction	Plant-specific	Cameron, LA

Figures

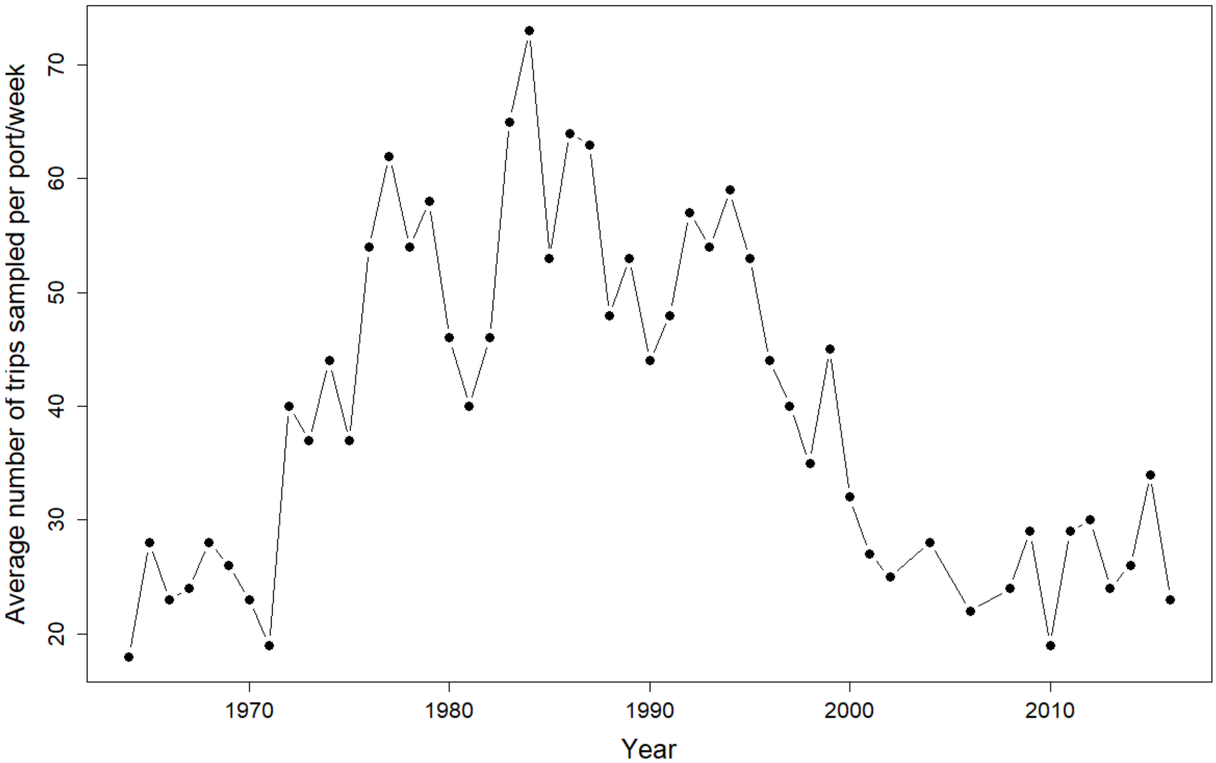

Figure 1. Average number of trips sampled across all plants per port/week in the Gulf Menhaden reduction fishery port sampling program.

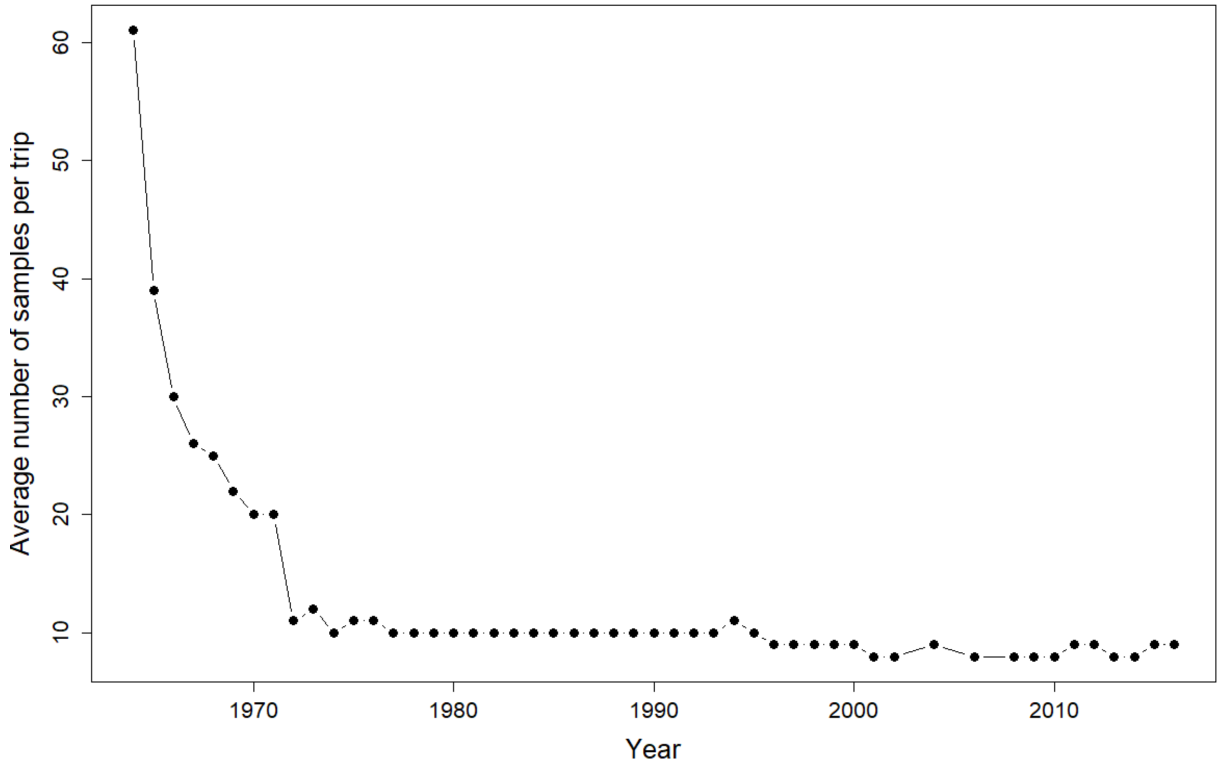

Figure 2. Average number of fish sampled per trip in the Gulf Menhaden reduction fishery port sampling program.

