Inferences from aerial surveys on the abundance of Atlantic menhaden from outside the normal fishery range: Implications for improved management of this resource

Dr. James Sulikowski [1], Dr. Alexia Morgan[1], Amy Carlson[1], and Dr. Doug Butterworth[2]

[1] Marine Science Department, University of New England, 11 Hills Beach Rd.
Biddeford, ME 04005 USA

[2] Department of Mathematics and Applied Mathematics, University of Cape Town,
Rondebosch 7701 South Africa

Abstract

Despite the substantial economic and ecological role of Atlantic menhaden in U.S. waters, abundance information used in stock assessments for this population is geographically limited. This limitation potentially leads to an overestimation of fishing mortality by assuming age 3+ menhaden are fully recruited to the fishery. In order to investigate the abundance of 3+ menhaden that may be outside the area fished, and thus unaccounted for, a pilot study was initiated to test the feasibility of an aerial survey for menhaden in their northern range (New England region). In addition, the ratio of estimated abundance for this northern region and for fish within the southern region, where the fishery takes place, has been estimated through the use of commercial spotter plane data from the fishery. The results suggest that estimates of menhaden in absolute terms for the New England surveys are negatively biased, as is to be expected, with a fair proportion of schools on the trackline probably to deep to be seen; that however does not compromise their use to provide relative measures to compare abundances by region or over time (as is done for example in assessments of Southern Bluefin tuna). The exercise of a relative abundance comparison between the New England and the southern fishing regions, albeit coarse and dependent on many assumptions, does suggest that the former is more than twice the latter, with the New England region comprised of older fish and larger fish. This has important management implications, in that it questions the current BAM results which indicate very heavy fishing on older age groups, suggesting instead that the catch-age-structure is more a reflection of emigration from the fishing grounds than of high fishing mortality. Thus, we suggest that a carefully designed synoptic aerial survey of both regions should be implemented, as an accurate estimate of this New England: southern fishing area abundance ratio would substantially improve assessment results.

Introduction

It is well documented that Atlantic menhaden, *Brevoortia tyrannus,* is both an environmentally (i.e. prey item) and commercially valuable fish species in U.S. coastal waters (e.g. Monroe, 2000; ASFMC, 2011). Historically, the Atlantic menhaden commercial industry consisted of both a reduction and a bait fishery spanning from Canadian maritimes to north Florida (ASFMC, 2001). However, over the last 19 years, the reduction fishery (historically comprising 80% or more of total landings) has contracted dramatically in terms of the geographical range over which it operates. As a result, the reduction fishery is now concentrated in the central range of the stock from approximately Cape Hatteras to northern New Jersey, although the majority of menhaden landings come from Virginia waters (ASFMC, 2011). Commercial landings of menhaden for bait occur in almost every Atlantic coast state; however, landings of menhaden are regionally dominated by harvests in Chesapeake Bay and New Jersey (ASFMC, 2011).

Despite the economic and ecological importance of menhaden, information that can be incorporated into stock assessments is limited, and based primarily upon reduction fishery landings from the center of the fishery. In addition, there are very few landings and age samples from the northern range of the fishery, (north of Long Island), where tagging studies have shown that larger and older fish tend to migrate during the summer (ASFMC, 2004a). Currently, no fishery-independent source of information on distribution and abundance of mature menhaden exists for specimens outside of the normal fishery range. As a result, there potentially may be a substantial, but effectively unknown, portion of the age 3+ menhaden biomass in this age-stratified, migratory stock, which is hardly subject to any fishing mortality. The Beaufort Assessment Model (the model currently used in menhaden management) however, is premised on the assumption that all age 3+ menhaden are fully recruited to the fishery. If this assumption is violated, because, for example, older age classes are outside the range of the fishery, the assumption of logistic or “flat-topped” selectivity to the fishery can potentially lead to severe overestimation of fishing mortality rates and underestimation of the spawning potential ratio, thus providing a biased estimate of the status of the resource. Without fishery-independent survey information, supplemented by biological sampling, there is no scientifically defensible means: (1) to prove whether or not the actual selectivity is domed; or (2) assuming the latter, to provide a scientifically robust estimate of the extent of the doming and hence the amount of menhaden biomass that exists beyond the range of the fishery (both temporally and spatially).

