Design of a cooperative winter survey for Atlantic menhaden

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Introduction

Purpose

The purpose of this report is to describe the scientific design of a collaborative (industry/academic) survey for Atlantic menhaden (*Brevoortia tyrannus*; Figure 1). The goal of this survey is to gather critical fishery-independent information about the biomass, spatial distribution, and structure of the portion of the menhaden stock inhabiting shelf waters off New Jersey in winter. We anticipate that data collected during the pilot year will provide the information needed to refine and improve this survey design. Feedback from fishery collaborators, Atlantic States Marine Fisheries Commission Menhaden Technical Committee members, and acoustic survey experts will be incorporated into the final design prior to implementation.

This survey design focuses on the shelf waters off New Jersey in winter for two reasons. First, lack of knowledge about the northern portion of the menhaden stock in winter has significant management consequences. A winter midwater trawl fishery targeting menhaden as bait began around 2014. Biological samples are regularly collected from this fishery as required in Amendment II (ASMFC 2012); however, the limited number of fishery-dependent samples collected likely provides insufficient information about the local stock as a whole. Additional fishery-independent information about the northern resident stock in winter is needed to ensure development of a sustainable bait fishery.

Second, lack of knowledge about the northern portion of the menhaden stock may have significant assessment consequences. The data that most strongly inform the current stock assessment are landings and biological samples obtained from the reduction fishery which concentrates effort in and near the Chesapeake Bay (ASMFC 2017, SEDAR 2015). The menhaden stock assessment assumes a dome-shaped fishery selectivity curve to account for the limited spatial distribution of the fleet relative to the coastwide distribution of the stock (ASMFC 2017, SEDAR 2015). As a result, the assessment estimates a large biomass of adult menhaden rarely encountered by the reduction fishery. Field confirmation of this cryptic biomass would expand our understanding of the menhaden stock as a whole. This survey would provide information about the biomass of menhaden located off New Jersey in winter for comparison with information used in the coastwide stock assessment.

Design rationale

We propose data collection using a combination of acoustics and midwater trawling in order to locate, identify, assess structure, and estimate biomass of menhaden in the shelf waters off New Jersey in winter. We focus on New Jersey in winter in part because it is the location and timing of a relatively new bait fishery. However, the scientific community may also find this region and season of interest given the development of new information about menhaden migration and spatial distribution that has been published since the last benchmark assessment (SEDAR 2015).

During the summer, menhaden migrate and spatially stratify along the coast such that larger, older fish are typically encountered at higher latitudes (ASMFC 2017). Until recently, scientists assumed that most spawning-age menhaden migrate south in winter to congregate offshore south of Cape Hatteras. However, recent re-analysis of historical tagging data indicates the presence of resident menhaden populations coastwide in winter (Liljestrand 2017). Also, recent analysis of long-term ichthyoplankton survey data corroborates the year-round presence of spawning menhaden across the Mid-Atlantic (Simpson et al. 2017, Simpson et al. 2016). Finally, the development of a successful bait fishery off New Jersey provides additional evidence of the presence of resident adult menhaden in winter. These new studies and fishery highlight the need to better characterize the northern resident menhaden stock, a portion of which would be covered by the survey described in this report.

In addition, the proposed winter timing of this survey may help lessen typical survey challenges such as vessel avoidance and double counting of mobile schools within and among transects. Menhaden are known to prefer temperatures of 15-20°C and align migration timing with shifts in the 10°C isotherm (Goode 1879, Reintjes 1969). New Jersey bait fishermen report menhaden form monospecific, sedentary schools and do not avoid sonar or the vessel once water temperatures drop to 4-6°C around February (S. Axelsson, *pers. comm.*). Thus, surveying during winter when menhaden schools are less mobile will help mitigate the potential bias associated with vessel avoidance and double counting of schools.

To adequately survey for menhaden, gear type and depth must be carefully considered because menhaden appear to school well below the surface but above the sea floor in winter. In most bottom trawl surveys, menhaden are captured at extremely low rates (SEDAR 2015). Thus, an aerial survey has been proposed for monitoring menhaden when schools are located near the surface in late summer to early fall (Latour 2013). However, an aerial survey will not suffice in winter because menhaden do not school at the surface between January and March (Ahrenholz 1991, June and Reintjes 1959, Reintjes 1969, Smith 1991). New Jersey bait fishermen report that menhaden form large schools below the surface but above the sea floor in winter (S. Axelsson, *pers. comm.*); thus gear operating at either the bottom or the surface will not be appropriate for surveying menhaden in winter.

Therefore, we propose to survey for menhaden in winter using a combination of acoustics and midwater trawling. This collaborative survey was designed to collect data using acoustic equipment currently used by the fishing industry, namely a combination of downward-viewing echosounders and omnidirectional sonar (Bernasconi et al. 2009, Brehmer et al. 2006, Stockwell et al. 2012). We propose a combination of sonar and echosounder data collection over the traditional use echosounders or trawling alone because sonar can cover a larger volume of water in a limited amount of time (Brehmer et al. 2006, Fässler et al. 2016, Hewitt 1976, Jones et al. 2017, Misund et al. 1995, Simmons and MacLennan 2005). Comparison of echosounder vs. sonar data collected from the same vessel indicates that sonar can encounter one to two orders of magnitude more school targets in the same amount of time (Hewitt 1976). Given menhaden schools are patchily distributed across the landscape, a comprehensive acoustic survey of biomass with trawl-based biological sampling is proposed below.

Survey Design

Timing and study area

The survey will be conducted in February when water temperatures drop to ~4-6ºC and menhaden schools exhibit greatly reduced mobility (S. Axelsson, *pers. comm.*). The study area includes the region extending 15-50 mi offshore from the southern border of Hudson Canyon in the north to the New Jersey/Delaware border in the south (Figure 1). The nearshore border of the survey area extends from 15 mi offshore the Manasquan Inlet area (73°44'56.4919"W 40°5'23.5729"N) southward to 15 mi offshore the New Jersey/Delaware border (74°46'20.0811"W 38°27'5.5581"N). The offshore border of the survey area extends from 50 mi offshore the Manasquan Inlet area (73°8'43.323"W 39°48'20.347"N) southward to 50 mi offshore the New Jersey/Delaware border (74°7'40.7701"W 38°27'5.5208"N; Figure 1).

This study area was chosen to represent the region off the New Jersey coastline in which the winter bait fishery typically operates and menhaden bycatch is concentrated (Figure 2). Also, the inshore limit was chosen so as not to overlap with winter tows of the NJ Ocean Trawl Survey (max extent ~13 miles offshore) and to focus on areas further offshore where adult menhaden are typically encountered (Figure 3, Figure 4). Midwater trawl fishery Vessel Trip Reports (VTRs) from 2014-2017 and logbooks voluntarily collected by the fishermen for this project during the 2018 fishing season, indicate schools of menhaden were caught at a mean depth of 38m (median 37 m; range 22-139 m) during January and February. The offshore limit was defined as the approximate maximum distance reported in midwater trawl VTRs (2014-2017) and all Northeast Fisheries Observer Program (1989 and 2016) reports within the study area in winter which happens to roughly follow the 50m isobath (Figure 2). Menhaden have been caught in winter bottom trawls in small numbers (relative to midwater trawls) and at greater distances from shore north of Hudson Canyon up to a max of ~250m and ~80 miles offshore (winter NEFOP data; Reintjes 1969). However, due to logistical and budget constraints, we limited the study area to 50 miles off the coast of New Jersey which represents the typical maximum extent of the local midwater trawl bait fishery in winter.

Given the lack of information about how menhaden utilize pelagic habitat in this region and season, it was deemed better not to stratify than to incorporate inappropriate strata

(Simmonds and Fryer 1996, Simmons and MacLennan 2005). Once pilot data are collected, it may become obvious that stratification is needed to more accurately estimate menhaden biomass and the survey design will be modified accordingly.

Simulation study to determine design

A spatially explicit simulation study was conducted to compare accuracy of biomass estimates among alternative survey designs and justify the recommended total transect distance to sample in the pilot year. Our analyses were based on limited available fishery-dependent data from this region and season, published literature, and local fishermen's knowledge. With collection of pilot data, we anticipate this design will be revised to improve biomass estimation and survey efficiency.

Fishery-dependent and environmental data

A combination of fishery-dependent and environmental data was used to simulate the potential distribution of menhaden schools across the study area. Two sources of fishery-dependent menhaden data were available from the study region in the winter season to help inform simulations. The first data source was menhaden bait fishery Vessel Trip Reports (VTRs) provided by NOAA Fisheries Greater Atlantic Regional Office with permission of the fishermen spanning the start of the fishery in 2014 to 2017. Second, a logbook designed for this project (Appendix 1) was kept voluntarily by the fishermen during the 2018 winter fishing season to obtain information on schools encountered (location, depth, temperature, lbs kept) and encounter rate (distance and time searched).

Monthly bottom temperature and salinity estimates were obtained from 0.2 degree monthly hydrographic climatology generated for the Mid-Atlantic Bight continental shelf (Richaud et al. 2016; https://www2.whoi.edu/staff/ykwon/data). Bathymetry data were obtained from NOAA's National Centers for Environmental Information U.S. Coastal Relief Model (https://www.ngdc.noaa.gov/mgg/coastal/crm.html).

Spatial distribution of schools - Poisson process model

Several features of the available commercial menhaden data pose challenges to a classical Point process model (Diggle 2013). Specifically, the occurrences of menhaden schools encountered by fishermen are not randomly sampled, and they were observed over dynamic environmental conditions. We used a dynamic Point process model to predict the presence of successful trips given the environmental conditions. Specifically, we assumed that the fisheries data follow a dynamic Poisson process with intensity $\lambda(u,t)$ for any possible cruise location u in the study area S and time step t. S represents the hypothetical collection of all possible cruise locations.

$$\log\big(\lambda(u,t)\big) = Z(u,t)^{\mathrm{T}}\beta \tag{1}$$

The term $Z(u,t)^T$ is the transpose (T) of a vector of time-varying environmental covariates depending on location $u \in S$ and time t, and β denotes the coefficient of interest.