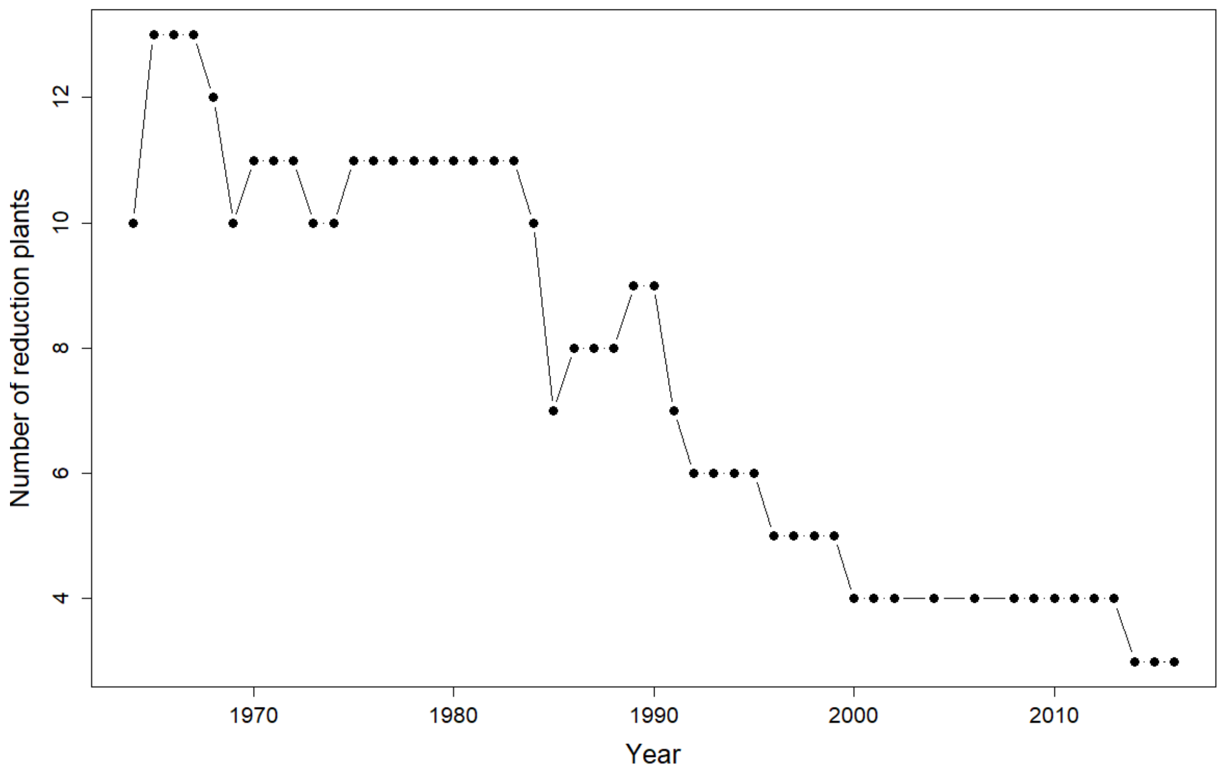

Figure 3. Number of Gulf Menhaden reduction plants since inception of the NOAA Beaufort Laboratory port sampling program in 1964.

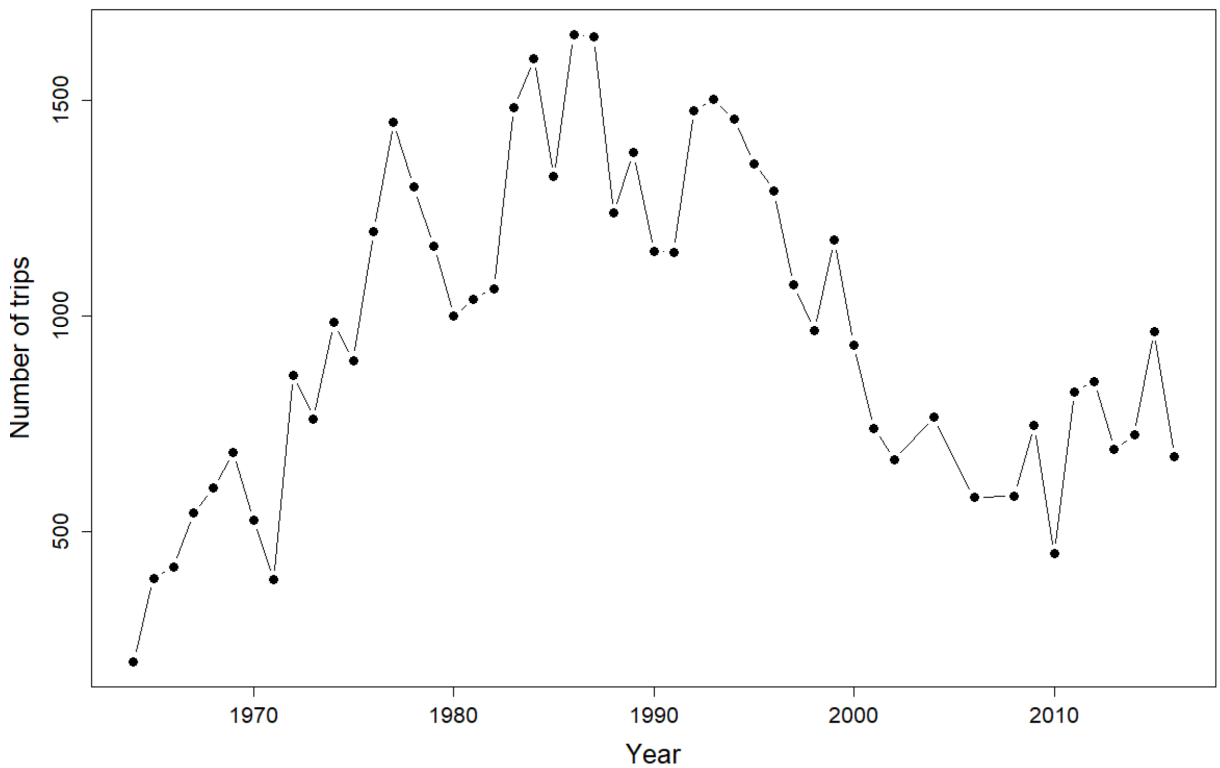

Figure 4. Number of trips sampled year across all plants in the Gulf Menhaden reduction fishery port sampling program.

