2014 Atlantic menhaden benchmark assessment
Fishery-independent survey data standardization
Methods and Results

JUVENILE (YOY) SEINE SURVEYS

***Figures and tables can be found in "YOY seine indices.xls"**

Data collected from seine surveys conducted within several states along the east coast of the U.S. were used to develop program-specific abundance indices for juvenile menhaden. These indices were then combined with others into an overall juvenile abundance index. The specific seine survey indices were based on the following data sources:

- Connecticut River seine survey (1987-2013)
- Connecticut - Thames River seine survey (1998-2013)
- Rhode Island seine survey (1988-2013)
- New York seine survey (1986-2013)
- New Jersey seine survey (1980-2013)
- Maryland striped bass seine survey (1959-2013)
- Virginia striped bass seine survey (1967-1973, 1980-2013)

Field sampling

The Connecticut River seine survey targets juvenile alosine fishes in the Connecticut River and has continuously operated from 1987-present. Sampling occurs monthly from July through October with a beach seine of dimensions 2.44 m x 15.2 m x 0.5 cm. Approximately 14 hauls are taken annually in the Deep, Essex, Glastonbury, and Salmon river tributaries.

The Connecticut Thames seine survey was initiated in 1998 to sample juvenile alosine fishes in the Thames River. The method of seine deployment and gear used is identical to what is used for the Connecticut River seine survey. From 1998 through 2001, eight fixed stations were sampled each week from mid-June through October. Since 2002, sampling has been conducted bi-monthly from July through October.

The Rhode Island seine survey targets a variety of fishes in Narragansett Bay and has operated continuously from 1988-present. A total of 18 fixed stations are sampled from June through October using a beach seine with dimensions 3.05 m x 61 m. ***NOTE: this survey was standardized, but then was mistakenly dropped from final, regional analyses. It is correlated with other surveys in the region. This survey will be included in the next assessment.***

The New York seine survey targets a variety of fishes in western Long Island Sound and has operated continuously from 1984-present. Sampling occurs with a 61 m beach seine primarily from May through October within three areas: Jamaica Bay, Little Neck Bay, and Manhasset Bay.

The New Jersey seine survey targets a variety of fishes and has operated continuously in the Delaware River from 1985-present. The sampling scheme has been modified over the years but the core survey area, sampling locations, and survey months (June-November) have remained consistent. The current sampling protocol, which was established in 1998, consists of 32 fixed stations sampled twice a month from June through November within three distinct habitats: Area 1 – brackish tidal water; Area 2 – brackish to fresh tidal water; Area 3 – tidal freshwater. A beach seine with dimensions 1.8 m x 30.5 m x 6.4 mm is used for sampling.

The Maryland striped bass seine survey targets juvenile striped bass and has operated continuously from 1959-present. Survey stations are fixed and monthly sampled occurs from July through September with occasional sampling in October and November. A beach seine of dimensions 1.2 m x 30.5 m x 6.4 mm is used to collect fishes at core survey stations in four regions of the northern Chesapeake Bay: Choptank River, Head of Bay, Nanticoke River, and Potomac River.

The Virginia striped bass seine survey was conducted from 1967-1973 and 1980-2013. The survey targets juvenile striped bass following a fixed station design, with most sampling occurring monthly from July through September and occasional collections in October and November. In 1986 the bag seine dimensions were changed from 2 m x 30.5 m x 6.4 mm to the "Maryland" style seine with the dimensions 1.2 m x 30.5 m x 6.4 mm. Tributaries sampled in the southern Chesapeake Bay include the James, Mattaponi, Pamunkey, Rappahannock, and York rivers.

<u>Potential biases</u>

Because of the schooling nature of Atlantic menhaden combined with the fact that these seine surveys were originally designed to measure the abundance of other species, it is possible that the menhaden catch data are not truly representative abundance. However, these data sources represent a large portion of the available information on juvenile relative abundance.

<u>Size Cutoffs</u>

For the surveys where length information was available, catch-per-haul data were adjusted based on the convention cut-off sizes by month adopted by the Atlantic menhaden Technical: June 1-June 30, 110 mm FL; July 1-August 15, 125 mm FL; and August 16-November 30, 150 mm FL.

<u>Data Filtering</u>

For each survey, the data were plotted across a variety of potential categorical (year, month, region) and continuous (temperature, salinity, DO) explanatory variables to explore the structure of the data and the distribution of zero and nonzero catches. These data summaries were used to identify potential 'spatial' and 'temporal' windows where sampling of juvenile menhaden appeared to be optimal. Accordingly, levels of spatial and temporal categorical variables with < 5% of the total catch across the lifetime of the survey were deemed uninformative and excluded from all analyses.

<u>Index Calculations</u>

State-specific indices of relative abundance were generated from the filtered data sets. Despite the filtering, examination of the raw catch-per-haul data for each state indicated that each data set contained a high proportion of zero catches, or alternatively, a low proportion of hauls where at least one juvenile menhaden was captured, particularly in recent years for most surveys (Figure YOYS-1). Zero catches can arise for many reasons, and it was reasoned that the use of an active sampling gear combined with the schooling nature of menhaden was the likely cause. Since the data structure were counts of individual fish, initial modeling efforts were focused on applying zero-inflated generalized linear models (GLM) to derive indices of abundance. However, use of zero inflated models was either highly overdispersed (Poisson) or unsuccessful due to numerical instability in the fitting process (negative binomial). Therefore, delta-GLMs were adopted where the probability of obtaining a zero catch and the catch rate, given that the catch is non-zero, were modeled separately. The general form of a delta model is:

$$\Pr(Y = y) = \begin{cases} w & y = 0 \\ (1-w)f(y) & \text{otherwise} \end{cases}$$

The probability of obtaining a zero observation was modeled using the binomial distribution and the distribution used to model the non-zero catches was assumed to be lognormal. For each state, a variety of model parameterizations for both the binomial and lognormal components were fitted and the fixed effects covariates considered were *year*, *month*, *region,* and when possible, *temperature, salinity,* and *DO*. The 'best' fitting model according to Akaike's Information Criterion (AIC) was used generated a predicted time-series of relative abundance. Estimates of precision for the annual index values were derived from 1000 bootstraps of the yearly catch data. All statistical analyses were conducted using the R software package.

Results

AIC based evaluation of the delta-lognormal GLM fits generally supported the saturated model for each survey data set (all ΔAIC < 2 for both saturated model components across data sets; Table YOYS-1). Although there was some slight variation regarding which parameterization received the most empirical support amongst the binomial and lognormal components (ΔAIC = 0.0), index predictions did not vary notably across model formulations within two AIC units. Predicted trends in relative juvenile menhaden abundance were variable for each data set, with many of the higher peaks in abundance corresponding to years in the middle of the respective time-series (Figure YOYS-2). Relative to those middle time-series peaks, most of the abundance trends decline in recent years. Estimates of bootstrapped CVs were generally high, particularly for the northern surveys. Average CVs across the respective time-series ranged between 0.61 and 0.70 for Maryland and Virginia; was 0.34 for New Jersey; and in excess of 0.8 with many very high values for the other surveys (Fig YOYS-2).

Rhode Island Trawl Survey

***Unless otherwise indicated, figures and tables can be found in "RI NYPB DEIB MDCB VIMS GA trawl indices.xlsx"**

Methods

Survey Design

Rhode Island Department of Environmental Management research trawl survey is conducted with a ¾ high-rise heavy-duty bottom trawl towed for 20 minutes at 2.5 knots. Sampled areas include Narragansett Bay and Rhode and Block Island Sounds. Data include a mixture of fixed and random sampling stations. Data collection has been consistent across seasons from 1990 to the present. Data elements include numbers caught by species and suite of environmental information including bottom and sea surface water temperature, depth, and sea conditions.

Sampling Intensity

The survey is conducted monthly throughout the year. A total of approximately 100–200 tows are recorded annually.

Biological Sampling

All Atlantic menhaden collected are measured in cm FL.

Potential Biases

This survey was not designed to target Atlantic menhaden. In order to use this data to generate an index of abundance for stock assessment, statistical, model-based standardization of the survey data was conducted to account for factors that affect menhaden catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis.

Development of Estimates

YOY menhaden were distinguished from age 1+ fish using the monthly length cutoffs for Region 1 as defined in Table 5.3.8 of the assessment report. Age 0 menhaden ranged from 2 to 15 cm with an average of 6.7 cm (Figure 1).

Following the approach described in the TC's standardization guidelines, an index of age 0 menhaden was created using a negative binomial generalized linear model with a log link and bootstrapped estimates of uncertainty. Tows conducted at stations (13, 26, 89, 132, 138) and in months (August to November) with >=5% of positive tows for menhaden were included in the analysis to eliminate places and times of the year during which age 0 menhaden would not be expected to be caught in Rhode Island waters. Proportion of positive tows for Atlantic menhaden averaged approximately 36% across the time series (Table 1).