The existing environmental covariates are distributed at multiple spatial resolutions, resulting in spatial misalignments between the covariates. We aligned the environmental layers onto a common ~500 "meter" resolution using the R package raster (Hijmans 2017). Parametric linear as well as additivity trends were fitted for each covariate during the fisheries observation period. Statistical inference was based on a computational efficient approximation of the intractable dynamic Poisson process likelihood, implemented in the R package spatstat (Baddeley et al. 2015). The additive trends were estimated using the R package mgcv (Wood 2011).

The predicted spatial patterns of encounter intensity (expected number of successful trips per unit area per winter month, Figure 5) demonstrated the uncertainty of school responses to oceanographic conditions. The school distribution based on linear covariates showed more variability across the study area (Figure 5a) than the patterns based on non-linear latitude effect (Figure 5b). Both predictions exhibit increased intensity offshore near the middle of the study area. The northern part of the study area exhibited lower encounter rates.

We simulated the spatial distribution of schools determined by the fitted Poisson process map representing the intensity of catching a school (Figure 5). The VTR data were re-sampled to represent the hypothetical number of trips required to catch the entire population. The re-sample size was determined based on fishery encounter rates with menhaden schools observed in the field. During the 2018 winter fishing season, encounter rates were around 1 school per hour or 0.43 schools per mile. The corresponding maximum number of simulated schools encountered per transect were around 7 and 15. Thus, the re-sample size was altered to between 40 and 400 to match the observed rates. Re-sample sizes of 50 and 100 similar VTR trips best represented the 2018 encounter rates (Table 1). The simulated total biomass represented a small proportion of the coastwide stock assessment estimate of menhaden biomass; re-sample sizes of 50 and 100 corresponded with ~15% and ~31% of the total biomass estimated in 2000, the year with lowest estimated coastwide biomass (ASMFC 2017).

School density - local kriging

School density encountered was determined by distribution of observed fishery catches (Figure 6). We used local kriging to align the simulated schools with the observed catch data. Specifically, a global variogram analysis was conducted for the catches to estimate its extent of spatial correlation, i.e. the distance beyond each simulated school at which the catches exhibit no dependence. The estimated extent of correlation was used to define a neighborhood around each simulated school. Optimal interpolation was conducted within the neighborhood to predict the catch at each school location. Kriging was implemented using the R package automap given the large number of simulations (Hiemstra et al. 2009).

Sampling design

For each set of simulated populations, sampling was conducted according to seven strategies assuming various detectabilities and number of vessels. The survey area was first divided into parallel transects with major axes perpendicular to the shoreline (Figure 7). Transect lengths varied due to the irregularly shaped survey area. A systematic random sampling design was chosen to select fixed number of transects (Figure 7). A systematic design was chosen due to its superior predictive performance for spatially structured populations (Overholtz et al. 2006). Sample size (i.e. the number of transects) were a priori chosen based on the assumed duration of the survey. Specifically, five to twelve transects were considered realistic for the given survey budget.

The seven sampling strategies simulated are defined below.

1. Downward-viewing echosounder only used to estimate biomass for each school encountered within the narrow detection distance beneath the vessel (20m).
2. Downward-viewing echosounder (same as Option 1) used to estimate the biomass of each school encountered. In addition, omnidirectional sonar is used to detect schools within 400 meters each side of the vessel to estimate the number of additional schools encountered. The average biomass identified using the downward-viewing echosounder was multiplied by the number of schools identified by sonar to estimate the total biomass along each transect (Lucca and Warren 2018).
3. Sonar used to identify locations of all schools within 400 meters each side of the vessel. Down-viewing echosounder is then used to estimate biomass of each encountered school. Total biomass is aggregated based on all down-viewing estimates.
4. This option is similar to Option 3, except one vessel is used to identify the menhaden schools using sonar and a second vessel physically trawls each identified school along the transect. Total biomass is aggregated based on the sum of biomass trawled.

Options 5-7 are similar to options 2-4 expect that a 200-meter detection distance each side of the vessel is assumed instead of 400 meters. Both 1 and 2 vessel scenarios (Options 3-4 and 6-7) were simulated to explore logistical considerations.

Data analyses

A design-consistent estimator of total biomass was used to obtain total biomass. Due to the intractable variance estimator of the systematic random sampling, a conservative estimator was used based on simple random sampling. In addition to design consistent estimation, a ratio estimator was also used to incorporate the varying lengths of transects as auxiliary information. Given that the survey catches are likely proportional to the transect lengths, a ratio estimator can provide superior estimation to classical design-consistent estimators.

Monte Carlo simulation was performed to evaluate the seven design options. For each Monte Carlo replicate $m = 1, \ldots, M$, a finite population of menhaden was generated from the predicted intensity of the fitted point process model. Systematic random sampling was conducted based on each option. Let B_m denote the simulated total biomass for a Monte Carlo sample and let $\hat{B}_{mj}$ denote the corresponding biomass estimate based on design option j. Let y_{imj} denote the biomass at transect i and L_{imj} the corresponding transect length. Let T denote the total number of transects in the sampling frame, n denote the sample size (i.e. number of transects), and define $L = \sum_{i=1}^{T} L_i$, the total length of the all transects. The design-consistent and ratio estimators are defined as follows:

$$\hat{B}_{mj,\text{design}} = T \sum_{i=1}^{n} y_{imj} \quad \text{and} \quad \hat{B}_{mj,\text{ratio}} = \frac{L \sum_{i=1}^{n} y_{imj}}{\sum_{i=1}^{n} L_{imj}} \tag{2}$$

The average biomass over Monte Carlo simulation B_0 was used as the true biomass. We computed the coefficient of variation (CV) as

$$\text{CV}_j = \frac{\sum_{m=1}^{M} \left(\hat{B}_{mj} - B_0\right)^2}{M \times B_0} \text{ where } B_0 = \frac{1}{M} \sum_{m=1}^{M} B_m \tag{3}$$

The coefficient of variation incorporated both spatial variability of schools encountered (captured by the Poisson process model; Figure 5) and the sampling variability (Figure 7). Both design-based and ratio-based estimation were conducted for each sample, but the type of estimator was omitted in equation (3) for brevity of notation.

For comparison, the traditional preliminary estimate of necessary sampling effort was calculated based on the degree of coverage (p. 29; Simmons and MacLennan 2005). In this calculation, the coefficient of variation was related to the total transect length sampled without considering the spatial heterogeneity of encounter rates.

$$\text{CV}_j^0 = \frac{0.5}{\sqrt{\Lambda_j}} \text{ , } \Lambda_\text{j} = \frac{D_j}{\sqrt{A}} \quad \text{and } D_j = \frac{1}{M} \sum_{m=1}^{M} D_{mj} \tag{4}$$

Here D_j is the average total transect length sampled over individual samples D_{mj}, and A is the survey area, Λ_j is the degree of coverage.

Simulation results

Options for down-viewing echosounder use (Option 1) and expansion of average biomass estimated from the down-viewing echosounder to schools spotted with sonar (Options 2 and 5) generated CVs between 200% and 400% (Figure 8). Lower CVs between 30% and 60% were generated by other options that involved both down-viewing echosounder and sonar using either one vessel (Figure 8Options 3 and 6) or two vessels (Options 4 and 7; Figure 8). The average cumulative transect distance sampled ranged between 120km and 300km across all options. Accuracy increased with increasing total distance surveyed. Narrower side scan swaths (400m; Options 5-7) generated lower accuracy than wider swaths (800m; Options 2-4) with the same survey effort. In general, the ratio estimator that accounted for unequal transect lengths generated more accurate estimates than the naïve design based estimator.

Simulation-based CVs were larger than those predicted by degree of coverage theory (Aglen 1989) and used for planning acoustic surveys (Parker-Stetter 2009, Simmons and MacLennan 2005). The extent of exceedance depended on the encounter rate, design options, and the choice of estimator. Simulated CVs were much higher for this schooling population with sparse encounter rate due to the narrow echosounder swath widths assumed. When a higher encounter rate was simulated using 100 re-samples of the VTR data (Figure 5), survey design Options 3 and 4 (800m swath) generated similar CVs as those predicted by degree of coverage theory Figure 9. The rate of change in CV per additional transect length was linear under the simulation as opposed to the super-linear decrease predicted by degree of average theory.

Qualitatively similar results (Appendix 2 - Figures 2-3) were obtained when we simulated school intensity using an alternative fitted Poisson process model (Figure 5b).

Conclusions and caveats

Our simulation study indicated a traditional acoustic survey that uses a down-viewing echosounder only will not be adequate for estimating biomass across the study area given the patchy distribution of menhaden schools and the limited resources available. Only scenarios where schools are first located via sonar then measured via trawl or echosounder produced more acceptable CVs (Options 3, 4, 5, 6). We anticipate the 800m detection distance (400m each side of the vessel) assumed in Options 3 and 4 is reasonable given the equipment readily available on industry vessels. Given these simulation results and a desire to minimize survey costs, we recommend a hybrid of Options 3 and 4 be implemented in the pilot year such that one midwater trawler with appropriate recordable acoustic equipment conduct the survey as described below.

Some caveats to our simulation study should be noted. We assumed the biomass of all schools encountered along the transect was estimated with 100% accuracy whether captured via trawl or measured with an echosounder. However, midwater trawls may not always be able to capture entire schools of menhaden and there is considerable uncertainty in acoustic estimation of biomass (Simmons and MacLennan 2005). Also, an echosounder swath width of 20m was assumed given limitations on the minimum resolution of the imagery used to spatially model menhaden school intensity. However, the actual diameter of the echosounder cone beneath the vessel will vary based on depth, salinity, and temperature (Simmons and MacLennan 2005). Therefore, the CV estimates generated by this simulation study should be used to weigh the relative merits of alternative survey design options and not be used as an estimate of anticipated survey estimate precision. With additional pilot survey data, more realistic estimates of uncertainty can be generated.