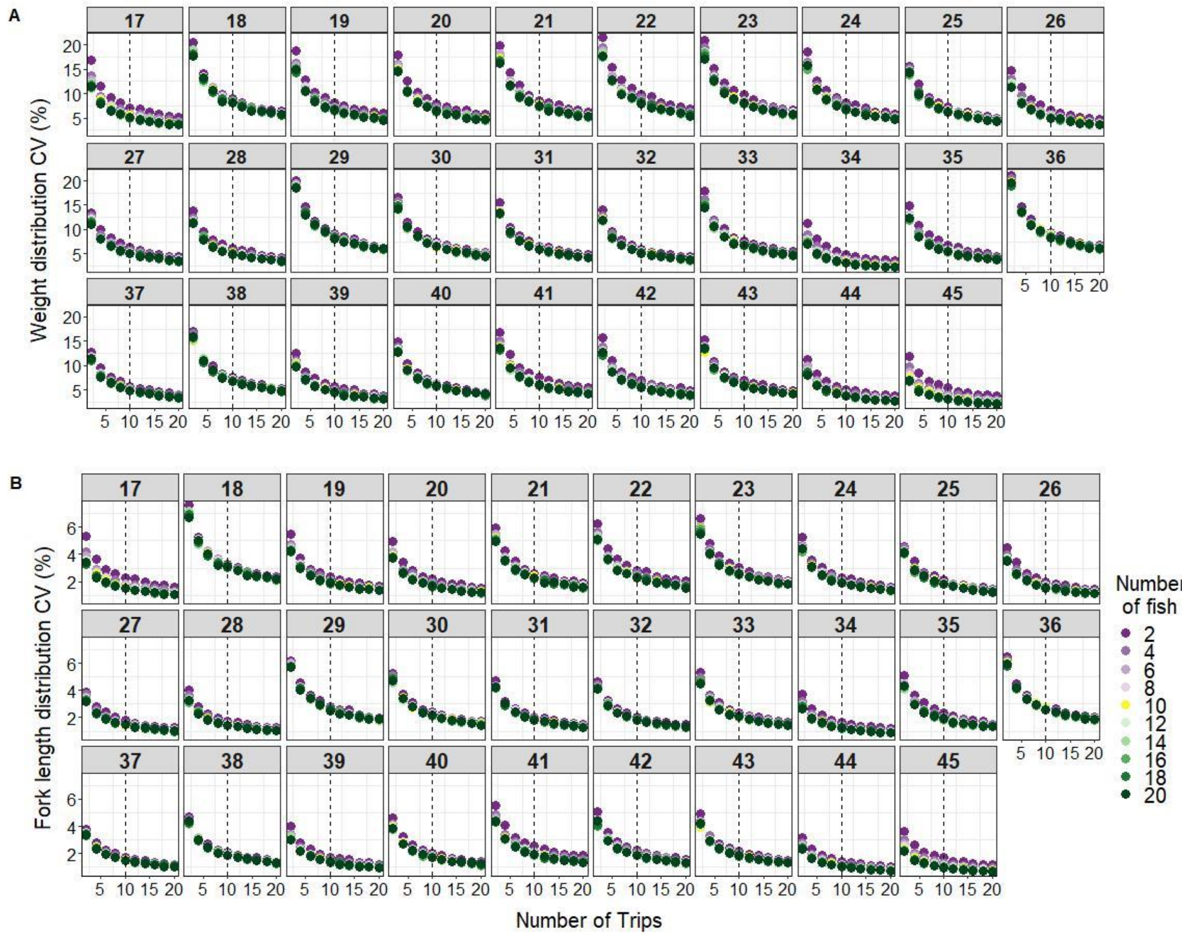

Figure 5. Bootstrap distribution coefficient of variation for Gulf Menhaden mean catch A) weight and B) fork length by resample size (x-axis: number or trips sampled per portweek; point color: number of fish samples collected per trip) for the coastwide reduction fishery, 2016. Panels represent portweeks for which adequate samples were available. A dashed bar indicates the current target of 10 trips per week and a yellow point represents the current target of 10 fish sampled per trip.

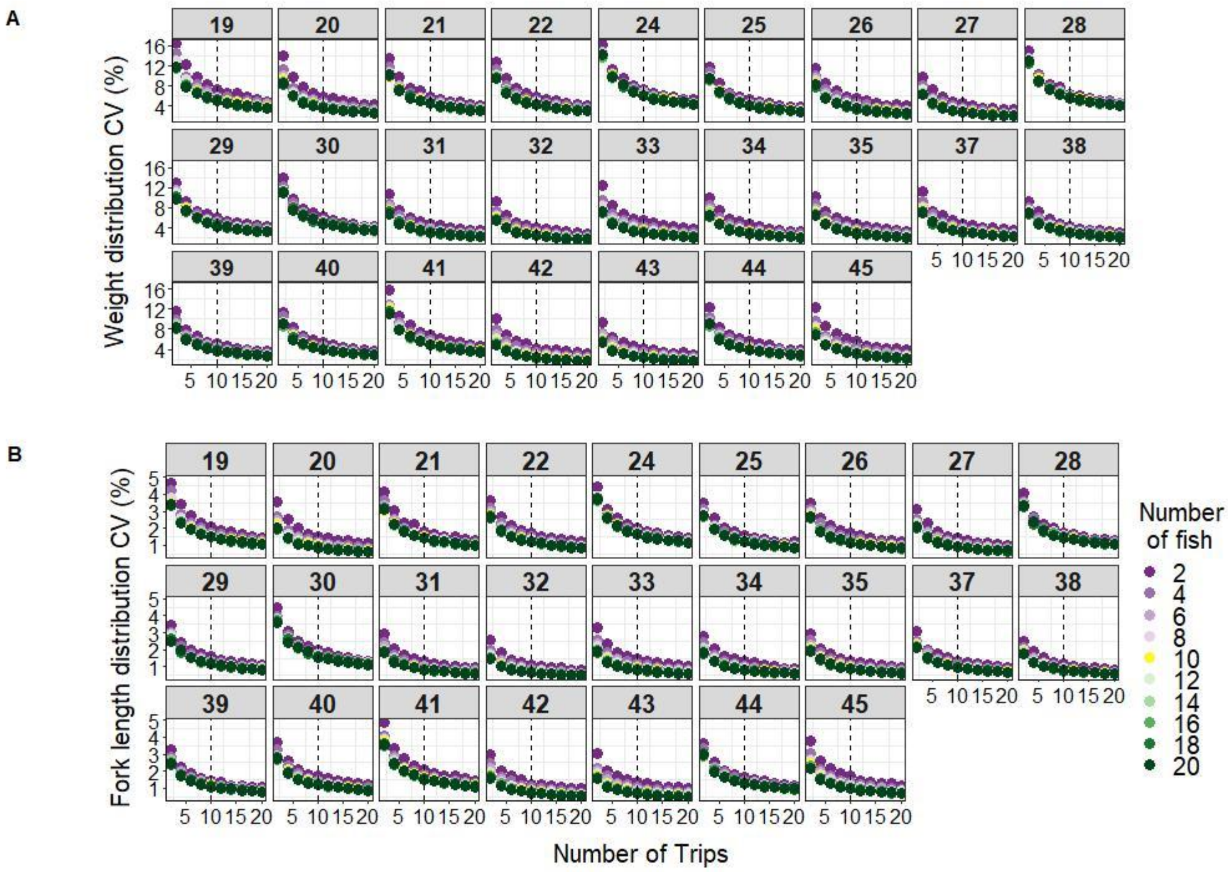

Figure 6. Bootstrap distribution coefficient of variation for Gulf Menhaden mean catch A) weight and B) fork length by resample size (x-axis: number or trips sampled per portweek; point color: number of fish samples collected per trip) for the Moss Point, MS reduction plant, 2016. Panels represent portweeks for which adequate samples were available. A dashed bar indicates the current target of 10 trips per week and a yellow point represents the current target of 10 fish sampled per trip.