Estimates

A full model that predicted catch as a linear function of year, bottom temperature, and depth as categorical factors was compared with nested submodels using AIC. The model that included year and depth was selected because it produced the lowest AIC (% deviance = 73). The index was highly variable over time, but exhibited a marked increase from low catches beginning in the mid-1990s (Figure 5.3.4 in assessment report). The index declined from the time series peak in the mid-2000s to the present. Diagnostics identified slight overprediction of average annual catch per tow (Figures 3-4).

CT Long Island Sound Trawl Survey

***Unless otherwise indicated, figures and tables can be found in "CTLISTTables&Figs.xlsx"**

Methods

Survey Design

The CT Long Island Sound Trawl Survey (LISTS) is conducted from longitude 72° 03' (New London, Connecticut) to longitude 73° 39' (Greenwich, Connecticut). The sampling area includes

Connecticut and New York waters from 5 to 46 m in depth and is conducted over mud, sand and transitional (mud/sand) sediment types.

Prior to each tow, temperature (°C) and salinity (ppt) are measured at 1 m below the surface and 0.5 m above the bottom using a YSI model 30 S-C-T meter. Water is collected at depth with a five-liter Niskin bottle, and temperature and salinity are measured within the bottle immediately upon retrieval (Connecticut DEEP, 2012).

Sampling Intensity

Sampling is divided into spring (April-June) and fall (Sept-Oct) periods, with 40 sites sampled monthly for a total of 200 sites annually. The sampling gear employed is a 14 m otter trawl with a 51 mm codend. To reduce the bias associated with day-night changes in catchability of some species, sampling is conducted during daylight hours only (Sissenwine and Bowman, 1978).

LISTS employs a stratified-random sampling design. The sampling area is divided into 1.85 x 3.7 km (1 x 2 nautical miles) sites, with each site assigned to one of 12 strata defined by depth interval (0 - 9.0 m, 9.1 - 18.2 m, 18.3 - 27.3 m or, 27.4+ m) and bottom type (mud, sand, or transitional as defined by Reid et al. 1979). For each monthly sampling cruise, sites are selected randomly from within each stratum. The number of sites sampled in each stratum was determined by dividing the total stratum area by 68 km^2 (20 square nautical miles), with a minimum of two sites sampled per stratum. Discrete stratum areas smaller than a sample site are not sampled. The survey's otter trawl is towed from the 15.2 m aluminum R/V John Dempsey for 30 minutes at approximately 3.5 knots, depending on the tide (Connecticut DEEP, 2012).

Biological Sampling

At completion of the tow, the catch is placed onto a sorting table and sorted by species. Menhaden, as well as other finfish and crustacean species, are counted and lengths are recorded to the centimeter as fork length. It is important to note that the length sampling for menhaden did not begin until 1996, and due to the fact that the LISTS samples both adults and juveniles, data prior to 1996 could not be used for the analysis.

The number of individuals measured from each tow varies by species, and also depends on the size of the catch and range of lengths. If a species is subsampled, the length frequency of the catch is determined by multiplying the proportion of measured individuals in each centimeter interval by the total number of individuals caught. Some species are sorted and subsampled by length group so that all large individuals are measured and a subsample of small (often young-of-year) specimens is measured. All individuals not measured in a length group are counted. The length frequency of each group is estimated as described above, i.e. the proportion of individuals in each centimeter interval of the subsample is expanded to determine the total number of individuals caught in the length group. The estimated length frequencies of each size group are then appended to complete the length frequency for that species (Connecticut DEEP, 2012).

Biases

This survey was not designed to target Atlantic menhaden. In order to use this data to generate an index of abundance for stock assessment, statistical model-based standardization of the survey data was conducted to account for factors that affect menhaden catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis.

Development of Estimates

YOY menhaden were distinguished from age 1+ fish using the monthly length cutoffs for Region 1 as defined in Table 5.3.8 of the assessment report. Menhaden in the LISTS ranged from 0.4 to 32.5 cm with an average of 2.9 cm (Figure 1).

Following the approach described in the TC's standardization guidelines, an index of age 0 menhaden was created using a negative binomial generalized linear model (glm) with a log link and bootstrapped estimates of uncertainty (Figure 2). Zero inflated negative binomial models were also tested and compared using a vuong non-nested hypothesis test. Tows conducted at stations, strata, and in months (April, and then September through November) with >=5% of positive tows for menhaden were included in the analysis to eliminate places and times of the year during which age 0 menhaden would not be expected to be caught in Connecticut waters.

Additionally, an index of age 1+ menhaden was created using a negative binomial generalized linear model with a log link and bootstrapped estimates of uncertainty (Figure 6). Zero inflated negative binomial models were again tested and compared using a vuong non-nested hypothesis test. Tows conducted at stations, strata, and in months (April through June and then September through November) with >=5% of positive tows for menhaden were included in the analysis to eliminate places and times of the year during which age 1+ menhaden would not be expected to be caught in Connecticut waters.

<u>Estimates</u>

In each case (YOY and age 1+), a full model that predicted catch as a linear function of year (categorical), month (categorical), season (categorical), station (categorical), stratum (categorical), depth (continuous), surface temperature (continuous), surface salinity (continuous), bottom temperature (continuous), and bottom salinity (continuous) was compared with nested submodels using AIC. The optimal model selected was then compared to a zero inflated negative binomial model of the same form using a vuong non-nested hypothesis test.

For the YOY data, a zero inflated negative binomial sub model of year and depth was selected because the model achieved convergence and it produced a favorable vuong test when compared to the negative binomial glm. The index declined from the time series peak in the mid-2000s to the present. Diagnostics identified slight underprediction by the model of average annual catch per tow (Figures 3-4). Overall, the model exhibited adequate diagnostics given the low sample size and high variability in the number of age 0 menhaden caught in this survey. The index was highly variable over time, but exhibited a marked increase from low catches beginning in the late-1990s (Figure 5).

For the age 1+ data, a sub model of year and season was selected because the model achieved convergence and it produced the lowest AIC value of the subset of converged models. The zero inflated model in this case did not converge. Diagnostics identified overprediction by the model of average annual catch per tow (Figures 7-8). Overall, the model exhibited adequate diagnostics given the low sample size and high variability in the number of age 1+ menhaden caught in this survey. The index was highly variable over time, but exhibited an increasing trend from the low catches seen in the 1990s (Figure 9). The increasing trend starts in the early 2000s and continues to the present.

New York Peconic Bay Trawl Survey

***Unless otherwise indicated, figures and tables can be found in "RI NYPB DEIB MDCB VIMS GA trawl indices.xlsx"**

Methods

Survey Design

New York Department of Environmental Conservation Peconic Bay trawl survey is conducted with a 4.8 m semi-balloon shrimp trawl towed for 10 minutes at 2.5 knots. Data include a mixture of fixed and random sampling stations. From 1987 – 1990, the net was set by hand and retrieved using a hydraulic lobster pot hauler. From 1991 to the present the net was set and retrieved using hydraulic trawl winches and an A-frame. Due to vessel problems, the survey was not conducted during the following time periods: 2005 from mid-July through October, 2006 from May through mid-July, 2008 from May through mid-August, and 2010 during May. Data elements include numbers caught by species and a suite of environmental information including surface and bottom temperature, salinity, dissolved oxygen, and secchi disc readings.

Sampling Intensity

Sixteen stations are randomly chosen each week for sampling during the months of May through October. A total of approximately 150–320 tows are recorded annually.

Biological Sampling

All finfish species are identified and counted.

Potential Biases

This survey was not designed to target Atlantic menhaden. In order to use this data to generate an index of abundance for stock assessment, statistical model-based standardization of the survey data was conducted to account for factors that affect menhaden catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis.

Development of Estimates

YOY menhaden were distinguished from age 1+ fish using the monthly length cutoffs for Region 1 as defined in Table 5.3.8 of the assessment report. Very few adult fish were caught in this survey. Age 0 menhaden ranged from 5 to 153 mm with an average of 45 mm (Figure 5). Records collected in 1993 were excluded because too few tows were conducted during peak months of menhaden abundance.

Following the approach described in Appendix X, an index of age 0 menhaden was created using a negative binomial generalized linear model with a log link and bootstrapped estimates of uncertainty (Figure 6). Tows conducted at stations (2, 9, 10, 16, 17, 26, 27, 38, 41, 44, 51, 52, 60, 62, 69, 70, 71, 72, 74, 76) and in months (July and August) with >=5% of positive tows for menhaden were included in the analysis to eliminate places and times of the year during which age 0 menhaden would not be expected to be caught in Peconic Bay. Proportion of positive tows in the subset of data for Atlantic menhaden averaged approximately 23% across the time series (Table 2). Few tows were conducted during the summer months in 1993; therefore, this year was excluded from the analysis in addition to the years with the survey was either not conducted or set by hand as described above.