Acoustic data collection

Coverage and effort

This survey would ideally be conducted by one midwater trawler equipped with appropriate omnidirectional sonar and recordable echosounder equipment. Due to vessel hold limitations and a desire not to discard menhaden overboard, we recommend a combination of trawl sets and echosounder data collection (hybrid of simulation Options 3 and 4) to obtain additional information about schools encountered within a specified sonar detection distance as described below (see Two-stage sampling).

Given the robust performance of systematic designs in acoustic surveys (Fiedler 1978, Overholtz et al. 2006, Simmonds and Fryer 1996), we recommend systematic transects be run perpendicular to shore beginning at a random starting latitude between 73°44'56.4919"W 40°5'23.5729"N and 73°51'57.8296"W 39°38'15.5024"N in order to ensure transect coverage is not replicated among years. The survey will proceed southward across the study area (Figure 1, Figure 10) to minimize the distance needed to return to port in Cape May, NJ to offload. Based on our simulation study, we recommend between 300 and 400 km of transects be surveyed to minimize uncertainty in biomass estimates (Figure 8, Figure 9). Transects will be of variable length due to the irregular shape of the study area and the random start location. Depending on the randomized start location, approximately 6-7 transects will be surveyed with either 26 or 23 km between transects, respectively, in order to distribute effort across the study area and avoid double counting of mobile schools, if present (example: Figure 10).

We estimate the survey will require approximately 11 days. This estimate assumes a 10-hour work day and approximately one quarter of survey time will be spent trawling or collecting acoustic data on schools encountered (Simmons and MacLennan 2005). This estimate also includes time to reach the first transect, move between transects, and return to port from the last transect based on an assumed speed of 8 knots. Total time also includes three 1-day offload events and one day near port for calibration of the echosounder.

Two-stage sampling

The skipper will monitor echosounder and sonar displays to locate schools within the specified detection distance, permitting the identification of more fish schools along the transect than a down-viewing echosounder alone (Hewitt 1976, Misund et al. 1995, Stockwell et al. 2012). Although most sonar can detect schools 800-1200m from the vessel depending on depth, bottom type, temperature, and salinity (Brehmer et al. 2007, Brehmer et al. 2006), we recommend data collection be restricted to schools detected within an observation window of 400m from the vessel based on the expected minimum distance available sonar can reliably detect schools at the lowest depths in the study area (~20m) and the results of previous sonar surveys (Brehmer et al. 2007, Hewitt 1976, Mackinson et al. 1999, Misund et al. 1995, Stockwell et al. 2012). If possible, sonar data will be recorded as well along the transect (Stockwell et al. 2012).

The skipper will scrutinize acoustic backscatter and identify menhaden schools based on expert judgement. Fishermen report that menhaden schools are easily distinguished from similar schooling species such as Atlantic herring during winter such that menhaden appear less densely packed within a school (S. Axelsson, *pers. comm.*). When a menhaden school is identified within 400m from the transect, the vessel will collect echosounder data on each school by passing over it at a speed of 4kn, ideally twice along two perpendicular axes to determine if orientation of schools is random across the study area (Simmons and MacLennan 2005). To collect target strength information, echosounder data should be collected while hovering over the school as well; if time and opportunity allows, hovering over a school while it disperses would provide ideal target strength data.

A subset of schools will also be sampled via trawling as described below. The GPS location of departure from the transect will be recorded so the vessel can return to that location and resume scanning for schools along the pre-determined transect. Trawl sets will be made on a minimum of 2 schools per transect to verify species composition and school depth, and collect biological data as described below. Trawl locations, depths, and durations will be chosen on an ad hoc basis. To the extent possible, the 12 schools sampled should be distributed evenly across a range of sizes with ~3 schools per size category: ≤50mt, 50-100mt, 100-150mt, and >150mt (based on examination of VTR catch per tow data). If no schools are encountered within the detection distance along a given transect, additional schools should be sampled on subsequent transects such that a minimum of 12 schools of different sizes are sampled across the study area. Multiple passes may be required to capture the school. The vessel will then re-cross the trawled area with the echosounder to estimate the proportion of the school not caught by the trawl sets.

Expert scrutinization of acoustic data is a common method used in scientific surveys to interpret acoustic data and identify target species (Jech and Michaels 2006). However, it is still a subjective process such that the ability of the expert to identify menhaden schools via inspection of acoustic data should be verified (ICES 2015). Therefore, we recommend an additional 4 sets be conducted on schools of different sizes that have been identified by the skipper as non-target species in order to improve interpretation of echograms (Overholtz et al. 2006).

Equipment and gear

The survey vessel must be equipped with midwater trawl gear sufficient to capture large menhaden schools typically encountered in winter. For example, the current vessel used in the New Jersey winter menhaden fishery (F/V Dyrsten) utilizes a Cosmos Trawl net with an 18m vertical opening, a 51m horizontal opening, and a mesh size of 3.8cm in the cod end. Fishermen report that most menhaden schools encountered in winter can be captured in 1-2 tows with a net of these dimensions.

The minimum acoustic equipment requirements for implementation of this pilot survey are long-range omnidirectional sonar and a down-viewing echosounder[1]. Raw acoustic echosounder data stamped with time and GPS position must be recordable to external hard disks. Sonar frequency range must be adequate to detect schools ≥400m from the vessel. If adequate acoustic equipment is not available, the appropriate equipment may be rented and pole-mounted to the midwater trawler or a two-vessel operation could be considered in which one vessel collects acoustic data and the other conducts trawls. Ideally, sonar data would be recorded as well via screen capture allowing the morphometrics of each school within the specified detection distance to be calculated (Lucca and Warren 2018, Stockwell et al. 2012) and used to generate an “area to biomass” relationship for menhaden schools in winter (Misund et al. 1992, Misund et al. 1995).

The ideal frequencies at which to ensonify menhaden may depend on the fish’s ability to detect and avoid ultrasound. Some clupeids such as blueback herring and American shad detect and actively avoid ultrasound up to 180kHz while other closely related species do not (Mann et al. 1997, Popper et al. 2004). Gulf menhaden have demonstrated avoidance response to ultrasound from 40 to 80 kHz with an upper threshold of 180kHz (Mann et al. 2001). However, fishermen report menhaden do not avoid long-range sonar (22kHz sonar) or the vessel when passing over menhaden schools with an echosounder operating at 38kHz in February; however, they do report being unable to catch highly mobile schools earlier and later in the season when water temperatures are warmer (S. Axelsson, *pers. comm.*). Thus, cold temperatures likely limit menhaden avoidance response to sound. If the survey cannot be conducted during a period when the water is sufficiently cold and schools largely immobile, we recommend acoustics be limited to higher frequencies in the 110-200kHz range.

Acoustic equipment should be calibrated prior to the survey (Demer et al. 2015, Foote et al. 1987). A GPS log should be kept throughout the survey so that all transect tracts,

[1] The collaborating vessel for this survey would likely be the F/V Dyrsten, a 44.5m midwater trawler currently used in the winter menhaden bait fishery operating out of Cape May, NJ. The Dyrsten is equipped with a recordable Simrad ES80 split-beam, hull-mounted echosounder with a 38kHz transducer (model ES38B), MAQ (22/90kHz) omnidirectional sonar, WASSP WMB-3220 multibeam sonar (160kHz), and Furuno FCV295 (50/200kHz) and FCV 1200L (160kHz) sonar. The MAQ sonar has three beam widths (5°, 10°, and 20°) and five operating modes (omnidirectional, tracking, search, vertical tracking, and trawl).

start and end points and times, as well as the location of all off-transect sets and acoustic data collection events are recorded.

Trawl set data collection

Midwater trawling will be used both to support interpretation of acoustic imagery and to collect biological information. Each school captured will be assigned an individual tank or tanks, and tank assignments will be recorded so that total catch weight can be measured and assigned to each school during offloading. Additionally, skipper's estimates of total catch weight per tow will also be recorded based on the pump time required to remove menhaden from the net (~6-8t/min). Skipper's estimates of total catch weight are generally consistent with NOAA observer catch weight measurements (Bell et al. 2017), but have not been explicitly compared for menhaden caught in midwater trawls.

Three baskets will be collected from each tow, one each from the beginning, middle, and end of the pump out process to distribute samples across the tow. Total weight by species will be recorded. Menhaden typically form schools that are highly homogenous in size and age structure (Chester 1984, June and Reintjes 1959); therefore, a random sample of 30 menhaden per school will be selected for full processing. Size, age, sex, and maturity information will be collected for each menhaden. Individual weights (to the nearest 0.5g) and fork and total lengths (to the nearest mm) will be recorded using an electronic scale and measuring board. A scale patch (~20-30 scales) will be removed from specimens with a blunt-edged scalpel along with both otoliths; scales and otoliths will be labelled and stored for later mounting and ageing in the lab.

Hydrographic data collection

Salinity, water temperature, and dissolved oxygen profiles will be recorded using a Hydrolab MS5 multi-sonde at the location of each menhaden school encountered along the transect. Additional readings will be made at the start and end of each transect as well as locations 10 km apart within each transect to characterize pelagic habitat conditions across the study area.

Data analysis

Acoustic and trawl data collected during the survey will be used to estimate 1) biomass of menhaden within the study area, 2) biological structure of the menhaden schools sampled, and 3) information on the spatial distribution and pelagic habitat use of menhaden in winter within the study area.