Improving Stock Assessments of Menhaden

Advisory bodies of the Atlantic States Fisheries Management Council (ASFMC), The National Marine Fisheries Service (NMFS), as well as the commercial fishing industry, have identified the need for additional fishery-independent indices of abundance to be developed for Atlantic menhaden outside of the typical survey range. A coast wide aerial survey was first identified at a scoping meeting (May 12-13, 2008) as the most efficient and effective way to monitor adult menhaden along the Atlantic coast. Aerial survey methods have been used previously to estimate stock abundance for several surface schooling species such as sardine (Hill et al. 2007) as well as Atlantic menhaden (Churnside et al. 2011). On January 21, 2010, a survey working group met to develop a plan for moving forward with a pilot aerial survey.

As described above, the contraction of the reduction (and to a certain extent) bait fisheries over time has potentially reduced the number of older menhaden in the commercial fishery. As the peer reviewers noted in their review of the 2010 menhaden stock assessment (ASFMC, 2011), the Beaufort Assessment Model assumes that all fish age 3+ are fully recruited to the fishery. However, the bulk of the fishery occurs in the mid-Atlantic during the summer and early fall when older fish are not present in the region. Thus, peer reviewers suggested investigating the use of “dome-shaped” selectivity curves for the southern fishery. Accordingly, the information gained from a survey outside of the normal fishing range will help provide an empirical basis to determine the existence and extent of such “doming.”

Survey data are critically important because the inappropriate assumption of asymptotically flat selectivity to the fishery can potentially lead to severe overestimation of fishing mortality rates and underestimation of the spawning potential ratio (“SPR”), thus providing a negatively biased estimate of the status of the resource. Given that the Menhaden Board is considering moving towards adoption of SPR-based reference points, and is currently in the process of developing management measures in accordance with these reference points, the need for these data takes on added importance.

Objectives

Given the necessity to address the aforementioned stock assessment gaps, a pilot study was initiated with two specific objectives in mind: 1) to test the feasibility of an aerial survey for menhaden in the northern range of the fishery; and 2) to gather preliminary data on the biomass and age of menhaden within this same area during the summer and fall months. In order to achieve these goals, the pilot survey utilized digital images collected by spotter airplanes to estimate menhaden school surface areas. In addition, sea sampling of menhaden schools was used to determine the relationship between menhaden school biomass and school surface area. Finally, the northern survey covered waters beyond the range of the fishery, from southern Long Island, New York, to Portland, Maine.

During the analysis of abundance data obtained from the northern survey, an opportunity to calculate the ratio of estimated abundance between this northern region to those within the southern fishery became available. Here, biomass indices were obtained from the Omega Protein Inc. spotter pilot flights that occurred between July 2011 and October of 2011. In addition to spotting the schools, these pilots help direct the setting of purse seine nets on the schools (Smith 2012). This relationship has been ongoing since the middle of the 20th century (Nicholson 1971) and is essential for successful fishing of menhaden (Smith 2012).

Material and Methods

On July 19, 2011 a fixed price research agreement was finalized between Omega Protein and the University of New England (UNE). On July 20th, UNE worked with several vendors to expedite the purchases of supplies and equipment necessary for the survey. In addition, the research team consisting of pilots, planes and research vessels used in the survey were assembled at this time. Finally, the coordination and implementation of the survey began on August 9th, 2011 and ended on October 25, 2011.