Estimates

A full model that predicted catch as a linear function of year, depth, and bottom salinity was compared with nested submodels using AIC. The model including year, depth, and bottom salinity factors was selected because it produced the lowest AIC (% deviance = 33). The index exhibited a marked increase from low catches beginning in the 2000s (Figure 5.3.8 in assessment report). The index peaked in the mid-2000s then declined from 2004 to 2011. An increase was again observed in the final two years of the time series. Diagnostics identified slight over prediction of average annual catch per tow (Figures 7-8).

New Jersey Ocean Trawl Survey

***Unless otherwise indicated, figures and tables can be found in "NJTables&Figs.xlsx"**

Methods

Survey Design

The survey area consists of New Jersey coastal waters from Ambrose Channel, or the entrance to New York Harbor, south to Cape Henlopen Channel, or the entrance to Delaware Bay, and from about the 3 fathom isobath inshore to approximately the 15 fathom isobath offshore. This area is divided into 15 sampling strata. Latitudinal boundaries are identical to those that define the sampling strata of the National Marine Fisheries Service (NMFS) Northwest Atlantic groundfish survey. Exceptions are those strata at the extreme northern and southern ends of New Jersey. Where NMFS strata extended into New York or Delaware waters, truncated boundaries were drawn which included only waters adjacent to New Jersey, except for the ocean waters off the mouth of Delaware Bay, which were also included.

Longitudinal boundaries consist of the 5, 10, and 15 fathom isobaths. Where these bottom contours were irregular, stratum boundaries were smoothed by eye. As a result, the longitudinal strata boundaries for the New Jersey survey area are similar, but not identical, to the corresponding NMFS boundaries.

Each stratum is divided by grid lines into blocks which represent potential sampling sites; each block is identified by a number assigned sequentially within each stratum. The dimensions of mid-shore (5-10 fathoms) and offshore (10-15 fathoms) blocks are 2.0 minutes longitude by 2.5 minutes latitude; inshore (3-5 fathoms) blocks were 1.0 minutes longitude by 1.0 minutes latitude. Inshore block dimensions were smaller because inshore strata were narrower and of much less area compared to mid- and offshore strata; small block size permits a greater number of potential sampling sites than would be possible with the larger dimensions. This is important for statistical analysis and follows the strategy of NMFS for their groundfish survey. Dimensions of blocks transected by stratum boundaries have less area than described above; blocks reduced in area by more than one-half were generally not assigned a number.

Prior to the January 2011 trawl cruise, surface and bottom water samples were collected with a 1.2 l Kemmerer bottle for measurement of salinity and dissolved oxygen, the former with a conductance meter and the latter by the Winkler titration method. Surface and bottom temperatures are measured with a thermistor. These water samples were collected prior to trawling. Starting January, 2011, and all subsequent trawl cruises thereafter, water chemistry data was collected via a YSI 6820 multiparameter water quality SONDE from the bottom, mid-point and surface of the water column. Parameters collected included depth, temperature, dissolved oxygen and specific conductance. All water chemistry data was collected prior to trawling (New Jersey DEP, 2013).

Sampling Intensity

Trawl samples are collected by towing the net for 20 minutes, timed from the moment the winch brakes are set to stop the deployment of tow wire to the beginning of haulback. Enough tow wire is released to provide a wire length to depth ratio of at least 3:1, but in shallow (< 10 m) water this ratio is often much greater, in order to provide separation between the vessel and the net (New Jersey DEP, 2013).

Biological Sampling

Following haulback, the catch is dumped into a 4 x 8-ft. sorting table where fishes and macroinvertebrates are sorted by species into plastic buckets and fish baskets. The total weight of each species is measured with metric scales and the length of all individuals comprising each species caught, or a representative sample by weight for large catches, is measured to the nearest cm. Fork length is measured for menhaden. Catches containing large numbers of relatively small specimens are often mixed and the mix subsampled by weight. The mix is then sorted and measured and species components later extrapolated, based upon their representation in the subsample, to determine contribution to the total catch (New Jersey DEP, 2013).

Biases

This survey was not designed to target Atlantic menhaden. In order to use this data to generate an index of abundance for stock assessment, statistical model-based standardization of the survey data was conducted to account for factors that affect menhaden catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis. In addition, there have been survey design changes through the time series, mainly vessel changes, but it is hoped that the standardization procedure employed accounts for these modifications.

Development of Estimates

YOY menhaden were distinguished from age 1+ fish using the monthly length cutoffs for Region 1 as defined in Table 5.3.8 of the assessment report. Menhaden in the New Jersey trawl survey ranged from 3 to 43 cm with an average of 11.6 cm (Figure 1).

Following the approach described in the TC's standardization guidelines, an index of age 0 menhaden was created using a negative binomial generalized linear model with a log link and bootstrapped estimates of uncertainty. Zero inflated negative binomial models were also tested and compared using a vuong non-nested hypothesis test. Tows conducted at stations, strata, and in months (January, June, August, October, and December) with >=5% of positive tows for menhaden were included in the analysis to eliminate places and times of the year during which age 0 menhaden would not be expected to be caught in New Jersey waters (Table 1).

Additionally, an index of age 1+ menhaden was created using a negative binomial generalized linear model with a log link and bootstrapped estimates of uncertainty (Figures 6-9). Zero inflated negative binomial models were again tested and compared using a vuong non-nested hypothesis test. Tows conducted at stations, strata, and in months (January, April, June, August, October, and December) with >=5% of positive tows for menhaden were included in the analysis to eliminate places and times of the year during which age 1+ menhaden would not be expected to be caught in New Jersey waters.

Estimates

In each case (YOY and age 1+), a full model that predicted catch as a linear function of year (categorical), stratum (categorical), month (categorical), station (categorical), block (categorical), vessel (categorical), depth (continuous), bottom temperature (continuous), bottom salinity (continuous), and bottom dissolved oxygen was compared with nested submodels using AIC. The optimal model selected was then compared to a zero inflated negative binomial model of the same form using a vuong non-nested hypothesis test.

For the YOY data, a sub model of year, bottom temperature, and bottom salinity was selected because the model achieved convergence and it produced the lowest AIC value of the subset of converged models (Figures 2-5). The zero inflated negative binomial model did not converge. The index was highly variable, but indicates a period of increasing YOY abundance beginning in the late-1990s to the mid 2000s. Since the mid 2000s abundance appears to be relatively low. Diagnostics identified both over and underprediction by the model of average annual catch per tow. Overall, the model exhibited adequate diagnostics given the low sample size and high variability in the number of age 0 menhaden caught in this survey.

For the age 1+ data, a sub model of year, bottom temperature, and bottom salinity was selected because the model achieved convergence and it produced the lowest AIC value of the subset of converged models. The zero inflated negative binomial model did not converge. The index was highly variable, but indicates a period of increasing age 1+ abundance beginning in the 2000s and continuing to the present. Diagnostics identified both over and underprediction by the model of average annual catch per tow (Figures 6-9). Overall, the model exhibited adequate diagnostics given the low sample size and high variability in the number of age 0 menhaden caught in this survey.

DE Delaware Bay 16’ Trawl Survey

***Unless otherwise indicated, figures and tables can be found in “DE16ft_Tables&Figs.xlsx”**

Methods

Survey Design

The survey design is a fixed station design that occurs on the DE side of the Delaware Bay and in the bay's tributary rivers and inland bays. Sampling was conducted monthly from April through October at 33 stations in the Delaware Bay and six stations in the Delaware River above the Chesapeake and Delaware Canal. Twelve stations were sampled monthly in the Indian River and Rehoboth Bays (Inland Bays). April sampling was missed in 2003 at station 22 in the Delaware Estuary and was permanently discontinued in July 2003 due to shoaling and draft considerations at the Mahon River entrance. Occasionally some stations have been missed due to extreme low water conditions or other navigational obstructions. There was no missed sampling in the Delaware Estuary or in the Inland Bays in the 2013 survey. An important note is that there have been vessel changes made during the survey time series.

Surface temperature (°C), salinity (ppt) and dissolved oxygen (ppm) were recorded at the beginning of each tow. Tidal stage, weather conditions, water depth and engine speed were recorded for each station at the start of each tow (Delaware DFW, 2013).

Sampling Intensity

Sampling at each station consisted of a ten-minute trawl tow, usually made against the prevailing tide. Occasionally, tows less than ten minutes were made in cases of unforeseen gear conflicts, draft considerations, etc. In such cases, tows were required to be at least five minutes in duration to be considered valid. Catches from short tows were standardized to ten minutes. Where only one individual of a species was collected in a short tow, no expansion was made. A 10:1 ratio of line-out was continually adjusted according to water depth (Delaware DFW, 2013).

Biological Sampling

At completion of the tow, the catch is placed onto a sorting table and sorted by species. Menhaden, as well as other finfish and crustacean species, are counted and a representative subsample of 30 specimens per species was measured for fork length to the nearest half centimeter (Delaware DFW, 2013).