Biomass estimation
Acoustic backscatter and target strength data recorded from the echosounder will be processed in Echoview® to remove near-bottom backscatter and reduce acoustic and electrical noise and interference[2]. The school detection module will be used to detect and integrate schools, allowing for school-specific estimates of biomass to be generated within manually defined regions using backscatter and in situ target strength data. For schools on which both acoustic and trawl data were collected, the relationship between acoustic estimates of school biomass and trawl-based measurements of total catch weight will be estimated. We anticipate schools will be monospecific, similar to Atlantic herring surveys (Stockwell et al. 2012); however, trawl catch information may indicate otherwise in which case estimates of species composition would then be used to apportion associated backscatter.

The total biomass of menhaden encountered within the detection distance will be summed across each transect and total biomass across the study area estimated as in Equation 2 above:

$$\hat{B}_{\text{ratio}} = \frac{L\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} L_i} \tag{5}$$

where y_i is the biomass at transect i, n is the number of transects, L_i is the length of transect i, and $L = \sum_{i=1}^{T} L_i$ is the total length of the all transects, T.

School structure
Biological data will be summarized (e.g., length and age distributions, sex ratios, etc.) and raw biological data made available to NOAA Beaufort Laboratory and the ASMFC Menhaden Technical Committee.

Pelagic habitat use
Pilot data on school location, size, and structure relative to environmental conditions will be used to develop a model of menhaden pelagic winter habitat use. This relationship could also be used to identify and explore the incorporation of survey strata into future, refined survey protocols.

[2] Although commercial acoustic equipment is in many ways comparable to that used in scientific research surveys (Jones et al. 2017), echosounder data collected by the Simrad ES80 or similar unit may require additional post-processing relative to scientific (e.g., Simrad EK series) equipment. The ES80 does not have an embedded systematic error component as other Simrad products designed for industry have had in the past (Jeff Condiotty (Simrad), pers. comm.; Fässler et al. 2016).

Additional logistics

Once the collaborators and participating vessel(s) have been identified, a logistics plan should be developed that incorporates the following issues not included in this report:

1. Staffing plan including the roles and responsibilities of the PIs, skipper and crew, acoustics consultants, and biologists.
2. GARFO exempted fishing permit and ASMFC scientific quota allocation.
3. Specific survey transect map with randomized start location.
4. Daily work plan and schedule.
5. Logbook data forms and associated instructions for each vessel.
6. Set up of the acoustic data acquisition system.
7. Acoustic equipment calibration and survey operation instructions.
8. Acoustic data post-processing and analysis.
9. If possible, an ex situ tank study of Atlantic menhaden target strength would accompany this pilot survey to quantify the side-aspect acoustic properties of menhaden and help interpret target strength data collected in situ by the survey (Boswell and Wilson 2008).
10. Written instructions for trawl data collection and subsequent biological sample collection methods.
11. Plan for error checking and digitizing all logbooks and biological data collected on board.
12. Logistics for delivery of biological samples to an appropriate fisheries laboratory, including a plan for mounting and reading scales, otoliths, etc.
13. Development of a long-term data storage and sharing plan.

Assessment and management utility of pilot data

Although longitudinal data collected over 10+ years are typically required to develop an index of abundance for use in stock assessment, information gathered during even one year of pilot data collection will be valuable to menhaden assessment and management in the following ways:

1. If menhaden are encountered, the pilot study would provide fishery-independent confirmation of resident Atlantic menhaden in winter offshore north of Cape Hatteras confirming the results of recent tagging and ichthyoplankton data analyses (Liljestrand 2017, Simpson et al. 2017, Simpson et al. 2016)
2. If a significant biomass of adult/spawning menhaden are encountered in this study region and season, this would help confirm the existence of cryptic spawning stock biomass estimated by the assessment model but not typically encountered by the fishery.
3. Collection of data including hydrographic conditions, depth, and physical location of menhaden schools will provide information currently lacking on the pelagic habitat use of menhaden in winter. This information could also be used to determine appropriate stratification of the survey design in future years.

4. A pilot survey may expand data collection (e.g., age, size, maturity, sex) on the larger, older portion of the stock not typically encountered by the bait or reduction fisheries.

Acknowledgments

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Tables

Table 1. Simulated total biomass (metric tons) and maximum encounter rate per transect based on two Poisson process modeling scenarios: (a) linear effects of bathymetry, sea bottom temperature, sea bottom salinity and latitude, (b) linear effects of bathymetry and sea bottom temperature, additive effects of latitude. Each Poisson process modeling scenario was applied to a simulated menhaden population created using resampled VTR fishing trips replicated either 50 or 100 times. Six out of eighteen VTR trips were not used due to missing temperature data (n=4) or because the trip was located outside the study area (n=2).

Scenario	Number of resampled VTR trips	Biomass (thous mt)	Lower 95% limit (thous mt)	Upper 95% limit (thous mt)	Max # schools per transect	Lower 95% limit	Upper 95% limit
(a)	50	86.7	80.7	93.8	9	7	12
	100	173.6	164.0	182.2	15	12	20
(b)	50	85.7	78.9	92.2	11	9	14
	100	171.8	162.9	181.5	18	15	22

Figures

Figure 1. Proposed survey area (black line) spanning 15-50 miles off the coast of New Jersey from the southern edge of Hudson Canyon extending southward to the New Jersey/Delaware border. Colors indicate depth (m).

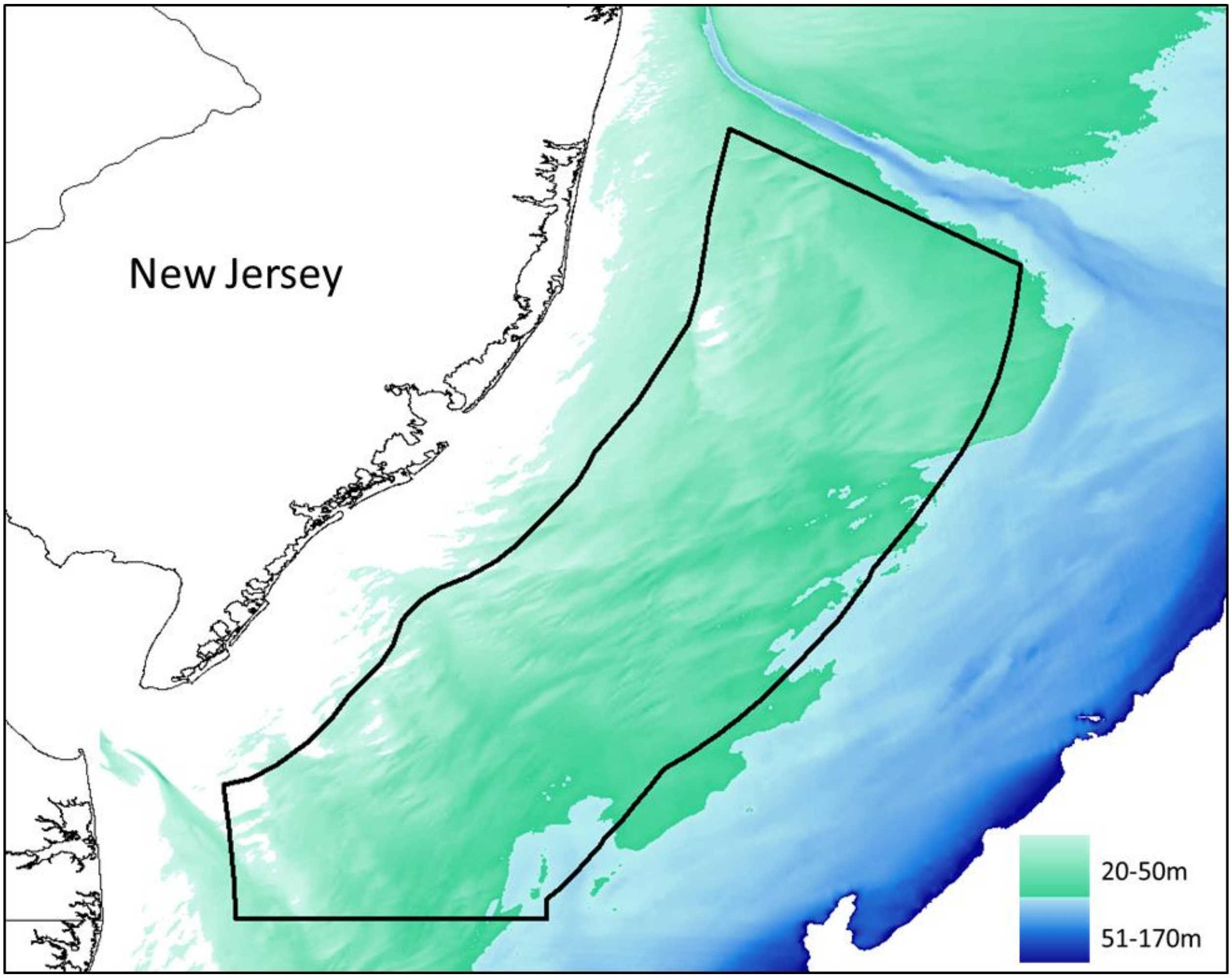

Figure 2. Location of menhaden catch reported by NEFOP between January and March, 2006-2016 (shaded squares) within the study area (black line). To maintain confidentiality, data are plotted by quarter degree square. Colors indicate depth (m).