Primary participants aerial survey

The expertise of five individuals were utilized in the design, development, execution, and analysis of the survey. Dr. James Sulikowski was the lead PI. He is an associate professor at the University of New England (UNE) who's expertise is in the biology and ecology of fish. George Purmont has been involved with commercial fishing since 1967 and began fish spotting in 1972. He has fished and spotted a variety of fish species for several scientific entities. Forrest Dameron is a 3rd generation fisherman who has 11 years of experience spotting and fishing for menhaden. Vincent Balzano is a 3rd generation commercial fisherman who has been actively involved in the management of New England fisheries. He has been fishing for menhaden since 2004. Amy Carlson is the primary graduate student of Dr. Sulikowski involved in this project. Her abilities include using the statistical package R, ArcGIS, Adobe Photoshop Lightroom 3.0 LI, and CS3 extended. In addition, Dr. Alexia Morgan provides quantitative and research related skills as an independent fisheries consultant, and Dr. Doug Butterworth who has worked on line transect analysis for estimating abundance from surveys for whales and for a number of fish species.

Aerial survey design

The menhaden survey employed a two-stage sampling design. In this design, stage one consisted of aerial transect sampling to estimate the surface area of individual menhaden schools from aerial images and flight logs. Stage two involved at-sea point sampling to quantify the relationship between individual school surface area and biomass.

Transects and Spotter planes

In order to provide adequate spatial coverage needed to observe potential menhaden schools, aerial surveys were split between three *ad hoc* regions (Figure 1). Region 1 (southern New England) consisted of southern Long Island, NY to southern Rhode Island; region 2 (middle New England) consisted of Rhode Island to Boston, MA; and region 3 (northern New England) from Boston, MA to Portland, ME. Each region represents approximately 210 kilometers of coastline. One pilot and spotting crew was dedicated to each survey region (see below for more information). The total square kilometers for each region were partitioned into opportunistic transects; up to 28 kilometers from coast to offshore, west to east and up to 114 kilometers wide, north to south (Figure 1). The *ad hoc* regions were defined based on the capability the area the aircraft and spotters could fly, leaving from one origin and expending one tank of fuel. Due to the proximity of fish close to shore and limited flight times (less than 5 hours per flight), a jigsaw pattern was flown. This consisted of flying along the coast from the designated start point (airport of origin) to the end of the survey region. During most surveys, at this point a 90 degree turn was made that was flown approximately 5-8 kilometers towards the east, before another 90 degree turn was made back towards the airport of origin, creating a vertical zigzag pattern (Figure 2). This was continued until fuel levels necessitated the return to the airport. On some survey occasions, a more horizontal zigzag patterns was flown where the first leg of the transect was flown from the airport of origin to the end of the survey region, where a 90 degree turn was made and flown for approximately 5-8 kilometers towards the north, before another 90 degree turn was made heading horizontally towards the coast or offshore. Again, this pattern was chosen due the proximity of fish to shore on all previous surveys and to cover as much survey area as possible in the given constraints of flight time.

Aerial survey spotter plane information

Three airplanes participated in the survey, one designated for each region. Forrest Dameron flew region 1 using a 1973 Cessna Skyhawk owned by Omega Protein. George Purmont flew region 2 using his personal modified 1968 Piper Super Cub, and region 3 was flown by a chartered Maine Aviation pilot using a 1972 Cessna Skyhawk. Spotter planes flew approximate altitudes of 1000 ft and at speeds of approximately 100 mph while conducting aerial surveys. Each spotter plane departed from airports associated with their respective region. After several hours of flying before data collection began, it was determined that identifying the smaller schools in region 2 and 3 was most effective at 1000 ft. Thus, in order to remain consistent throughout the survey area, an altitude of 1000 ft was chosen to be flown throughout all the regions. In addition, since all images were taken at 1000 ft, flying at this altitude made this component of the survey more efficient (i.e less time was spent ascending and descending to investigate potential schools).