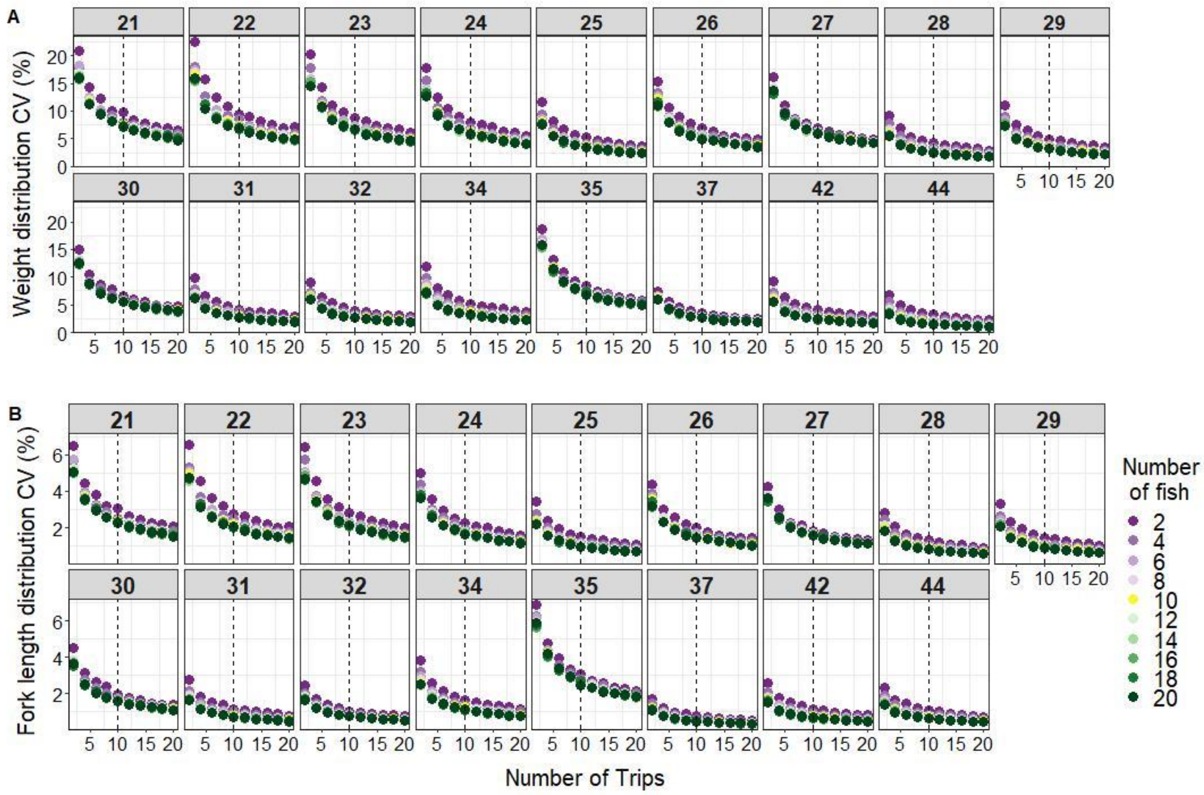

Figure 7. Bootstrap distribution coefficient of variation for Gulf Menhaden mean catch A) weight and B) fork length by resample size (x-axis: number or trips sampled per portweek; point color: number of fish samples collected per trip) for the Empire, LA reduction plant, 2016. Panels represent portweeks for which adequate samples were available. A dashed bar indicates the current target of 10 trips per week and a yellow point represents the current target of 10 fish sampled per trip.

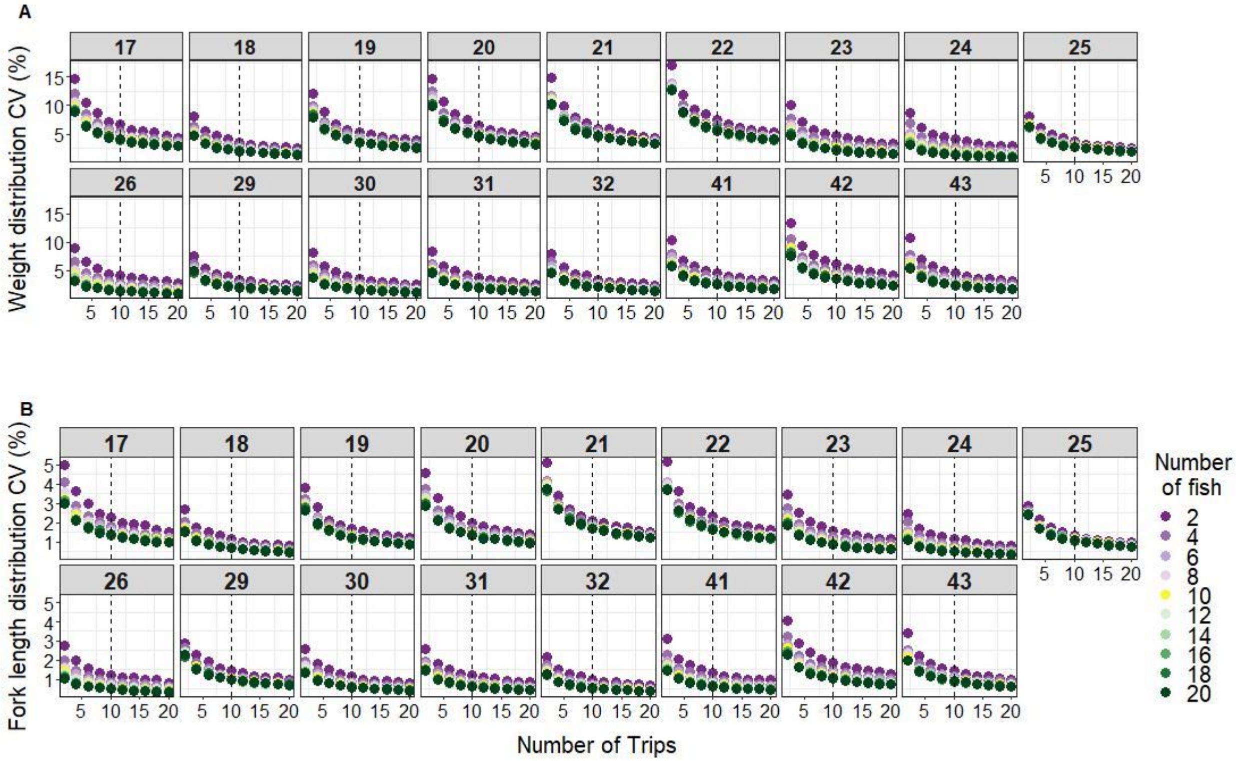

Figure 8. Bootstrap distribution coefficient of variation for Gulf Menhaden mean catch A) weight and B) fork length by resample size (x-axis: number or trips sampled per portweek; point color: number of fish samples collected per trip) for the Abbeville, LA reduction plant, 2016. Panels represent portweeks for which adequate samples were available. A dashed bar indicates the current target of 10 trips per week and a yellow point represents the current target of 10 fish sampled per trip.