Biases

This survey was not designed to target Atlantic menhaden. In order to use this data to generate an index of abundance for stock assessment, statistical model-based standardization of the survey data was conducted to account for factors that affect menhaden catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis. In addition, there have been survey design changes through the time series, including vessel changes, but it is hoped that the standardization procedure employed accounts for these modifications.

Development of Estimates

YOY menhaden were distinguished from age 1+ fish using the monthly length cutoffs for Region 1 as defined in Table 5.3.8 of the assessment report. Menhaden in the Delaware 16 foot trawl survey ranged from 2 to 31.5 cm with an average of 10.4 cm (Figure 1).

Following the approach described the TC's standardization guidelines, an index of age 0 menhaden was created using a negative binomial generalized linear model with a log link and bootstrapped estimates of uncertainty. Zero inflated negative binomial models were also tested and compared using a vuong non-nested hypothesis test. Tows conducted at stations, strata, and in months (April through October) with >=5% of positive tows for menhaden were included in the analysis to eliminate places and times of the year during which age 0 menhaden would not be expected to be caught in Delaware waters.

Additionally, an index of age 1+ menhaden was created using a negative binomial generalized linear model with a log link and bootstrapped estimates of uncertainty. Zero inflated negative binomial models were again tested and compared using a vuong non-nested hypothesis test. Tows conducted at stations, strata, and in months (April through October) with >=5% of positive tows for menhaden were included in the analysis to eliminate places and times of the year during which age 1+ menhaden would not be expected to be caught in Delaware waters.

Estimates

In each case (YOY and age 1+), a full model that predicted catch as a linear function of year (categorical), month (categorical), station (categorical), tide (categorical), depth (continuous), surface temperature (continuous), surface salinity (continuous) was compared with nested submodels using AIC. The optimal model selected was then compared to a zero inflated negative binomial model of the same form using a vuong non-nested hypothesis test.

For the YOY data, a sub model of year and surface temperature was selected because the model achieved convergence and it produced the lowest AIC value of the subset of converged models. The zero inflated negative binomial model had a favorable vuong test, but after a review of some diagnostics, this more complex model was abandoned for the more parsimonious negative binomial glm. Diagnostics identified both over and underprediction by the model of average annual catch per tow (Figures 2-4). Overall, the model exhibited adequate diagnostics given the low sample size and high variability in the number of age 0 menhaden caught in this survey. The index was highly variable over time, but potentially indicates periods of high YOY abundance in the late-1980s to the early 1990s and again in the late 1990s to the early 2000s (Figure 5). There are other shorter term spikes in abundance early in the time series and again late in the time series.

For the age 1+ data, a sub model of year, surface temperature, and surface salinity was selected because the model achieved convergence and it produced the lowest AIC value of the subset of converged models. The zero inflated negative binomial model had a favorable vuong test, but after a review of some diagnostics, this more complex model was abandoned for the more parsimonious negative binomial glm. The index was highly variable over time, but exhibited a period of high abundance in the 1980s and then again in the 2000s (Figure 6-8). Diagnostics identified underprediction by the model of average annual catch per tow (Figures 9). Overall, the model exhibited adequate diagnostics given the low sample size and high variability in the number of age 1+ menhaden caught in this survey.

Delaware: Delaware Bay 30 ft Trawl Survey

***Unless otherwise indicated, figures and tables can be found in "DE32ft_Tables&Figs.xlsx"**

Methods

Survey Design

Delaware Division of Fish and Wildlife (DDFW) 30 ft research trawl survey is conducted in Delaware Bay using nine fixed sampling stations, although one station was censored as less than 5% of catches were caught at one of the stations. Data collection has occurred intermittently from 1966-2013 with data being collected in 1966-1971, 1974, 1979-1984, and 1990-2013. The years of 1990 to 2013 were used to create the final index of abundance in order to keep the longest uninterrupted time series. Sampling has occurred most often during March through December, but has also occurred in some years in January and February. Catches in March were less than 5% of the total catches. The months of April through December were used to create the index of abundance in order to maintain consistent sampling and catches throughout the time series. Data elements include numbers caught by species and a suite of environmental information including bottom and sea surface water temperature, salinity, and dissolved oxygen.

Sampling Intensity

The survey is conducted March through December. A total of approximately 44–71 tows are recorded annually (Table 1). Proportion of positive tows for Atlantic menhaden averaged approximately 59% across the time series (Table 1).

Biological Sampling

All Atlantic menhaden collected are measured in mm FL. Length compositions were provided in 1 cm length bins for the duration of the trawl survey sampling (Table 3).

Biases

This survey was not designed to target Atlantic menhaden. In order to use these data to generate an index of abundance for the stock assessment, statistical model-based standardization of the survey data was conducted to account for factors that affect menhaden catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis.

Development of Estimates

Following the TC's index standardization guidelines, an index of age-1+ menhaden was created using a negative binomial glm with a log link function and bootstrapped estimates of uncertainty. Tows conducted at stations (11, 21, 31, 41, 51, 52, 71, and 72) and in months (April to December) with >=5% of positive tows for menhaden were included in the analysis to eliminate places and times of the year during which age-1+ menhaden would not be expected to be caught in Delaware Bay waters. Tows were excluded is they caught fish less than the size cutoffs used to indicate age-0 fish. The Vuong test did not indicate that the zero-inflated negative binomial model was a significantly better fit to the data than the negative binomial glm ($p = 0.32$); however, the test did indicate that it was the preferred model overall. In addition, the diagnostic plots of both models also indicated that the zero-inflated negative binomial model was a better fit overall.

Estimates

A full model that predicted catch as a linear function of year, month, and station as categorical factors was compared with nested sub-models using AIC. The model with year and month as factors was selected as the best fit model because it produced the lowest AIC value (-5320) with 65 df. The index was highly variable over time with the lowest points in 2003 and 2004 with a general increase to the present (Figure 5.3.12 in assessment report). Diagnostics showed that the model predicted average annual catch per tow was fairly good (Figures 1-3). Overall, the model exhibited adequate diagnostics given the sample size and high variability in the number of menhaden caught in this survey.

Delaware Inland Bays Trawl Survey

***Unless otherwise indicated, figures and tables can be found in "RI NYPB DEIB MDCB VIMS GA trawl indices.xlsx"**

Methods

Survey Design

Delaware Division of Fish and Wildlife operates a fixed station, bottom trawl survey within the inland bays during the months of April to October. Bottom readings not collected across most of time series, so surface readings were used instead.

Sampling Intensity

Twelve fixed stations are sampled monthly. An average of 78 tows was recorded annually.

Biological Sampling

A subset of menhaden caught are identified and counted. A maximum of 24 menhaden were measured in each sample.

Potential Biases

This survey was not designed to target Atlantic menhaden. In order to use this data to generate an index of abundance for stock assessment, statistical, model-based standardization of the survey data was conducted to account for factors that affect menhaden catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis.

Development of Estimates

Lengths of sampled fish were compared with the monthly length cutoffs defined for Regions 1-3 as defined in Table 5.3.8 of the assessment report. Less than 5% of the sampled fish were of adult size across the entire time series. Given a maximum of 24 fish were measured in each sample and very few fish sampled were of adult size, all menhaden caught were assumed to be age0. Menhaden in this survey ranged from 25 to 305 mm with one peak at ~45 mm and another at ~110 mm (Figure 9).

Following the approach described in Appendix X, an index of age 0 menhaden was created using a negative binomial generalized linear model with a log link and bootstrapped estimates of uncertainty (Figure 10). Tows conducted at stations (4, 5, 6, 7, 16, 14)) and in months (June to October) with >=5% of positive tows for menhaden were included in the analysis to eliminate places and times of the year during which age 0 menhaden would not be expected to be caught in the inland bays. Proportion of positive tows in the subset of data for Atlantic menhaden averaged approximately 37% across the time series (Table 3).

Estimates

A full model that predicted catch as a linear function of year, sea surface temperature, and surface salinity was compared with nested submodels using AIC. The full model was selected because it produced the lowest AIC (% deviance = 43). The index exhibited high values in the late 1980s to early 1990s, low values through most of the 1999s, and another series of high values between 2000 and 2008 (Figure 5.3.6 in assessment report). Diagnostics identified slight over prediction of average annual catch per tow and some systematic deviation outside confidence limits in the quantile-quantile plots (Figures 9-12).

Maryland Coastal Bays Trawl Survey

***Unless otherwise indicated, figures and tables can be found in "RI NYPB DEIB MDCB VIMS GA trawl indices.xlsx"**

Methods

Survey Design

The Maryland Department of Natural Resources Fisheries Service has maintained a fish population-monitoring project in the Maryland coastal bays since 1972. Data from 1972 – 1988 were collected prior to implementing a standardized protocol. Since 1989, samples were collected at 20 trawl and 19 beach seine sites in Assawoman Bay, Isle of Wight Bay, Turville Creek, Grays Creek, St. Martins River, Sinepuxent Bay, Chincoteague Bay, Trappe Creek, and Newport Bay. Samples were taken using a 16 foot semi-balloon trawl in open water and a 100 foot or 50 foot bag seine at shore locations. These gears were selected to target finfish. Data elements include numbers caught by species and a suite of environmental information including surface and bottom temperature, salinity, dissolved oxygen, and secchi disc readings. Bottom readings were not collected across most of time series, so surface readings were used in this analysis.