Aerial survey flight logistics

For region 1, Dr. Sulikowski and/or A. Carlson were co-pilots who recorded the survey data (i.e took digital images, recorded flight log, etc.). On the day of a designated survey, Forrest Dameron would fly from Reedville, VA to the Monmouth Regional Airport in Monmouth, NJ, the origin of region 1's survey. This flight took approximately 2 hours on way. Dr. Sulikowski and/or A. Carlson would leave Maine the day prior to the survey and drive down (approximately 640 kilometers one way) to Monmouth, NJ. After the survey was completed, Dr. Sulikowski and/or A. Carlson remained in Monmouth to analyze data then would return first thing to Maine the next morning. In the event that Dr. Sulikowski could not go on the designated survey, another graduate student in Dr. Sulikowski's lab would accompany A. Carlson on the trip. This routine was determined to be the most cost and time effective (as opposed to flying from ME to NJ to meet F. Dameron at the origin). For region 2, G. Purmont flew and recorded survey data via a flight log book and through digital images (Nikon D50 camera with a Nikon AF Nikkor 70-300 lens set to 70 mm). G. Purmont flew out of New Bedford Regional Airport, New Bedford, MA. In region 3, Dr. Sulikowski and A. Carlson, were co-pilots who recorded the survey data. The two of them drove to meet the pilot the day of the flight. All attempts were made to fly each region within three days of having flown another. Thus, the entire survey area was flown over the course of one week's time.

Menhaden adults stratify by size during the summer, with older, larger individuals found farther north. The oldest and largest fish migrate farthest, reaching the Gulf of Maine in May and June and begin migrating south from northern areas to the Carolinas in late fall. (ASMFC, 2001). To avoid the possibility of "double counting" during the survey, transects were conducted in a north to south progression in regions 1 and 2. Due to the logistics of the airport associated with region 3 (northern end of the survey), the flight pattern was south to north.

Aerial survey data collection

Data from aerial surveys were collected from spotter logs and using a hand held Canon Mark IV and a Nikon D50 high resolution camera. Each camera was fitted with a 70-300 mm lens set to 70 mm and a polarized filter. In addition, GPS waypoints of spotted schools and survey track lines were recorded with either a Garmin Oregon 550t (regions 1 and 3) or a Garmin GPS map 76CSx (region 2). An Olympus digital voice recorder was used to record aerial spotter plane estimates of the observed schools. Plane and camera angle, altitude, and position was accounted for with a MicroStrain 3DM-GX3-35 AHRS with GPS attitude sensor, mounted to the cameras in use. This system was connected to a Dell Latitude E6420 ATG laptop, which recorded this data real time. Communication to the at sea sampling boats was established with Standard Horizon HX290 handheld radios. Either a Duracell Powerpack 450 or Black and Decker Electromate 400 was used to power the equipment in flight. Images taken of the schools were restricted to the right side of the plane, as the photographer was seated in the passenger seat of the aircraft. Trials of spotting schools off the left side of the plane proved to take too much time to circle back to get the photographer situated over the school. Additionally, when the pilot attempted to circle back, the majority of the time the school could not be found again (especially in region 3). The area of the *ad hoc* regions and transects flown were calculated in ArcMap 9.3.1.

Aerial survey data transfer

Images and flight log files were downloaded and archived at the end of each survey day. At the end of each flight, scientific personnel verified that the camera and data collection system operated properly and that images collected were acceptable for analysis.

Aerial Measurement Calibration

Each airplane photographed football fields from the altitude of 1000 ft. to provide the ability to ground truth the aerial estimates of menhaden. An aerial pass was made to place the target onto the right, middle, and left portions of the digital image. The observed vs. actual sizes of the objects were compared to evaluate photogrammetric error.

At Sea Point Set Capture

The fishing vessel (FV) North Star (Captain Vincent Balzano) was chartered for the at sea point sampling. This 45 foot steel hull vessel was equipped with a 175 by 15 fathom purse seine (4 cm mesh size). The goal of these point sets were to encircle (wrap) and fully capture the school selected by the spotter pilot for the point set. Any schools not “fully” captured would not be considered a valid point set for analysis. Both the spotter pilot and the purse seine captain independently made note of the “percent captured” on their survey log forms for this purpose. The scientific PI reviewed these estimates to ensure quality control.