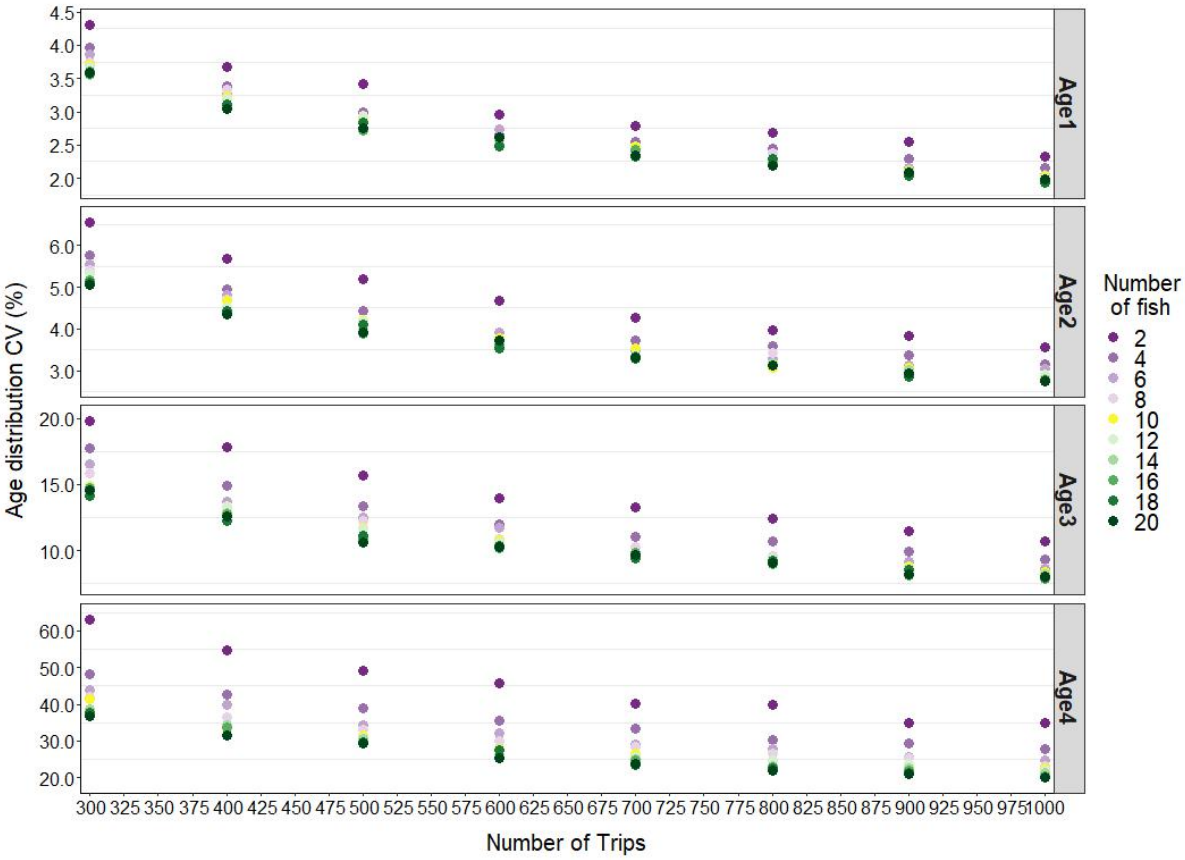

Figure 9. Bootstrap distribution coefficient of variation for Gulf Menhaden proportions at by resample size (x-axis: number or trips sampled per portweek; point color: number of fish samples collected per trip) for the coastwide reduction fishery, 2016. Yellow points represent the current target of 10 fish sampled per trip.

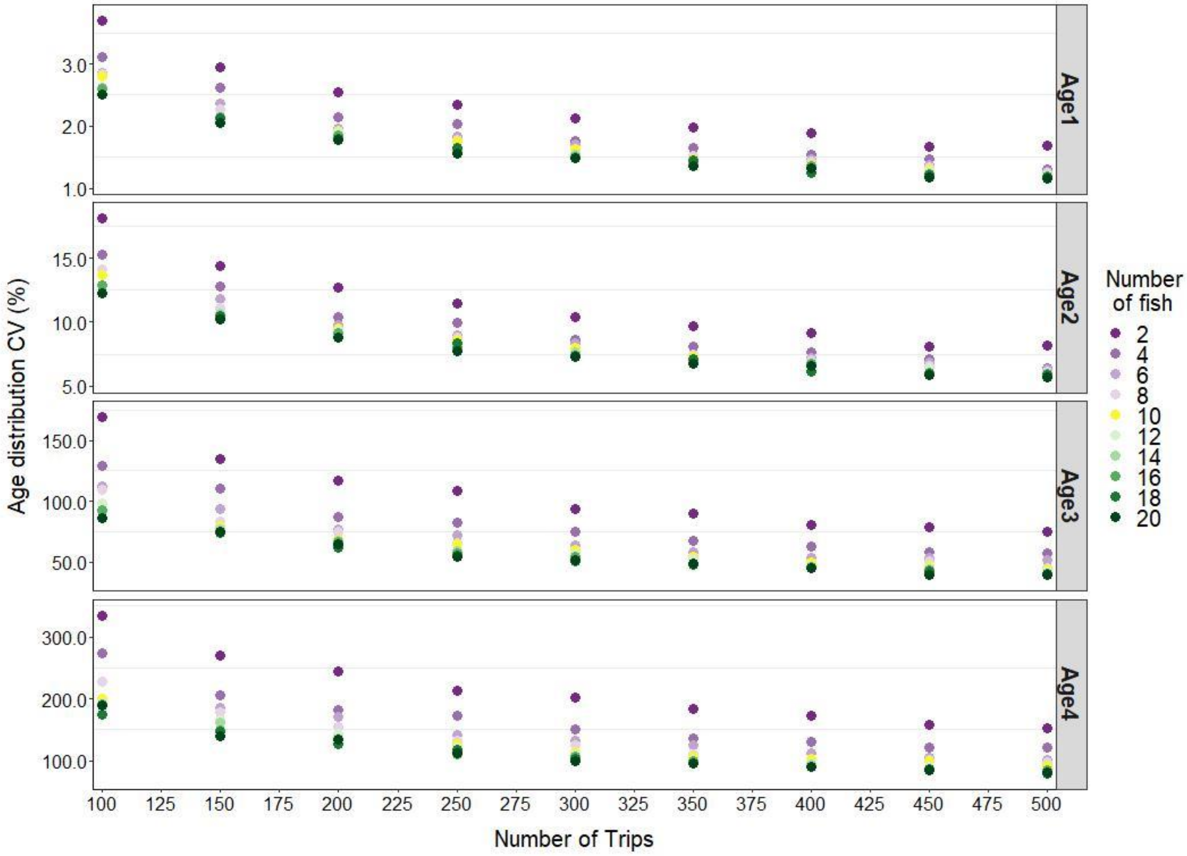

Figure 10. Bootstrap distribution coefficient of variation for Gulf Menhaden proportions at by resample size (x-axis: number or trips sampled per portweek; point color: number of fish samples collected per trip) for the Moss Point, MS reduction plant, 2016. Yellow points represent the current target of 10 fish sampled per trip.

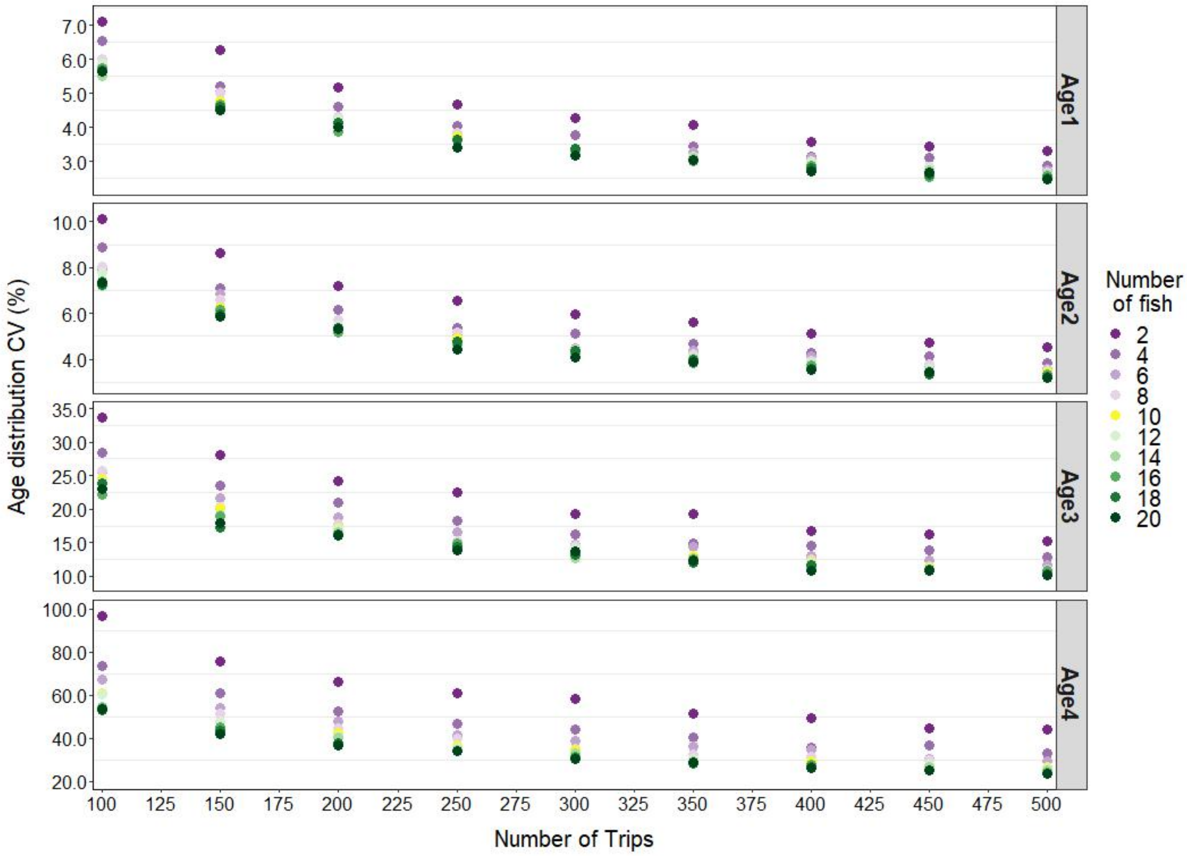

Figure 11. Bootstrap distribution coefficient of variation for Gulf Menhaden proportions at by resample size (x-axis: number or trips sampled per portweek; point color: number of fish samples collected per trip) for the Empire, LA reduction plant, 2016. Yellow points represent the current target of 10 fish sampled per trip.