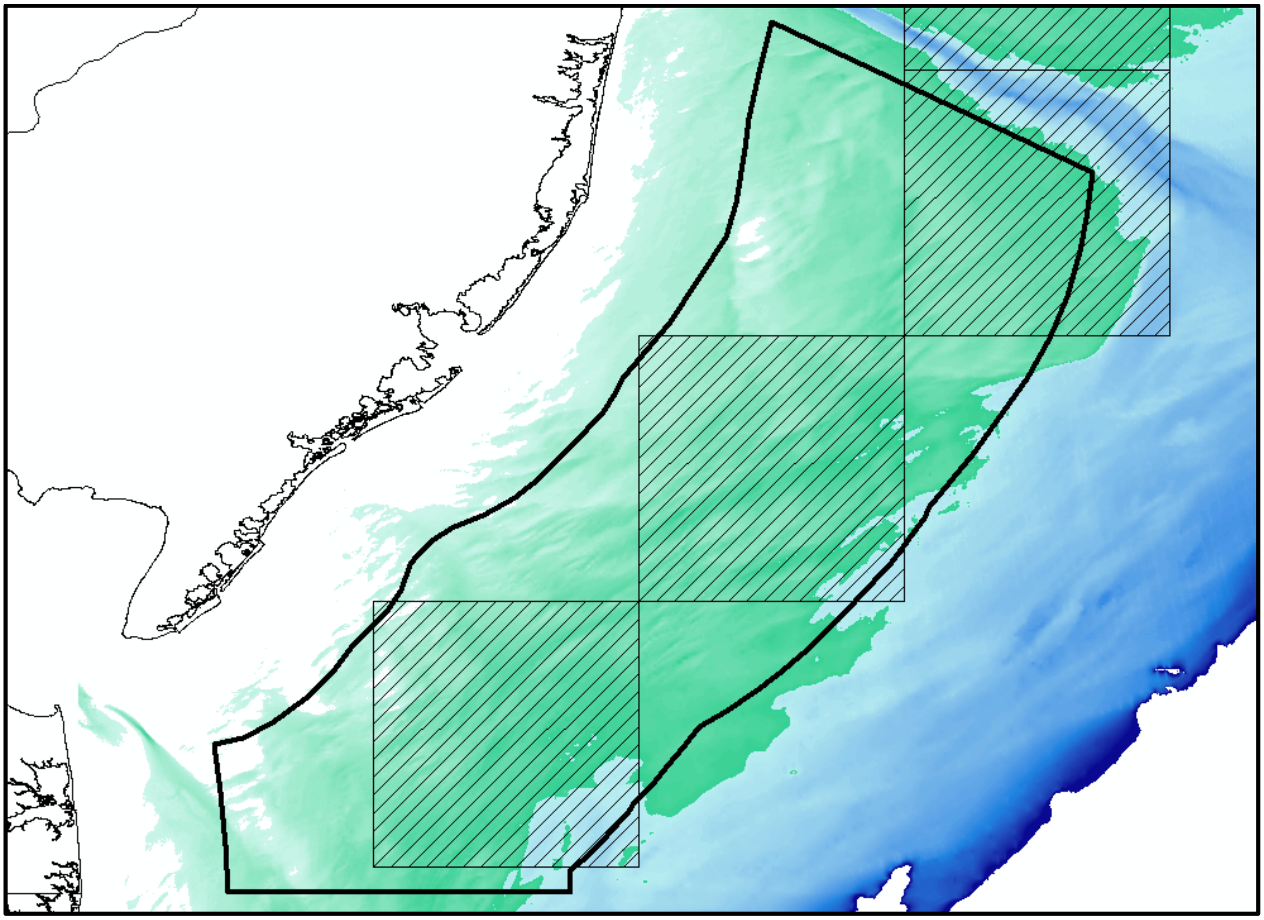

Figure 3. Fork length distribution (mm) of Atlantic menhaden recorded on midwater trawl NEFOP trips conducted in statistical areas overlapping the study area in January and February, 1993-2016. Dashed red line represents mean length observed.

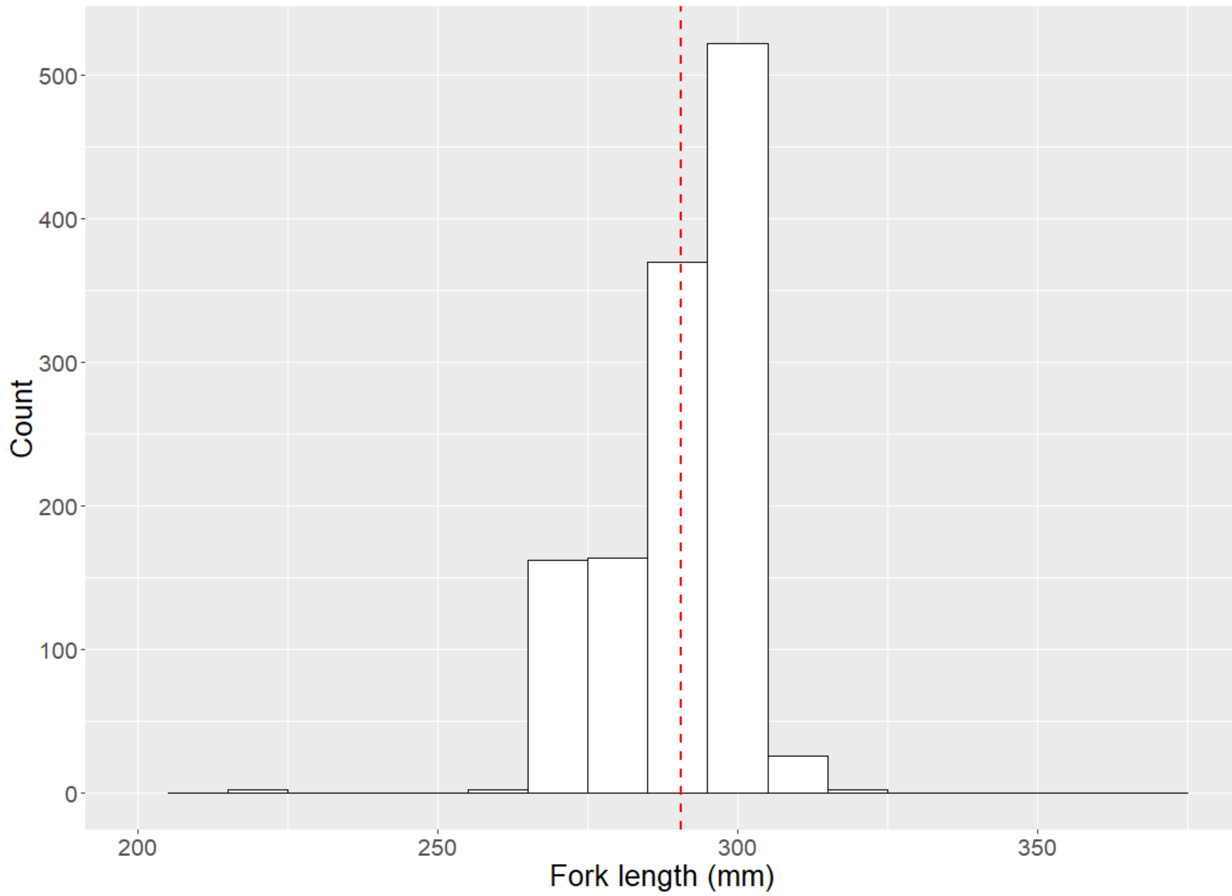

Figure 4. Fork length distribution (mm) of Atlantic menhaden port samples collected in New Jersey in January and February, 2006-2016. Dashed red line represents mean length observed.

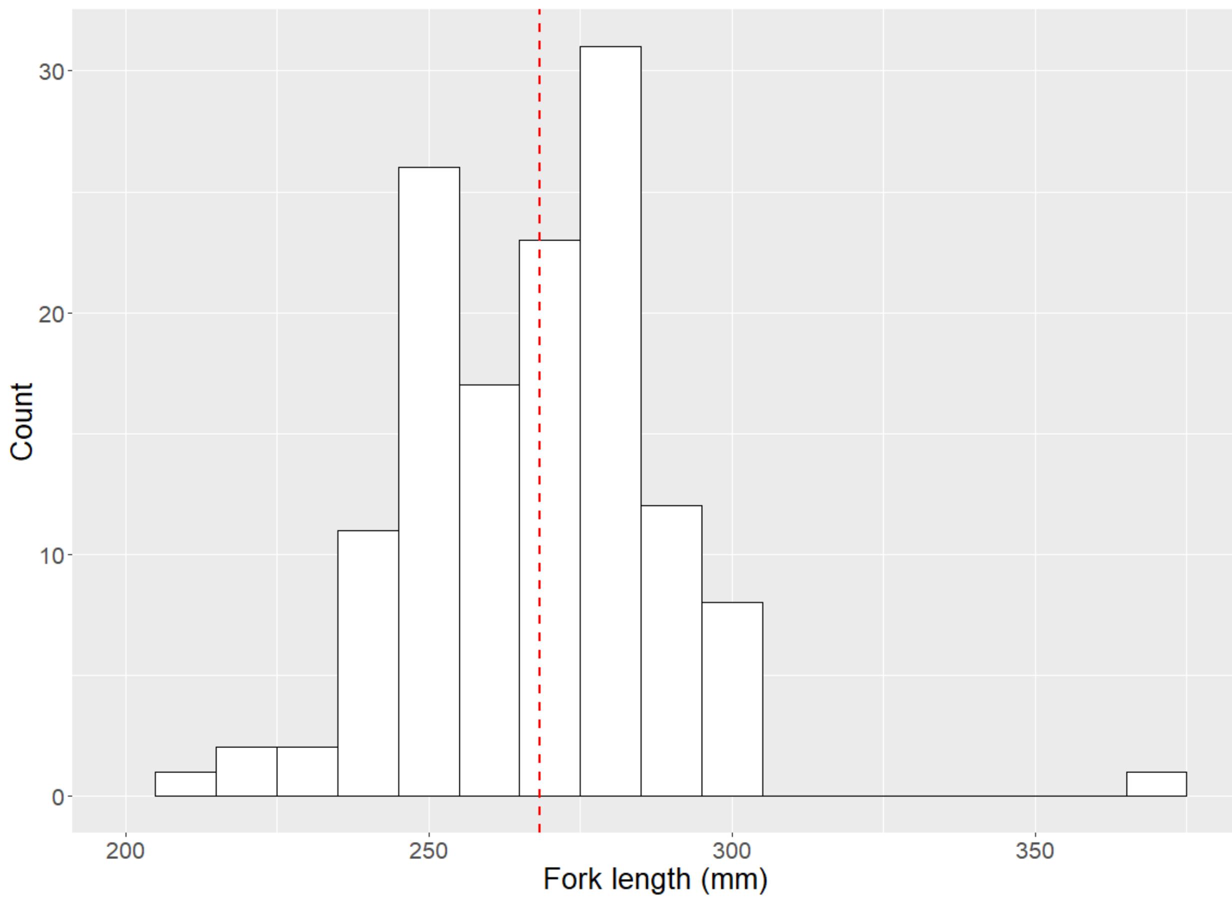

Figure 5. Choropleth maps of spatial prediction of trip success intensity across two modeling scenarios: (a) linear effects of bathymetry, sea bottom temperature, sea bottom salinity and latitude, (b) linear effects of bathymetry and sea bottom temperature, additive effects of latitude. Intensity represents expected number of success trip per 1x1 decimal degree area, January 2017. Dot plots indicate simulated success trips based on 100 replicated fishing seasons in 2016-2017.