Biological Sampling

Biological samples of individual point sets were collected either at sea or the fish processing plants upon landing. Each point set sample was individually bagged, identified with sample number and frozen with other fish in the subsample, clearly identified as to point set number, vessel, and location captured. All fish were transported to the University of New England where they were then shipped overnight to the NMFS Beaufort, NC laboratory where the fish were processed using standard techniques utilized in ongoing age analysis of this species (NMFS, 1995).

Menhaden fishery spotter pilot data collection

Spotter pilots begin searching for menhaden schools around the middle of May and flights generally occur on Sunday mornings or on Mondays if a holiday weekend had occurred (Smith 2012). Three fish spotters were typically deployed from and returned to a landing strip near Omega Protein’s fish factory in Reedville, VA (Smith 2012). Spotter pilots observed menhaden schools in the Chesapeake Bay, adjacent Virginia Ocean waters and north to New Jersey if necessary (M. Deihl OPI). Spotters hand recorded information on the geographic locations of menhaden schools, number of fish schools, and biomass of fish schools onto a spotter pilot report form. This information was subsequently translated by the head spotter pilot onto National Marine Fisheries Service (NMFS) spotter log forms (Figure 3). Based on communications with OPI, along with information provided in the head spotter pilots notes, it appears there is some variation in the sections of Chesapeake Bay and adjacent ocean areas observed by pilots during individual flights. Therefore, for these comparative analyses, we have defined four areas within Chesapeake Bay as in the upper Chesapeake Bay (Smith Point, Pocomoke, Rappahannock River and Silver Beach) thereby corresponding to flight times from the “Upper Bay”; three areas (York River, Cape Charles, and Ocean View) in the lower Chesapeake Bay that correspond to the “Lower Bay” flight times, and two areas (Eastern Shore and Virginia Beach) are included in the Virginia Ocean and correspond to the “Up the beach” flight times (Figure 3). The Mid-Atlantic region was not included because data were collected only sporadically and because 90% of menhaden fishing occurs within the regions described here (M.Deihl OPI). Transfer of the pilot data to the NMFS forms included translating the recorded biomass of fish schools out of industry jargon (i.e. 1,000 standard fish = ~0.3 mt; one million standard fish = ~300 mt), and recording the size and locations as well as information on the winds, tides, sea state and flight time (Smith 2012). Joe Smith provided us with data from nine flights conducted during 2011.

Quantitative Analysis
Digital images were analyzed to determine the number, size, and shape of menhaden schools observed on each Northern survey. Adobe Photoshop Lightroom 3.0 LI software was used to bring the menhaden schools into clear resolution so that measurements of menhaden school size (m^2) and shape (circularity) could be calculated using Adobe Photoshop CS3-Extended.

An estimate of the biomass of menhaden schools in the Northern survey area was obtained from: 1) measurement of individual school surface area observed on each survey; 2) estimation of individual school biomass (from measured school surface area and estimated school density); and 3) correlations between harvested schools and observed school size.

Quantifying menhaden abundance using the point sampling data
A linear regression model and regression parameters for the surface area – biomass relationship was used to create the following relationship:

Wt (lbs)= -1175.94 + (634.077*surface area (m^2))

Here, the surface areas of the two point sampling events (measured with Adobe Photoshop CS3-Extended) and the biomass (lbs) of menhaden from those discrete point sampling events were used in the regression analysis. These values were:

	Surface Area (m^2)	At sea sample (lbs)
RI	20.8	12000
NJ	380.3572548	240000

This regression model was used to quantify individual school biomass for photographed schools observed on the survey transects. However, it must be noted that this is under the assumption that the density of mass per square meter is constant regardless of total surface area of the school. This could be affected by many factors, most notably behavior and size of the fish in the school (Castillo and Robotham 2004). However, given that there were only two point estimates, we considered that a linear relationship was the best option. None the less, it is important to note that the ratios between surface area and at sea were similar between the two regions samples (0.0017 and 0.0016 for RI and NJ, respectively).