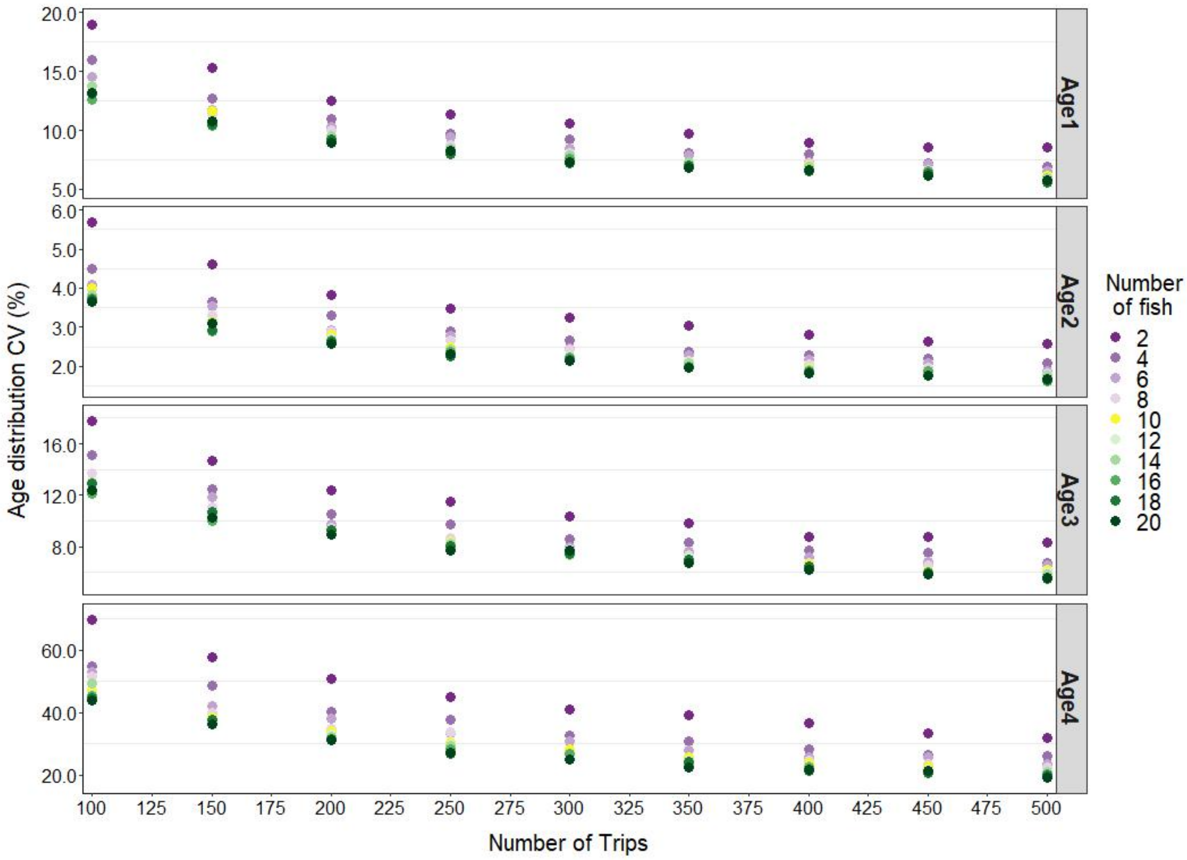

Figure 12. Bootstrap distribution coefficient of variation for Gulf Menhaden proportions at by resample size (x-axis: number or trips sampled per portweek; point color: number of fish samples collected per trip) for the Abbeville, LA reduction plant, 2016. Yellow points represent the current target of 10 fish sampled per trip.