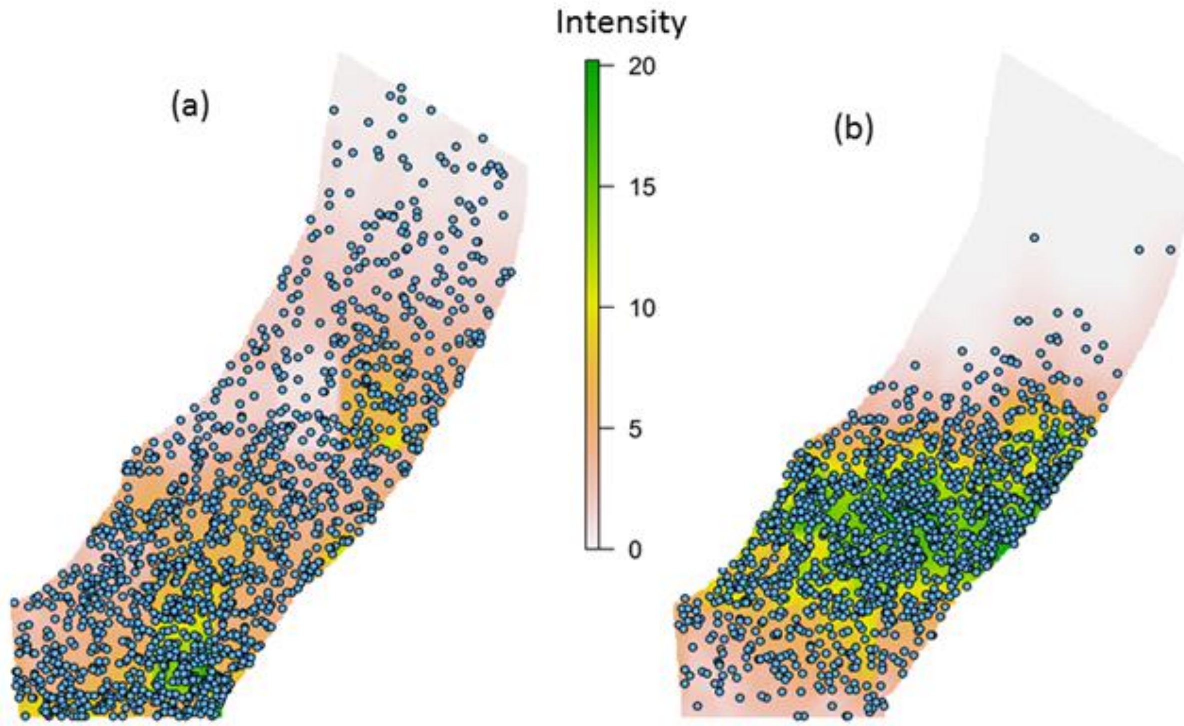

Figure 6. Simulated school density (lbs) based on kriging observed VTR catch per school onto simulated school distribution (Figure 3. Fork length distribution (mm) of Atlantic menhaden recorded on midwater trawl NEFOP trips conducted in statistical areas overlapping the study area in January and February, 1993-2016. Dashed red line represents mean length observed.

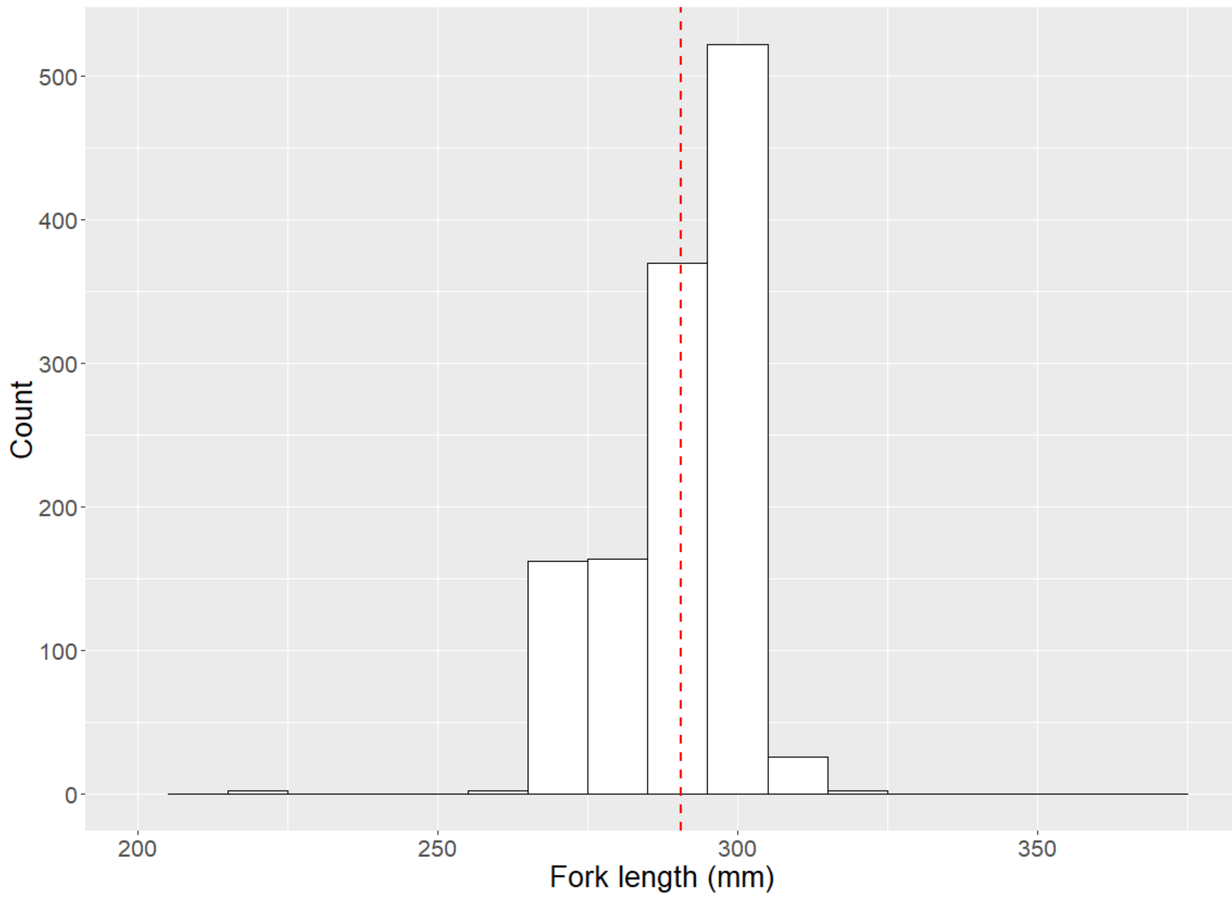

Figure 4. Fork length distribution (mm) of Atlantic menhaden port samples collected in New Jersey in January and February, 2006-2016. Dashed red line represents mean length observed.