Estimating biomass

Line transect survey theory provides estimates of biomass from the following basic formula:

$$B = \frac{Ab}{2Lw\,g(0)} \tag{1}$$

where

B is the estimate of biomass within the region being surveyed,
A is the open ocean area of that region,
b is the estimated biomass of schools sighted on the survey,
$g(0)$ is the probability that a school on the survey trackline is seen,
L is the distance surveyed in searching mode, and
w is the effective search half width.

Typically equation (1) is applied for separate transects which are treated as independent, and the standard error of B estimated on the basis of inter-transect variation.

Being primarily a feasibility study which had to be carried out at short notice, the New England (northern) survey does not satisfy all of the assumptions of line transect theory, nor provide data to estimate all the parameters of equation (1). Nevertheless equation (1) can be applied to give a rough estimate of biomass in absolute terms given certain assumptions.

- The flights, each on different days, are treated as the independent transects
- $g(0)=1$ – all schools on the trackline are definitely seen
- L is taken to be the total distance travelled by the plane, though some of this actually related to confirming information on schools sighted rather than searching along the trackline
- Information on perpendicular distances to schools sighted was not collected, precluding direct estimation of w, but a value of $w=1$ km is considered likely to be broadly indicative for the purposes of illustrative calculations.

The formula specifically applied to estimate B is:

$$B = \frac{A\sum_i b_i}{\sum_i L_i .1} \tag{2}$$

where i is an index for the different flights in the region (i=1,…..n).

Note that the factor 2 has disappeared from the denominator of equation (2) as all searching was to only one side of the plane for the New England surveys.

This estimator was used in preference to:

$$B = \frac{A}{n}\sum_i \left({}^{b_i}\!/_{L_i} \right) \qquad (3)$$

as equation (2) weights biomass density (b_i/L_i) values by the length of trackline searched (L_i) and also tends to produce more precise estimates.

This approach cannot be applied to the southern regions where most of the fishing takes place because only flight time (t) rather than distance searched (L) is available for industry spotter pilot flights. Therefore to be able to compare biomasses in the New England regions to biomasses where the fishery operates, an alternative approach is needed which treats the ratio (b/t) as an index of density in a region. Thus:

$$b^* = A\,\frac{\sum_i b_i}{\sum_i t_i} \qquad (4)$$

where b^* is an index of biomass in the region concerned, which has open ocean area A. Note that in using this index to provide a ratio of the biomass outside (I.e. off New England) to that inside the current fishing area, the far-reaching assumption of equal efficiencies of the New England and southern commercial spotting exercises is being made (see Discussion section below).

A jackknife approach is used to provide standard error estimates for b^* with flight as the sampling unit. Jackknife estimates can tend to be more stable than the standard formulae in situations of high variability.

Clearly estimates of both B and b^* are sensitive to the values for A, the open-ocean area surveyed. For the New England surveys, perimeters were drawn (see Figure 1) to encompass the flight paths so that in broad terms all the area enclosed could be claimed to have been reasonably covered by the survey. Flight paths are not available for the southern region flights by spotter pilots. For the Virginia Ocean eastward boundary was set 8 nm from the coast on the basis that this was the furthest recorded distance offshore in 2011. Furthermore M. Deihl (Omega, pers. comm.) advises that spotters typically fly out as far as 8-12 nm, and estimates that 90% of landings are from the Chesapeake Bay and Virginian Ocean region (shown in Figure 1).