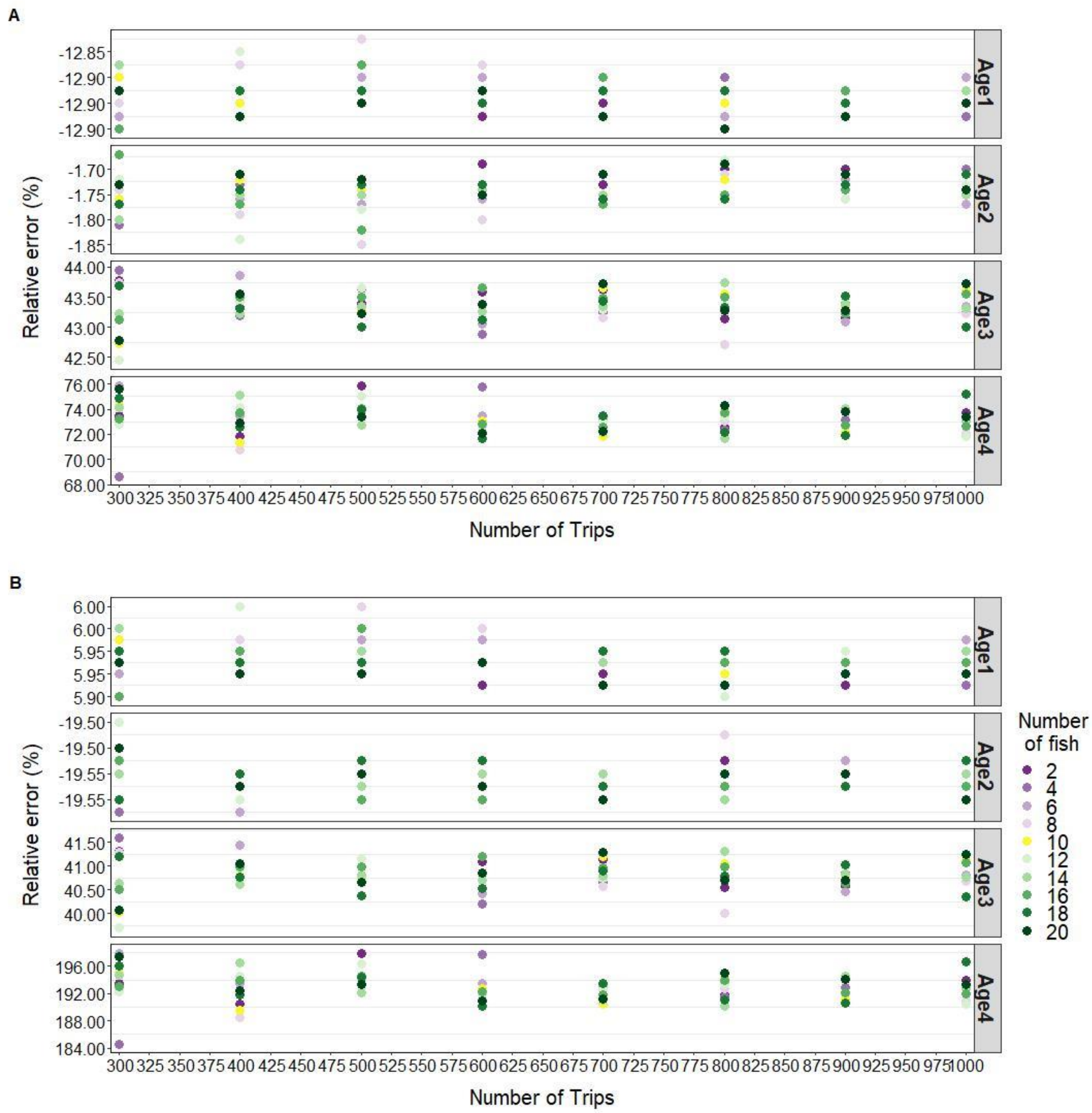

Figure 13. Estimated relative error in Gulf Menhaden proportions at age by resample size (x-axis: number or trips sampled per portweek; point color: number of fish samples collected per trip) for the reduction fishery, 2016. Panel A represents relative error generated using an ageing error matrix from blind reads and Panel B represents relative error generated using an ageing error matrix from informed reads. Yellow points represent the current target of 10 fish sampled per trip.

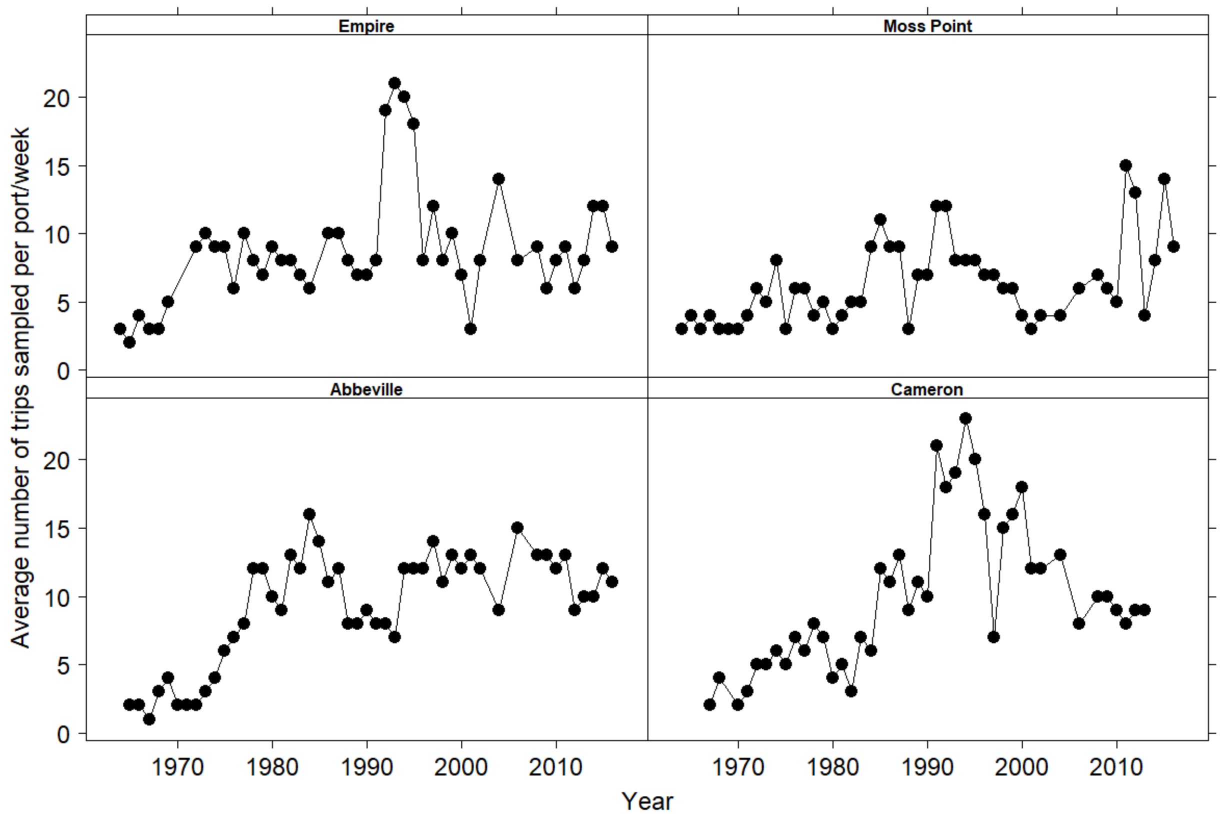

Figure 14. Average number of trips sampled per port/week in the Gulf Menhaden reduction fishery port sampling program by recently active plant.

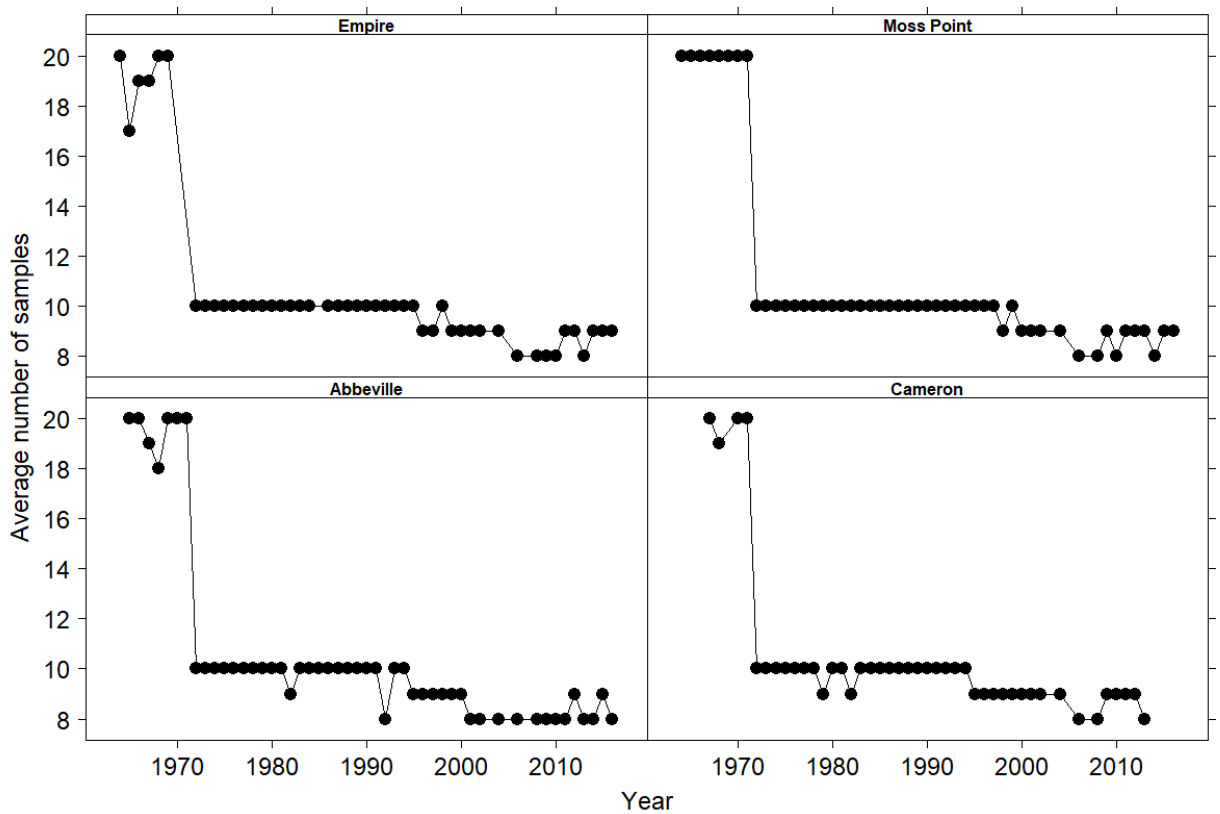

Figure 15. Average number of individual fish sampled per trip in the Gulf Menhaden reduction fishery port sampling program by recently active plant.