Sampling Intensity

Trawl sampling was conducted at 20 fixed sites throughout Maryland's Coastal Bays on a monthly basis from April through October. With the exception of June and September, samples were taken beginning the third week of the month. Sampling began the second week in June and September in order to allow enough time to incorporate beach seine collections. Number of tows ranged from 116 to 162 annually.

Biological Sampling

At each site, a sub-sample of the first 20 fish (when applicable) of each species were measured and the remainder counted. Only 9 adult fish were caught (<0.5% of the sampled fish) across the time series. Typically, menhaden ranged from 38 to 118 mm total length with a mean length of 57 mm (Figure 13).

Potential Biases

This survey was not designed to target Atlantic menhaden. In order to use this data to generate an index of abundance for stock assessment, statistical, model-based standardization of the survey data was conducted to account for factors that affect menhaden catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis.

Development of Estimates

Following the approach described in Appendix X, an index of age 0 menhaden was created using a zero-inflated negative binomial generalized linear model with a logit link and bootstrapped estimates of uncertainty (Figure 14). The Vuong test indicated that the zero-inflated negative binomial model was a better fit to the data than the negative binomial glm ($p = 7.5\ e^{-5}$).

Given the limited length measurements available for menhaden, all fish caught were assumed to be age0 menhaden after the dataset was limited to places and times of the year during which age 0 menhaden would be expected to be caught in the coastal bays. Only tows conducted at stations (T001-2, T004-7, T0012, T0015, T0018-T0019, W006, and W017) with >=1% of positive tows for menhaden and in months (May, June, and July) with >=5% of positive tows for menhaden were included in the analysis; catches for this dataset where distributed widely across many stations, so a 1% (vs. 5%) threshold for station inclusion was used. Proportion of positive tows in the subset of data for Atlantic menhaden averaged approximately 30% across the time series (Table 4).

Estimates

A full model that predicted catch as a linear function of year, surface salinity, and sea surface temperature was compared with nested submodels and the submodel that included year, and salinity was selected because it produced the lowest AIC. The index began at a time-series high in the late 1980s to early 1990s, dropped to low values through most of the late 1990s, then rose to a slightly higher level of catch between 2000 and 2010 (Figure 5.3.6 in assessment report). Diagnostics identified slight over prediction of average annual catch per tow (Figures 15).

Virginia Gill Net Shad Survey

***Unless otherwise indicated, figures and tables can be found in "VA_gillnet_Tables&Figs.xlsx"**

Methods

Survey Design

The Virginia Marine Resources Commission (VMRC) gill net survey is conducted with a staked gill net, which is set for a 24 hour period. Sampled areas include lower Chesapeake Bay including the James and York Rivers (with a 273 m net and 12.4 cm stretched mesh), as well as the Rappahannock River (with a 277 m net and 12.7 cm stretched mesh). Sites are at fixed sampling locations. Data collection has occurred between late February and early May from 1998 to the present. Because February catches were less than 5% of the total catches, data records from February were censored. Data elements include numbers caught by species and environmental information including temperature and salinity.

Sampling Intensity

The survey is conducted February through May, but February was censored due to low catches. A total of approximately 42–68 tows are recorded annually (Table 1). Proportion of positive tows for Atlantic menhaden averaged approximately 92% across the time series (Table 1).

Biological Sampling

Atlantic menhaden were collected and measured in mm FL in 2013 only. The length composition was provided in 1 cm length bins for 2013 (Table 3).

Biases

This survey was not designed to target Atlantic menhaden. In order to use these data to generate an index of abundance for stock assessment, statistical model-based standardization of the survey data was conducted to account for factors that affect menhaden catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis.

Development of Estimates

Following the TC's standardization guideliens, an index of age-1+ menhaden was created using a negative binomial generalized linear model with a log link and bootstrapped estimates of uncertainty. Gill nets set in the months (March to May) with >=5% of positive tows for menhaden were included in the analysis to eliminate and times of the year during which age-1+ menhaden would not be expected to be caught in lower Chesapeake Bay rivers.

<u>Estimates</u>

A full model that predicted catch as a linear function of year, month, and river as categorical factors and effort as an offset was compared with nested sub-models using AIC. The full model was selected because it produced the lowest AIC and largest percent deviance (10%). The index was highly variable over time with no trend. Diagnostics identified slight under prediction of average annual catch per set, while the QQ plot indicated a reasonable level of fit to the observed data (Figures 1-3). Overall, the model exhibited adequate diagnostics given the low sample size and high variability in the number of menhaden caught in this survey.

<u>VIMS Juvenile Fish Trawl Survey</u>

***Unless otherwise indicated, figures and tables can be found in "RI NYPB DEIB MDCB VIMS GA trawl indices.xlsx"**

<u>Methods</u>

Survey Design

A 30' semi-balloon otter trawl, with 1.5" stretched mesh and 0.25" cod-end liner, is towed along the bottom for five minutes during daylight hours. Sampling occurs monthly except during January and March, when few target species are available. A combination or stratified random and fixed stations have been consistently sampled according to their location and depth since 1988. Data elements include numbers caught by species and a suite of environmental information including temperature, salinity, dissolved oxygen, tide, and depth readings.

Sampling Intensity

Only tows conducted in the James, York, and Rappahannock Rivers were used in the development of this index due to low occurrence of stations with consistent sampling and positive menhaden tows in other regions. Annual number of tows in these three systems ranged from 13 to 849 between 1988 and 2013.

Biological Sampling

All fishes collected were identified to species, counted, and menhaden measured to the nearest millimeter fork length (FL). In instances of extremely large catches, subsampling was performed volumetrically.

Potential Biases

This survey was not designed to target Atlantic menhaden. In order to use this data to generate an index of abundance for stock assessment, statistical, model-based standardization of the survey data was conducted to account for factors that affect menhaden catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis.

Development of Estimates

Age0 index #1: Using the methods used by VIMS to identify juvenile menhaden in their survey, only tows conducted in the months of May and June were included in the analysis. Lengths of fish caught in these months were compared with the monthly length cutoffs for Regions 1-3 as defined in Table 5.3.8 of the assessment report. Note that an index generated using the length cutoffs applied by VIMS was compared with the index described here and found to be almost identical; to maintain consistency, the length cutoffs defined in Table 5.3.8 of the assessment report were applied to the final index. Typically, age0 menhaden ranged from 23 to 150 mm fork length with a mean length of 88 mm (Figure 16). Proportion of positive tows in the subset of data for Atlantic menhaden averaged approximately 15% across the time series (Table 5).

Following the approach described in Appendix X, an index of age 0 menhaden was created using a negative binomial generalized linear model with a log link and bootstrapped estimates of uncertainty (Figure 17).

Age0 index #2: Lengths of fish were compared with the monthly length cutoffs for Regions 1-3 as defined in Table 5.3.8 of the assessment report. Fish caught in months with >=5% of positive tows for menhaden (December, January, February, March) were included in the analysis. Typically, age0 menhaden ranged from 17 to 150 mm fork length with a mean length of 84 mm (Figure 20). Proportion of positive tows in the subset of data for Atlantic menhaden averaged approximately 24% across the time series (Table 6).

Following the approach described in Appendix X, an index of age 0 menhaden was created using a zero-inflated negative binomial generalized linear model with a logit link and bootstrapped estimates of uncertainty (Figure 21). The Vuong test indicated that the zero-inflated negative binomial model was a better fit to the data than the negative binomial glm ($p = 1.31\ e^{-12}$).

Adult index: Lengths of fish caught throughout the year were compared with the monthly length cutoffs defined for Regions 1-3 as defined in Table 5.3.8 of the assessment report. Typically, adult menhaden ranged from 106 to 344 mm fork length with a mean length of 221 mm (Figure 23). Proportion of positive tows in the subset of data for Atlantic menhaden averaged approximately 7% across the time series (Table 7).

Following the approach described in Appendix X, an adult index was created using a negative binomial generalized linear model with a log link and bootstrapped estimates of uncertainty (Figure 24). One exception to the standard methods was that all months were used in the generation of this index because catch was more evenly distributed across months (>=4% in each month) for adults than for age0 fish. Given the low number of observations of adults, all months were included in order to attempt to generate an index.

Estimates

Age0 index #1: Models that predicted catch as a linear function of year, river system and either bottom salinity, bottom temperature, depth, or dissolved oxygen were compared using AIC. The model that included year and depth was selected because it produced the lowest AIC and no convergence problems (% deviance = 36). The index exhibited a decline from moderate values in the 1980s through the early 2000s, then rose to highly variable but larger values from 2003 to 2010; the final 3 years of the index exhibited a decline to the low values similar to those observed in the late 1990s. Diagnostics identified slight over prediction of average annual catch per tow (Figures 19-20).