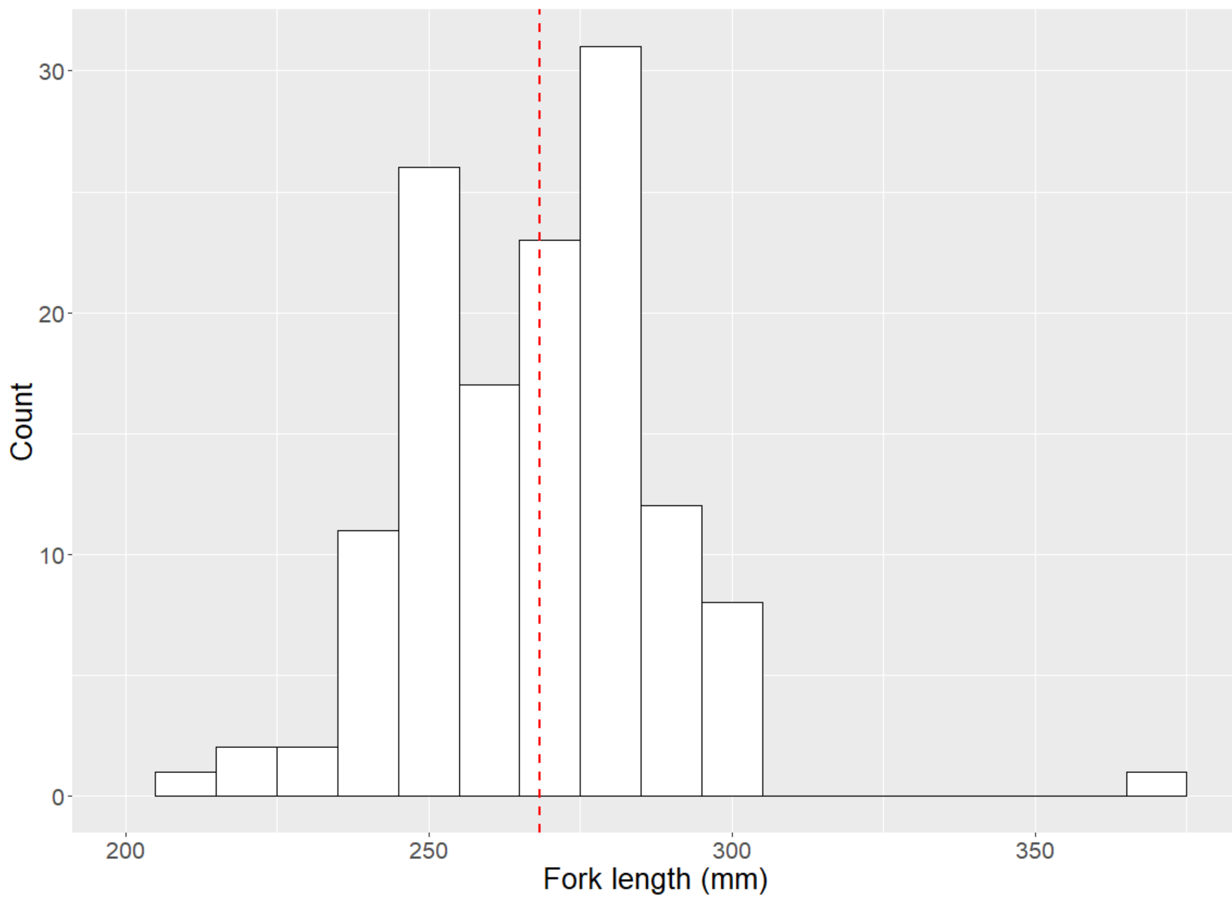

Figure 5). Magnitude of catches increase with darker colors, but are not reported to protect confidentiality of industry data.

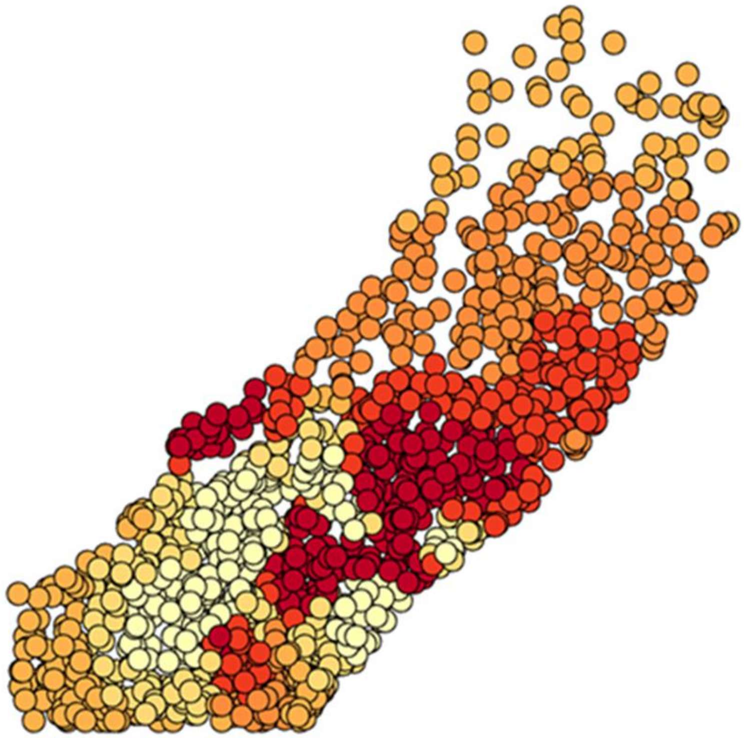

Figure 7. An example sample of 10 transects using systematic sampling from a frame of 16,514 cells (833 m raster size) on 562 transects of unequal lengths. Dark circles represent schools encountered within the detection distance.

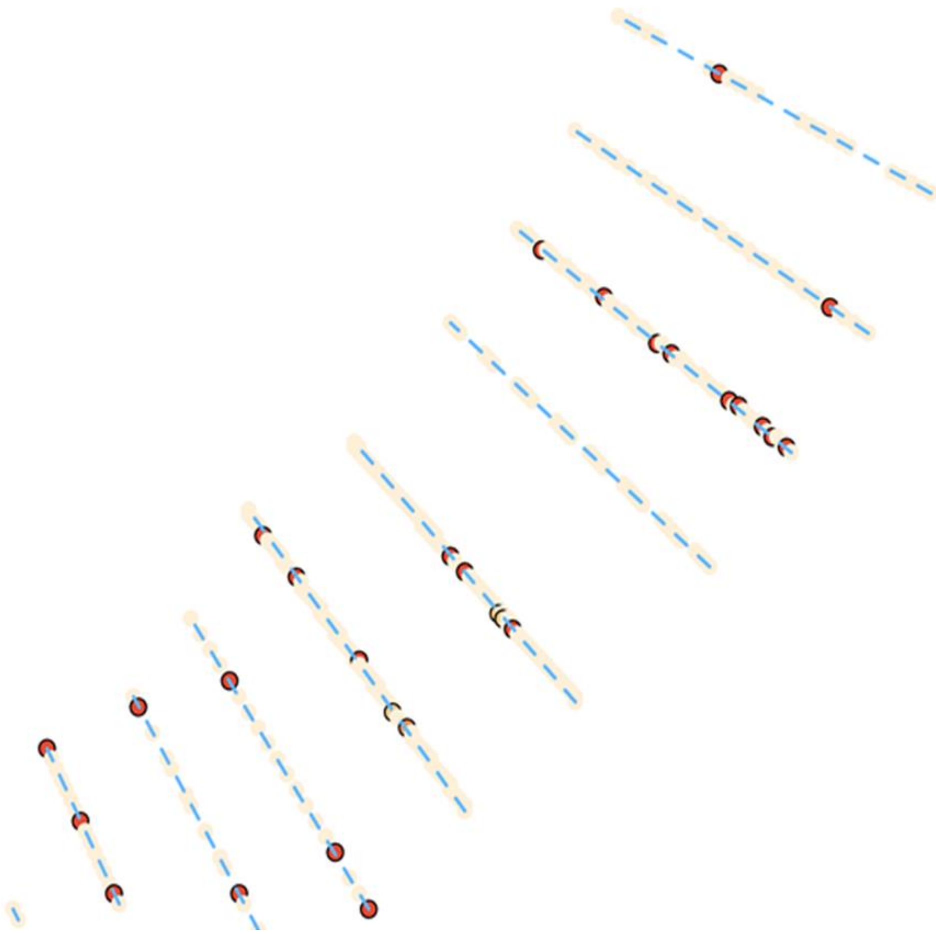

Figure 8. Coefficient of variation based on 999 Monte Carlo samples and the average cumulative distance sampled (km) for seven survey design options: (1) Down-viewing echosounder only – 1 vessel; (2) Expansion of down-viewing echosounder biomass to all schools encountered by sonar across 800m swath – 1 vessel; (3) Biomass estimated for all schools encountered by sonar via down-viewing echosounder across 800m swath – 1 vessel; (4) Schools identified via sonar across 800m swath and biomass determined by trawl sets– 2 vessels; (5) Expansion of down-viewing echosounder biomass to all schools encountered by sonar across 400m swath – 1 vessel; (6) Biomass estimated for all schools encountered by sonar via down-viewing echosounder across 400m swath – 2 vessels; (7) Schools identified via sonar across 400m swath and biomass determined by trawl sets– 2 vessels. Population simulated based on **50 re-samples** of vessel trip reports in winter 2017 based on a fitted Poisson model with **linear** environmental covariates.

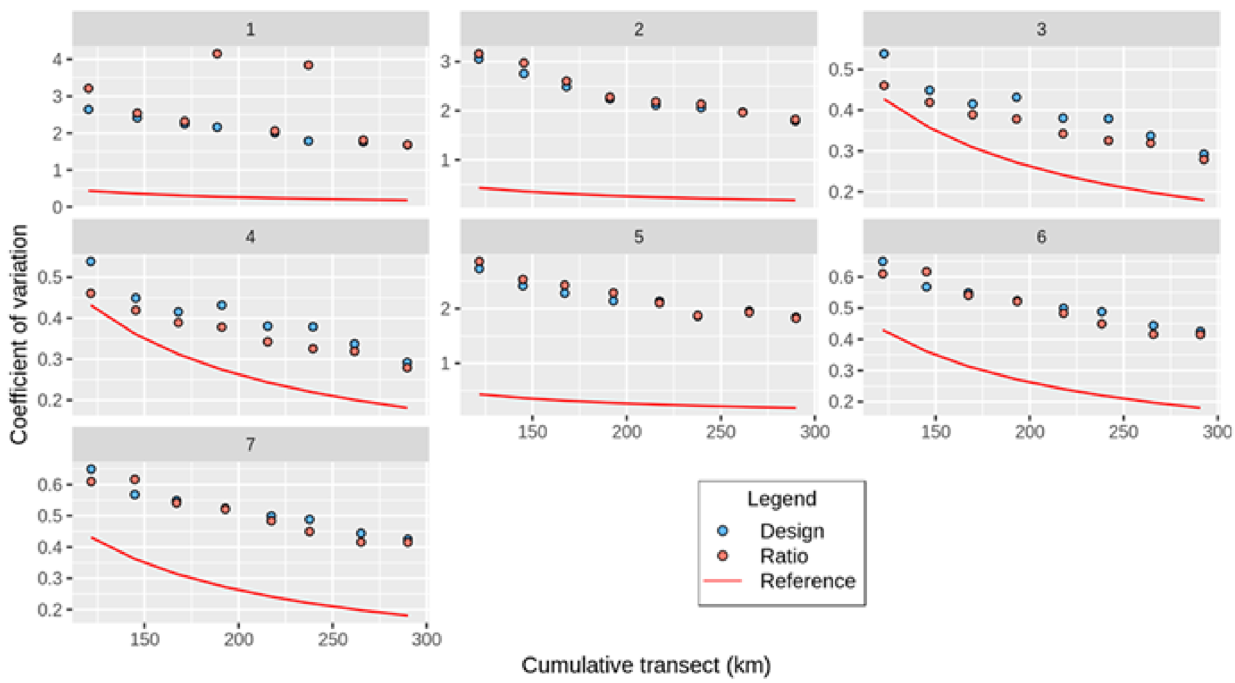

Figure 9. Coefficient of variation based on 999 Monte Carlo samples and the average cumulative distance sampled (km) for seven survey design options: (1) Down-viewing echosounder only – 1 vessel; (2) Expansion of down-viewing echosounder biomass to all schools encountered by sonar across 800m swath – 1 vessel; (3) Biomass estimated for all schools encountered by sonar via down-viewing echosounder across 800m swath – 1 vessel; (4) Schools identified via sonar across 800m swath and biomass determined by trawl sets– 2 vessels; (5) Expansion of down-viewing echosounder biomass to all schools encountered by sonar across 400m swath – 1 vessel; (6) Biomass estimated for all schools encountered by sonar via down-viewing echosounder across 400m swath – 2 vessels; (7) Schools identified via sonar across 400m swath and biomass determined by trawl sets– 2 vessels. Population simulated based on **100 re-samples** of vessel trip reports in winter 2017 based on a fitted Poisson model with **linear** environmental covariates.