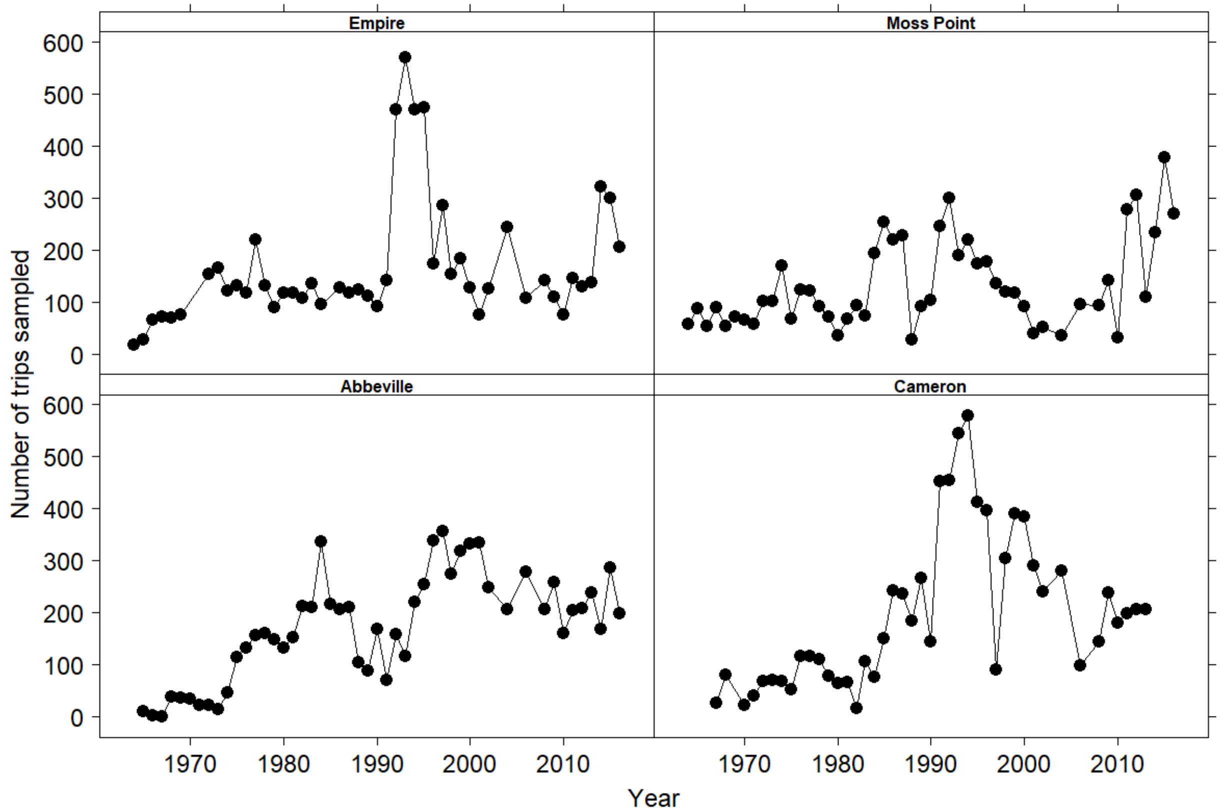

Figure 16. Total number of trips sampled per year in the Gulf Menhaden reduction fishery port sampling program by recently active plant.

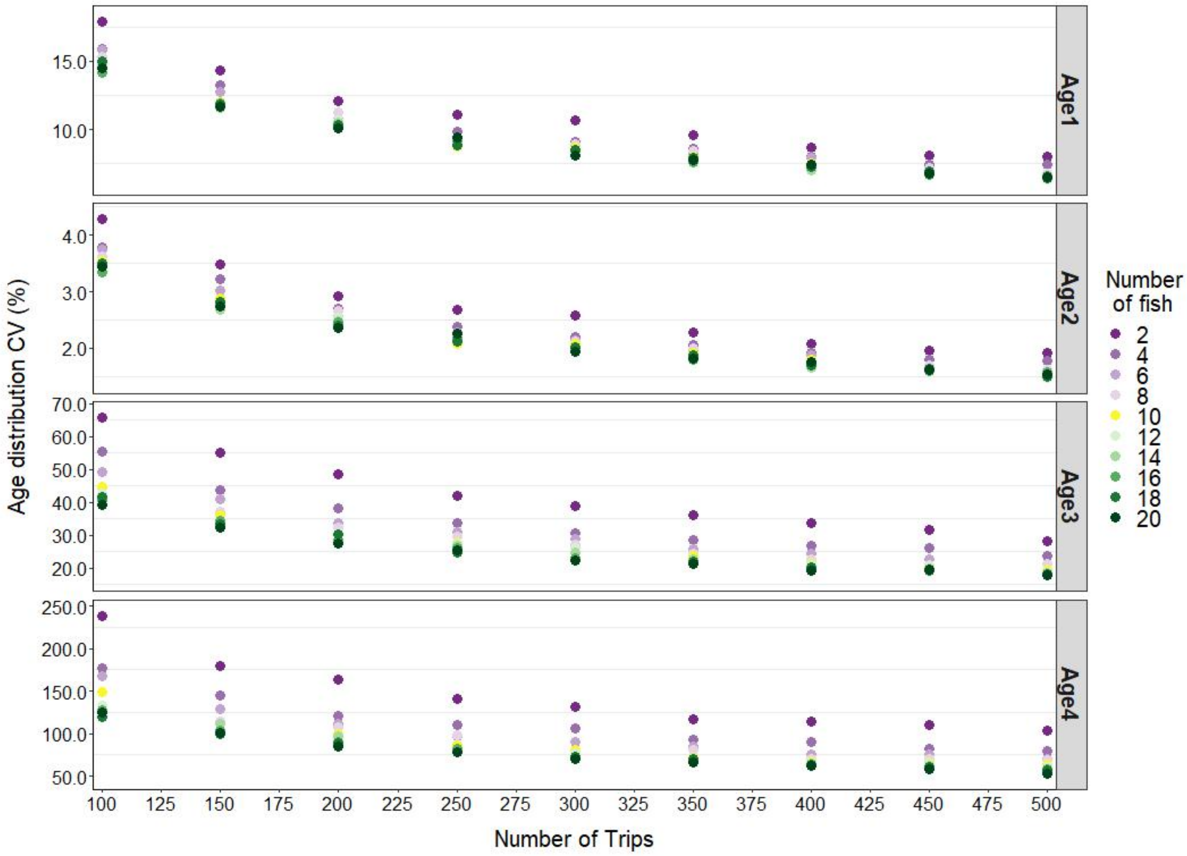

Figure 17. Bootstrap distribution coefficient of variation for Gulf Menhaden proportions at by resample size (x-axis: number or trips sampled per portweek; point color: number of fish samples collected per trip) for the Cameron, LA reduction plant, 2013. Yellow points represent the current target of 10 fish sampled per trip.