Age0 index #2: Models that predicted catch as a linear function of year, river system, bottom salinity, bottom temperature, and depth were compared using AIC. The model that included year, bottom salinity, and bottom temperature was selected because it produced the lowest AIC and no convergence problems (% deviance = 36). The index exhibited peaks in the early 1900s and 2000s and periods of low catch in the late 1990s and 2010 to present. Diagnostics identified slight underprediction of average annual catch per tow (Figures 22).

Adult index: A full model that predicted catch as a linear function of year, river system, bottom salinity, bottom temperature, depth, or dissolved oxygen was compared with nested submodels using AIC. The full model was selected because it produced the lowest AIC (%deviance=16). The index exhibited a decline from high values from the 1980s through the 1990ss, then returned to equally high values throughout the 2000s (Figure 5.3.11 in assessment report). Diagnostics identified slight over prediction of average annual catch per tow, some systematic deviation outside confidence limits in the quantile-quantile plots, and some patterning in the residuals (Figures 25-26).

ChesFIMS Trawl Survey

***Unless otherwise indicated, figures and tables can be found in "ChesFIMS_TablesFigs.xlsx"**

Methods

Survey Design

The Chesapeake Bay Fishery-Independent Multispecies Survey (CHESFIMS) was a NOAA-funded research program conducted co-operatively by researchers from the University of Maryland Center for Environmental Science Chesapeake Biological Laboratory and the Maryland Department of Natural Resources. CHESFIMS built upon the earlier work of the NSF-funded Trophic Interactions in Estuarine Systems (TIES) program. Combined, these two surveys represent a 13-year survey of the abundances and key trophic interactions in the Chesapeake Bay fish community. The survey had a complemented design, with a mixture of fixed and random stations. The fixed stations were located along fixed transects that were defined during the early TIES program while a stratified random sample of random stations were selected annually based on proportional allocation to strata based on strata area. The survey area was divided into three strata: upper bay (38°45' to 39°25' N), mid bay (37°55' to 38°45' N) and lower bay (37°5' to 37°55' N). The sampling gear was composed of an 18m^2 mid-water trawl with 3-mm codend mesh that was found to be effective at catching fish between 30-256 mm TL of most species. For each deployment of the gear, an oblique tow was performed whereby the trawl was towed for two minutes in each of ten depth zones distributed throughout the water column leading to a 20 minute standardized tow. All tows were conducted at night. Data elements include numbers caught by species and individual menhaden lengths (nearest mm FL).

Sampling Intensity

The survey was conducted seasonally, with a spring, summer, and fall cruise annually. During each cruise an assortment of fixed and random stations were selected for sampling for a total of 94-650 stations sampled annually (Table 1). The proportion of positive tows for Atlantic menhaden averaged approximately 9% across the time series (Table 1).

Biological Sampling

Individual lengths of Atlantic menhaden are measured to the nearest mm FL. Either the entire sample or random subsamples of 100 individuals are measured from each tow.

Biases

This survey was not designed to target Atlantic menhaden optimally, but rather to provide data on a suite of estuarine species found within the Chesapeake Bay. In order to use this data to generate an index of abundance for stock assessment, statistical model-based standardization of the survey data was conducted to account for factors that affect menhaden catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis.

Development of Estimates

Age 1+ Atlantic menhaden were distinguished from YOY using the monthly length cutoffs defined in Table 2. Age 1+ menhaden ranged from 12 to 39 cm FL with an average of 22.3 cm FL (Figure 1).

Following the TC's standardization guidelines, an index of age 1+ Atlantic menhaden was created using a zero-inflated negative binomial generalized linear model (ZINB) and bootstrapped estimates of uncertainty. Tows from all seasonal cruises were included in the model as percent positive tows in all was greater than 5% thus there was no need to eliminate times of the year during which age 1+ Atlantic menhaden would not be expected to be caught in Chesapeake Bay waters. A histogram of the frequency of catches of a given size can be found in Figure 2.

<u>Estimates</u>

A full ZINB that predicted catch as a function of the categorical variables year and season was compared with nested submodels using AIC. A reduced model that removed the covariate season from the count model of the ZINB was selected because it produced the lowest AIC (2x – logLik = -2500.12). The index was relatively stable over the period 1995-2000, with a subsequent steady increase through 2007 (Figure 3). Diagnostics indicated that the ZINB model was able to appropriately account for overdispersion, as the estimated phi from the final model was 0.89. Residual diagnostics plots can be found in Figures 4- 10. Overall, the model exhibited adequate diagnostics given the low sample size and high variability in the number of menhaden caught in this survey.

ChesMMAP Trawl Survey

***Unless otherwise indicated, figures and tables can be found in "ChesMMAPTablesFigs.xlsx"**

Methods

Survey Design

The Chesapeake Bay Multispecies Monitoring and Assessment Program (CHESMMAP) is conducted through the Virginia Institute of Marine Science. The sampling gear is composed of a 45' 4-seam balloon otter trawl towed for 20 minutes, with the current, at a speed of 3.0-3.3 knots. The survey area includes waters of the Chesapeake Bay from just outside the Chesapeake Bay Bridge Tunnel north to Poole's Island (near Baltimore, MD). Within this range, bay waters are divided into fifteen strata based on latitude (5 regions of approximately 30 latitudinal minutes each) and depth (3 depth strata ranging from 3.0-9.1 m, 9.1-15.2 m, and >15.2 m). Stations for sampling are selected using a stratified random sampling design that incorporates both latitudinal and depth strata. Data elements include numbers caught by species, individual menhaden lengths (nearest mm), and a suite of environmental and water quality data including water temperatures, depth, and salinity.

Sampling Intensity

A total of five cruises are conducted annually during the months of March, May, July, September, and November. During each cruise 80 stations are selected for sampling using the stratified random sampling design for a total of approximately 400 stations sampled annually. However, small catches and a percent positive tow rate of less than 5% led to the exclusion of the July and September cruises and strata 301 from final data analysis. A final constraint based on the area swept of the trawl gear resulted in additional tows being removed from consideration as Atlantic menhaden were never caught when area swept was less than 0.7 or greater than 3.0. After consideration of constraints, this resulted in between 136 and 245 tows annually being included in the estimate of relative abundance (Table 1). The proportion of positive tows for Atlantic menhaden averaged 14% across the time series (Table 1).

Biological Sampling

Individual lengths of Atlantic menhaden are measured to the nearest mm FL.

Biases

This survey was not designed to target Atlantic menhaden optimally, but rather to provide data on a suite of estuarine species found within the Chesapeake Bay. In order to use this data to generate an index of abundance for stock assessment, statistical model-based standardization of the survey data was conducted to account for factors that affect menhaden catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis.

Development of Estimates

Age 1+ Atlantic menhaden were distinguished from YOY using the monthly length cutoffs defined in Table 2. Age 1+ menhaden ranged from 12 to 35 cm FL with an average of 23.6 cm FL (Figure 1).

Following the TC's guidelines for standardization, an index of age 1+ Atlantic menhaden was created using a zero-inflated negative binomial generalized linear model (ZINB) and bootstrapped estimates of uncertainty. The catch distribution of individual CHESMMAP trawls is available in Figure 2.

Estimates

A full ZINB model that predicted catch as a function of the categorical variables year, stratum and cruise, and the continuous variable area swept was compared with nested submodels using AIC. A reduced model that removed the covariate year from the negative binomial count sub-model was selected because it produced the lowest AIC (2x –logLik = -3061.602). The index exhibited a general pattern of increase throughout the time series, though there was a sharp decrease in estimated relative abundance in 2013 (Figure 3). Diagnostics indicated that the ZINB model may not have been able to appropriately account for overdispersion, as the estimated phi from the final model was 2.04. Residual diagnostic plots can be found in Figures 4- 8. Overall, the model exhibited adequate diagnostics given the low sample size and high variability in the number of menhaden caught in this survey.

North Carolina: Gill Net Survey

***Unless otherwise indicated, figures and tables can be found in "NC_gillnet_Tables&Figs.xlsx"**

Methods

Survey Design

North Carolina Division of Marine Fisheries (NCDMF) gill net survey is conducted as a stratified random sampling design based on area and depth. Each gill net consists of 30-yard segments of 3, 3½, 4, 4½, 5, 5½, 6, and 6½ inch stretched mesh webbing (240 yards of gill net) and was fished for 12 hours. Data collection has occurred consistently from 2003-2013. Sampling occurs throughout the year, except January. The greatest catches occurred in March and April, as well as from August through November, with a decrease in catches during the summer months. Therefore, the months of August through November were used to create the index of abundance in order to maintain consistency in catches throughout the areas included. Data elements included numbers caught by species and a suite of environmental information including temperature, salinity, and dissolved oxygen.

Sampling Intensity

A total of approximately 224–304 sets are recorded annually (Table 1). Proportion of positive sets for Atlantic menhaden averaged approximately 56% across the time series (Table 1).