Results

This survey was neither designed to, nor could it, supplant the need for an annual, stock-wide aerial survey, though the methods pioneered and experience gained here can aid in the development and feasibility assessment of just such an annual survey. Moreover, it was not primarily intended to provide an estimate of total biomass, but rather only a basis for estimating the age, numbers, and biomass resident in the northern waters beyond the range of the fishery. Despite the limited temporal period (August-October) appreciable amounts of menhaden were observed outside standard fishery areas. Some of these spotting events observed millions of pounds of menhaden over a very finite time frame. For example:

a. As a whole, over 17 million lbs (nearly 8000 mt) of menhaden were observed outside of the standard fishery area (southern Long Island to southern Maine) during approximately 50 hours of flight time.

b. Nearly 11 million lbs (5178 mt) of menhaden were spotted on August 21, 2011 along the entire coast of Long Island over a 4.5 hour period.

c. Approximately 340,000 lbs (154 mt) of menhaden where observed along the coast of southern Maine on August 17, 2011 over a four hour period.

While menhaden schools were consistently observed from southern Long Island to southern Maine, the majority of menhaden were observed in regions 1 (southern New England) and 2 ((middle New England); approximately 16,898,259 lbs; 7665 mt). In addition, the state of Rhode Island opened up Narragansett Bay (region 2) to commercial fishing from October 14th to 27th, 2011 when an estimated 3,440,000 lbs (1542 mt) of fish were observed in the bay (this biomass was not included in the estimates provided herein as part of this Omega Protein sponsored aerial survey).

The basic data used to estimate biomass (B) and the biomass index (b^*) are provided in Table 1. Note that the biomass estimates listed there are those made from the plane rather than as adjusted by the regression model discussed above. This has been done in the interests of comparability for the New England *vs* South regions comparison, as only these direct observations of estimates of biomass are available for the South regions.

Biological sampling

A total of 85 specimens were deemed viable for age analysis from the fish captured during the at sea/point sampling in Rhode Island. Of these fish, 61% were aged to year 4, while 25% and 14% were aged to 3 and 5 years respectively (Table 3).

Table 1: Data recorded on flights in each region (surveys in New England; spotter planes in the Southern fishing area) Entries in each cell are in order biomass observed in mt, flight distance in km (New England only), and flight time in hours.

Flight no.	Northern New England	Middle New England	Southern New England	Upper Chesapeake Bay	Lower Chesapeake Bay	Virginia Ocean
1	0; 63.8; 4.0	41; 105.7; 3.0	2177; 223.2; 4.5	0; 2.5	300; 2.5	4500; 3.5
2	131; 81.7; 3.6	236; 108.2; 3.25	5178; 205.9; 4.5	0; 1.5	0; 2.5	1050; 2.0
3	154; 84.8; 4.0	0; 89.9; 2.1	0; 210.2; 4.0	0; 2.0	450; 2.5	4800; 3.0
4	18; 104.6; 4.0	33; 40.9; 3.5		0; 2.5	150; 2.5	7350; 3.0
5	18; 80.1; 4.0			0; 2.0	240; 2.5	1950; 2.5
6	0; 85.9; 2.0			0; 2.5	1170; 2.5	300; 3.0
7	0; 116.5; 4.5			45; 2.25	0; 2.0	450; 2.5
8				750; 2.5	0; 3.0	1050; 3.0
9				0; 2.5	0; 2.5	1530; 3.0

The results of the estimated biomass (*B*) and the biomass index (*b**) are reported in Table 2 and include:

- An estimate of absolute biomass of 127 thousand tons for the regions covered by the New England surveys.
- An estimate of the ratio of the biomass in the New England regions surveyed to that in the area to the south where the fishery operates of 2.57 with a standard error of 1.1.

Table 2: Estimates of time-based biomass indices (*b**) for each region and illustrative transect-based biomasses (*B*) for the New England regions. Figures in parenthesis are jackknife-based standard errors.