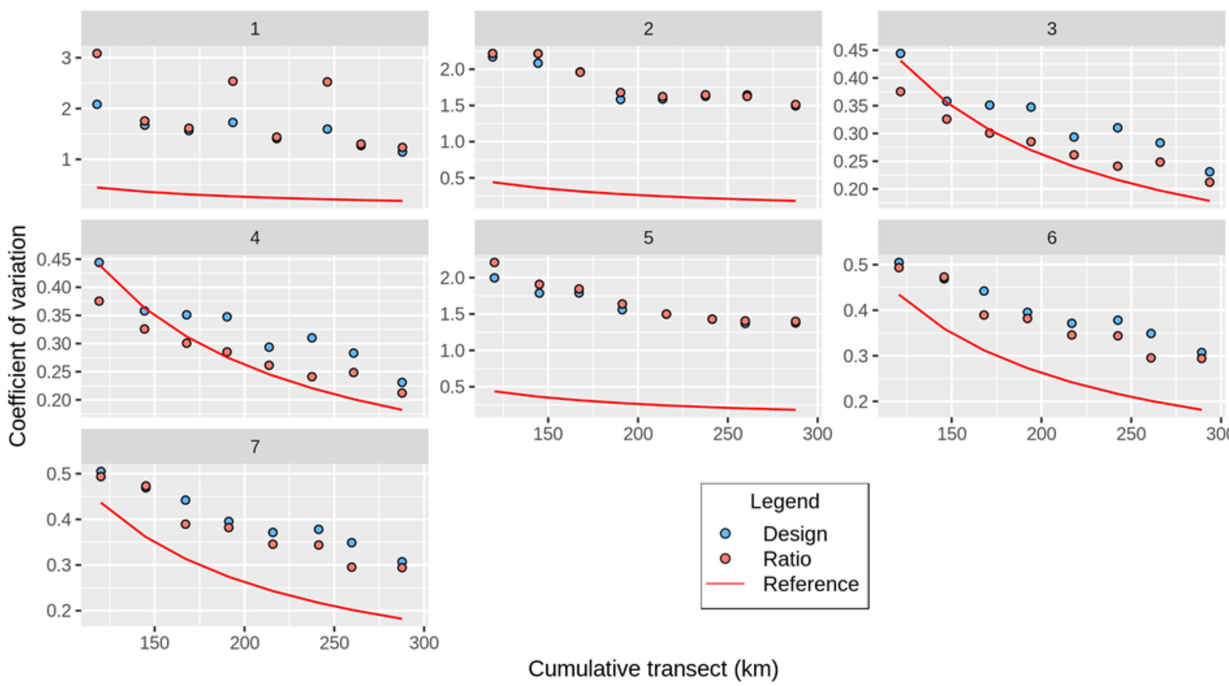

Figure 10. Example of a set of 6 transects (black line) of variable length totaling approximately 350 km of cumulative transect distance sampled within the study area (shaded area).

Appendix 1

Today’s date: ______________

Is this the first day of the trip? (Select yes if a 1-day trip.) Yes No

If so, what from what port did you depart? _____________________

Is this the last day of the trip? (Select yes if a 1-day trip.) Yes No

If so, what was the port of landing? __________________________

If so, what was the approx. min and max degrees latitude at which you searched for fish? Min: ______ Max: ______

If so, what was the approx. min and max distance offshore (miles) you searched for fish? Min: ______ Max: ______

Approx. total hours spent searching for schools today: _______ Approx. total distance traveled today (miles): ________

When you encounter a school **you think might be menhaden**, please note the following (continue on back if necessary).

School	GPS location	Approx. school depth (fathoms)	Confirmed to be menhaden? Yes/No	If not menhaden, what species?	Roughly what % of catch was menhaden?	Approx. lbs menhaden caught	Approx. % of school caught	Water temp
1.								
2.								
3.								
4.								
5.								
6.								
7.								
8.								
9.								
10.								
11.								
12.								
13.								
14.								
15.								

Appendix 2

Figure A1. Coefficient of variation based on 999 Monte Carlo samples and the average cumulative distance sampled (km) for seven survey design options: (1) Down-viewing echosounder only – 1 vessel; (2) Expansion of down-viewing echosounder biomass to all schools encountered by sonar across 800m swath – 1 vessel; (3) Biomass estimated for all schools encountered by sonar via down-viewing echosounder across 800m swath – 1 vessel; (4) Schools identified via sonar across 800m swath and biomass determined by trawl sets– 2 vessels; (5) Expansion of down-viewing echosounder biomass to all schools encountered by sonar across 400m swath – 1 vessel; (6) Biomass estimated for all schools encountered by sonar via down-viewing echosounder across 400m swath – 2 vessels; (7) Schools identified via sonar across 400m swath and biomass determined by trawl sets– 2 vessels. Population simulated based on **50 re-samples** of vessel trip reports in winter 2017 based on fitted Poisson model with **non-linear** latitude plus linear environmental covariates.

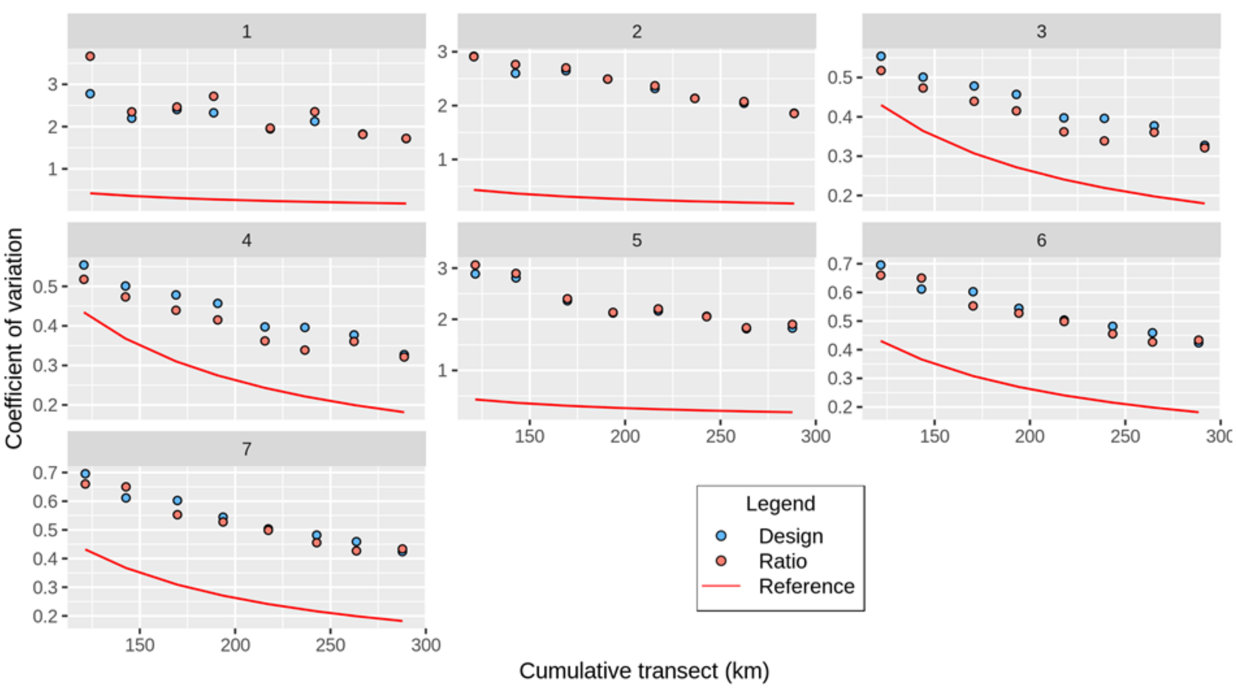

Figure A2. Coefficient of variation based on 999 Monte Carlo samples and the average cumulative distance sampled (km) for seven survey design options: (1) Down-viewing echosounder only – 1 vessel; (2) Expansion of down-viewing echosounder biomass to all schools encountered by sonar across 800m swath – 1 vessel; (3) Biomass estimated for all schools encountered by sonar via down-viewing echosounder across 800m swath – 1 vessel; (4) Schools identified via sonar across 800m swath and biomass determined by trawl sets– 2 vessels; (5) Expansion of down-viewing echosounder biomass to all schools encountered by sonar across 400m swath – 1 vessel; (6) Biomass estimated for all schools encountered by sonar via down-viewing echosounder across 400m swath – 2 vessels; (7) Schools identified via sonar across 400m swath and biomass determined by trawl sets– 2 vessels. Population simulated based on **100 re-samples** of vessel trip reports in winter 2017 based on fitted Poisson model with **non-linear** latitude plus linear environmental covariates.