Biological Sampling

Atlantic menhaden collected are measured in mm FL. Length compositions were provided in 1 cm length bins for the duration of the gill net survey sampling (Table 3).

Biases

This survey was not designed to target Atlantic menhaden. In order to use these data to generate an index of abundance for the stock assessment, statistical model-based standardization of the survey data was conducted to account for factors that affect menhaden catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis.

Development of Estimates

Following the TC's standardization guidelines, an index of age-1+ menhaden was created using a zero-inflated negative binomial model with a logit link function and bootstrapped estimates of uncertainty. The Vuong test indicated that the zero-inflated negative binomial model was a better fit to the data than the negative binomial glm ($p = 3.16 \times 10^{-47}$).

Estimates

A full model that predicted catch as a linear function of year, month, mesh, and area as categorical factors was compared with nested sub-models using AIC. The full model including the factors year, month, mesh, and area was selected as the best fit model because it produced the lowest negative log likelihood (-5682) with 67 df. The index was variable over time with the lowest point in 2008 and relatively flat from 2009 to the present (Figure 5.3.13 in assessment report). Diagnostics identified slight underprediction of average annual catch per set (Figures 1-3). Overall, the model exhibited adequate diagnostics.

SCDNR Electrofishing Survey

***Unless otherwise indicated, figures and tables can be found in "SCDNR ElectrofishingTablesFigs.xlsx"**

Methods

Survey Design

The South Carolina Department of Natural Resources (SCDNR) electrofishing survey is conducted through the SCDNR Marine Resources Division. The sampling is conducted via the use of a Smith-Root electrofishing boat with a constant intensity of ~3,000 watts of pulsed direct current. This constant current is maintained via voltage and amperage adjustments in different salinity waters. Shoreline transects are made with the tidal current. The survey area includes five estuarine strata (Combahee river, upper Ashley river, upper Cooper river, and Winyah Bay system) found along coastal South Carolina with the shoreline of each strata being partitioned into 926 m long segments. Each month, a random sample of available segments were selected for sampling. Data elements include numbers caught by species, individual menhaden lengths (nearest standard length in mm; converted to fork length using a length-length conversion factor), and a suite of environmental and water quality data including water temperature, depth, dissolved oxygen concentration, and salinity.

Sampling Intensity

Electrofishing surveys of each of the five strata are conducted monthly throughout the year. During each survey, shoreline sections within each strata are randomly selected for sampling. Each strata is composed of 35-60 possible shoreline sections. However, small catches and/or a percent positive tow rate of less than 5% led to the exclusion of samples collected during the months of January, February, and August-December from index development. For similar reasons, all collections made during late flood tide and in waters greater than 12 PSU (electrofishing gear is ineffective at sampling at high salinities) were excluded during index development. After consideration of constraints, this resulted in between 51 and 137 electrofishing transects annually being included in the estimate of relative abundance (Table 1). The proportion of positive transects for Atlantic menhaden averaged 43% across the time series (Table 1).

Biological Sampling

Individual lengths of Atlantic menhaden are measured to the nearest mm SL. All SL measurements were converted to fork length (FL) using the following SL to FL conversion:

$$FL = 0.2121 + 1.0919 * SL.$$

This conversion is based upon paired SL and FL measurements made by SCDNR staff.

Biases

This survey was not designed to target Atlantic menhaden optimally, but rather to provide data on a suite of estuarine species found within oligohaline-freshwater transition zone areas of South Carolina estuaries. In order to use this data to generate an index of abundance for stock assessment, statistical model-based standardization of the survey data was conducted to account for factors that affect menhaden catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis.

Development of Estimates

Age 0 (YOY) Atlantic menhaden were distinguished from age 1+ menhaden using the monthly length cutoffs defined in Table 2. YOY menhaden ranged from 1.7 to 13 cm FL with an average of 4.8 cm FL (Figure 1).

Following the TC's standardization guidelines, an index of age 0 Atlantic menhaden was created using a zero-inflated negative binomial generalized linear model (ZINB) and bootstrapped estimates of uncertainty. The catch distribution of individual electrofishing transects is available in Figure 2.

Estimates

A full ZINB model that predicted catch as a function of the categorical variables year, month, tidal stage, and stratum, and the continuous variables depth, salinity duration, and water temperature was compared with nested submodels using AIC. A reduced model that removed the covariates month, tidal stage, depth, duration and water temperature from the negative binomial count sub-model and the covariates depth duration and water temperature from the binomial sub-model was selected because it produced the lowest AIC (2x –logLik = -6571.5013). The index exhibited a general pattern of decrease throughout the time series (Figure 3). Diagnostics indicated that the ZINB model may not have been able to appropriately account for overdispersion, as the estimated phi from the final model was 2.49. Residual diagnostic plots can be found in Figures 4- 10. Overall, the model exhibited adequate diagnostics given the low sample size and high variability in the number of menhaden caught in this survey.

SCDNR Trammel Net Survey

***Unless otherwise indicated, figures and tables can be found in "SCDNR TrammelTablesFigs.xlsx"**

Methods

Survey Design

The South Carolina Department of Natural Resources (SCDNR) trammel net survey is conducted through the SCDNR Marine Resources Division. This survey uses a 183 x 2.1 m trammel net composed of three panels. The inner panel is composed of 63.5 mm stretched-mesh while the two outer panels are composed of 355.6 mm stretched-mesh. Trammel nets are set along the shoreline (10 to 20 m from an intertidal marsh flat, <2 m depth) during an ebbing tide with each end anchored on the shore or in shallow marsh. Once set, the waters enclosed by the net are disturbed to agitate fish and then the net is immediately retrieved. The survey area includes seven estuarine strata (ACE Basin, Ashley River, Charleston Harbor, Lower Wando River, Muddy & Bulls Bays, Cape Romain, and Winyah Bay) found along coastal South Carolina. Data elements include numbers caught by species, individual menhaden lengths (nearest standard length in mm; converted to fork length using a length-length conversion factor), and a suite of environmental and water quality data including water temperature, depth, dissolved oxygen concentration, and salinity.

Sampling Intensity

Trammel net surveys of each of the seven strata are conducted monthly throughout the year. Each month, 10 to 12 randomly selected stations are randomly selected for sampling. Each strata has 22 to 30 possible sampling stations in their pool for random selection. However, due to limited sampling coverage, low catches and/or a percent positive tow rate of less than 5% prior to index development all collections made in the years 1990-1993, in the months Dec. – April, durations shorter than 12 minutes or longer than 125 minutes (indication of some problems sampling that station), water temperatures less than 13.8°C and greater than 34.0°C, and at depths greater than 5 m. After consideration of constraints, this resulted in between 269 and 520 trammel net collections being included in annual estimates of relative abundance (Table 1). The proportion of positive trammel net collections for Atlantic menhaden averaged 9% across the time series (Table 1).

Biological Sampling

Individual lengths of Atlantic menhaden are measured to the nearest mm SL. All SL measurements were converted to fork length (FL) using the following SL to FL conversion:

$$FL = 0.2121 + 1.0919 * SL.$$

This conversion is based upon paired SL and FL measurements made by SCDNR staff. In addition, in cases of large catches a random sub-sample of 25 individual menhaden was retained for length measurements.

Biases

This survey was not designed to target Atlantic menhaden optimally, but rather to provide data on a suite of estuarine species found within South Carolina estuaries. In order to use this data to generate an index of abundance for stock assessment, statistical model-based standardization of the survey data was conducted to account for factors that affect menhaden catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis.

Development of Estimates

Age 1+ Atlantic menhaden were distinguished from age 0 (YOY) menhaden using the monthly length cutoffs defined in Table 2. Age 1+ menhaden ranged from 11 to 34 cm FL with an average of 19 cm FL (Figure 1).

Following the TC's standardization guidelines, an index of age 1+ Atlantic menhaden was created using a zero-inflated negative binomial generalized linear model (ZINB) and bootstrapped estimates of uncertainty. The catch distribution of individual trammel net hauls is available in Figure 2.

<u>Estimates</u>

A full ZINB model that predicted catch as a function of the categorical variables year, month, tidal stage, and stratum, the continuous variables depth, salinity, and water temperature, and an offset term for sampling duration was compared with nested submodels using AIC. A reduced model that removed the covariates tidal stage and salinity from the negative binomial count sub-model and the offset term from the binomial sub-model was selected because it produced the lowest AIC (2x –logLik = -8650.5072). The index exhibited a general pattern of increase through the late 1990s, steady or very slight decrease through the mid-2000s, followed by a more sustained decrease in recent years (Figure 3). Diagnostics indicated that the ZINB model was able to appropriately account for overdispersion, as the estimated phi from the final model was 1.49. Residual diagnostic plots can be found in Figures 4- 11. Overall, the model exhibited adequate diagnostics given the low sample size and high variability in the number of menhaden caught in this survey.

Georgia Ecological Monitoring Trawl Survey

***Unless otherwise indicated, figures and tables can be found in "RI NYPB DEIB MDCB VIMS GA trawl indices.xlsx"**

Methods

Survey Design

The Ecological Monitoring Trawl Survey (EMTS) is performed monthly using an otter trawl configured with a naked (i.e. no BRD or TED) 40' flat net towed behind the Research Vessel Anna (62' wooden shrimp boat). Six of Georgia's commercially important estuarine sound systems are sampled each month at fixed stations: Wassaw, Ossabaw, Sapelo, St. Simons, St. Andrew, and Cumberland. Each system is divided into three separate sectors: (1) large creeks and rivers, (2) open sounds and (3) nearshore ocean waters, all of which are in the state's territorial waters. Fifteen-minute tows are performed at each station (min. tow len. =13min.). At each station, GPS coordinates, tow duration, tow speed, depth, and tide information are recorded, as are hydrological data (water temperature, salinity, and dissolved oxygen). No gear changes have been made for the time period used in this analysis (1995 to present).

Sampling Intensity

In each system, at least two trawl stations occur within each sector, making a total of at least six stations per estuarine system. Since 2005, additional stations have been added to the original 36 stations sampled historically, bringing a coastwide total of 42 stations sampled monthly.

Biological Sampling

After each tow, catches are deposited on deck where penaeid shrimp, blue crabs, horseshoe crabs, finfish, and other marine organisms are sorted to the species level. Total weights are recorded for each species and representative random samples of up to 30 individuals of each species are measured.

Potential Biases

This survey was not designed to target Atlantic menhaden. In order to use this data to generate an index of abundance for stock assessment, statistical, model-based standardization of the survey data was conducted to account for factors that affect menhaden catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis.

Development of Estimates

Age0 index: Following the approach described in Appendix X, an index of age 0 menhaden was created using a zero-inflated negative binomial generalized linear model with a logit link and bootstrapped estimates of uncertainty (Figure 28). The Vuong test indicated that the zero-inflated negative binomial model was a better fit to the data than the negative binomial glm ($p = 9.8\ e^{-6}$).

Lengths of fish caught throughout the year were compared with the monthly length cutoffs for Region 4 as defined in Table 5.3.8 of the assessment report. Given the limited length measurements available for menhaden, all fish caught during the months of January to March were assumed to be age0 menhaden. Age0 menhaden ranged from 42 to 287 mm fork length with a mean length of 118 mm (Figure 27). Catches for this dataset where distributed relatively evenly across all sectors, so the 5% of positive tows threshold for station and month inclusion was not used. No models converged when two tows pulled in 2008 that contained extremely large catches of menhaden were included. These tows appeared to be rare occurrences of entire schools of menhaden being caught by the trawl. The magnitude of fish caught in these tows was likely not proportional to true abundance of the menhaden stock; therefore, the catch value for the 2 tows in 2008 (with 9,184 and 20,456 menhaden per tow, respectively) was replaced with the maximum catch in the remained of the time series (2,897). Proportion of positive tows in the subset of data for Atlantic menhaden averaged approximately 46% across the time series (Table 8).

Adult index: Following the approach described in Appendix X, an index of adult menhaden was created using a zero-inflated negative binomial generalized linear model with a logit link and bootstrapped estimates of uncertainty (Figure 31). The Vuong test indicated that the zero-inflated negative binomial model was a better fit to the data than the negative binomial glm ($p = 0.001$).

Lengths of fish caught throughout the year were compared with the monthly length cutoffs for Region 4 as defined in Table 5.3.8 of the assessment report. Given the limited length measurements available for menhaden, all fish caught during the months of April to June were assumed to be adult menhaden; greater than 85% of sampled fish in these months were adult-sized fish. Adult menhaden ranged from 109 to 305 mm fork length with a mean length of 135 mm (Figure 30). Catches for this dataset where distributed relatively evenly across all sectors, so the 5% of positive tows threshold for station and month inclusion was not used. Proportion of positive tows in the subset of data for Atlantic menhaden averaged approximately 36% across the time series (Table 9).

Estimates

Age0 index: A full model that predicted catch as a linear function of year, surface salinity, tow duration, depth, and sea surface temperature was compared with nested submodels. The submodel that included year, tow duration, temperature, and salinity was selected because it produced the lowest AIC. The index was low in the mid-1990s through early 2000s, increased through the mid- to late-2000s, then dropped to low values again in the last few years of the survey (Figure 5.3.6 in assessment report). Diagnostics identified over prediction of average annual catch per tow (Figures 29).

Adult index: A full model that predicted catch as a linear function of year, surface salinity, tow duration, depth, and sea surface temperature was compared with nested submodels. The submodel that included year, temperature, and salinity was selected because it produced the lowest AIC. The index was low in the mid-1990s through mid-2000s, then increased through

2013 (Figure 5.3.13 in assessment report). Diagnostics identified over prediction of average annual catch per tow (Figures 32).

SEAMAP-SA Coastal Trawl Survey

***Unless otherwise indicated, figures and tables can be found in "SEAMAPTablesFigs4.xlsx"**

Methods

Survey Design

The Southeast Area Monitoring, Assessment, and Prediction, South Atlantic Region (SEAMAP-SA) coastal trawl survey is conducted through the South Carolina Department of Natural Resources. The sampling gear is composed of paired 75-ft mongoose-type Falcon trawl nets towed for 20 minutes at 2.5 knots. Sampled areas include 24 coastal latitudinal strata found between Cape Hatteras, NC, and Cape Canaveral, FL bounded inshore and offshore by the 4 m and 10 m depth contours, respectively. Stations are selected for sampling using a stratified random sampling design, with data collection being consistent across seasons from 1990 to the present. Data elements include numbers caught by species, individual menhaden lengths (nearest cm), and a suite of environmental information including bottom and sea surface water temperatures, depth, and salinity.

Sampling Intensity

The survey is conducted seasonally, with a spring (mid-April to mid-May), summer (mid-July to mid-August), and fall (late-September to mid-November) cruise annually. During each cruise, 78-112 stations are selected for sampling via optimal allocation among strata for a total of approximately 234-336 stations sampled annually (Table 1). The proportion of positive tows for Atlantic menhaden averaged approximately 15% across the time series (Table 1).

Biological Sampling

Individual lengths of Atlantic menhaden are measured to the nearest cm FL. Either the entire sample or random subsamples of 30-50 individuals are measured from each tow.

Biases

This survey was not designed to target Atlantic menhaden optimally, but rather to provide data on a suite of coastal species found along the U.S. South Atlantic coast. In order to use this data to generate an index of abundance for stock assessment, statistical model-based standardization of the survey data was conducted to account for factors that affect menhaden catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis.

Development of Estimates

Age 1+ Atlantic menhaden were distinguished from YOY using the monthly length cutoffs defined in Table 2. Age 1+ menhaden ranged from 11 to 32 cm FL with an average of 13.5 cm FL (Figure 1).

Following the approach described in section X, an index of age 1+ Atlantic menhaden was created using a zero-inflated negative binomial generalized linear model (ZINB) and bootstrapped estimates of uncertainty. Tows from all strata and seasonal cruises were included in the model as percent positive tows in all was greater than 5% thus there was no need to eliminate places or times of the year during which age 1+ Atlantic menhaden would not be expected to be caught in U.S. South Atlantic waters. A histogram of the frequency of catches of a given size can be found in Figure 3.

Estimates

A full ZINB that predicted catch as a function of the categorical variables year, season, and strata and continuous variables water temperature and salinity was compared with nested submodels using AIC. A reduced model that removed the covariate salinity from the count model of the ZINB was selected because it produced the lowest AIC (2x –logLik = -12097.34). The index was highly variable over time, but exhibited a general decrease from higher catches initially to series lows in the late-1990s before subsequently generally increasing through the present (Figure 3). Diagnostics indicated that the ZINB model was able to appropriately account for overdispersion, as the estimated phi from the final model was 1.82. Residual diagnostics plots can be found in Figures 4- 10. Overall, the model exhibited adequate diagnostics given the low sample size and high variability in the number of menhaden caught in this survey.

References

Connecticut Department of Energy and Environmental Protection. 2013. A study of marine recreational fisheries in Connecticut – Marine finfish survey – Long Island Sound Trawl Survey Annual report. Federal Aid Project F-54-R-32.

Delaware Division of Fish and Wildlife. 2013. Coastal finfish assessment survey – Annual report. Project F-42-R-25.

New Jersey Department of Environmental Protection. 2013. Ocean Stock Assessment Program Annual Report.

Reid, R.N., A.B. Frame and A.F. Draxler. 1979. Environmental baselines in Long Island Sound, 1972-73. NOAA Tech. Rpt. NMFS SSRF-738, 31 pp.

Sissenwine, M.P. and L. Bowman. 1978. Factors affecting the catchability of fish by bottom trawls. ICNAF Research Bulletin No.13: 81-87.