Region	Area *A* km^2	Biomass index *b** $mt.km^2/hr \times 10^6$	Transect biomass estimate *B* $mt \times 10^3$
Northern New England	2088	0.026 (0.005)	1.1
Middle New England	1224	0.032 (0.015)	1.1
Southern New England	10885	6.158 (2.058)	125.2
Total New England	14197	6.216 (2.058)	127.4
Upper Chesapeake Bay	3005	0.118 (0.037)	
Lower Chesapeake Bay	2192	0.225 (0.203)	
Virginia Ocean	2298	2.071 (0.639)	
Total South fishing area	7495	2.414 (0.671)	
Ratio New England: South fishing area	1.89	2.57 (1.11)	

Table 3: Age estimates and average fork lengths for 85 fish captured during the point set sampling in Rhode Island on October 7th, 2011. The number in parenthesis is the number of fish associated with each age class. The average fork length values are expressed as mean ± standard deviations of the mean.

	Percent age 3	Percent age 4	Percent age 5
	25 (21)	61 (52)	14 (12)
Average Fork Length (mm)	453 ± 50	465 ± 50	481± 29

A total of 50 specimens were deemed viable for age analysis from the fish captured during the at sea/point sampling in New Jersey. Of these fish, 50% were aged to year 2, while 40% and 10% were aged to 3 and 4 years respectively (Table 4).

Table 4: Age estimates and average fork lengths for 50 fish captured during the point set sampling in New Jersey on October 9th, 2011. The number in parenthesis is the number of fish associated with each age class. The average fork length values are expressed as mean ± standard deviations of the mean.

	Percent age 2	Percent age 3	Percent age 4
	50 (25)	40 (20)	10 (5)
Average Fork Length (mm)	332 ± 47	389 ± 41	391± 10

Fish captured during at sea/point sampling trials in Rhode Island (October 7th, 2011) were significantly (ANOVA; $P< 0.001$) older and larger than fish captured off Cape May, New Jersey (October 9th, 2011).

Summary and Conclusions

The illustrative estimate of biomass in the regions covered by the New England survey is 127 thousand mt (this changes to 122 thousand mt if regression-based estimates of school biomass are used rather than observer estimates). Taken together with the New England:South fishing area biomass ratio estimate of 2.57, this suggests that there is only about 50 thousand mt in the fishing area, which would seem unrealistically low given the annual catches from and the current baseline BAM abundance estimates which essentially apply to that fishing area only. Almost certainly the implication is that *g(0)* is well below 1, i.e. a large proportion of schools on the flight trackline are not seen (unsurprisingly as they could well be too far below the surface to be visible). For example, although spotter planes failed to observe any menhaden schools in Narragansett Bay, RI, after October 25th, several menhaden were captured in an unrelated bottom trawl survey conducted by Dr. Sulikowski in and around Block Island (RI). The capture of these fish by this method in early November in this area raises interesting questions as to the behavior and possible distribution of this species outside of the normal fishery.

As discussed below, an estimate of more than twice the menhaden biomass north of the fishing area compared to that in the fishing area has important management implications. Thus, it is important to consider possible sources of bias in this ratio estimate.

- *Factors biasing the ratio downward*: While the area in which the fishery operates would seem to have been reasonably reflected in the calculations whose results are reported in Table 2, many areas to the north which may contain menhaden were not covered in the New England survey. Furthermore, the effects of severe storms or hurricanes on fish communities have been documented from many parts of the world (e.g. Bouchon et al. 1994; Greening et al. 2006; Greenwood et al. 2006). However, the effects of catastrophic storms on fish communities are still unclear and highly variable (e.g. Walsh 1983; Greening et al. 2006) but suggest such impacts do disrupt normal distributions and behaviors. When the pre (7935 mt) and post (51 mt) hurricane Irene menhaden observed biomasses are compared, it would appear that this catastrophic event may have affected the abundance of menhaden within the survey area. Especially since pre (30 hrs) and post (21 hrs) flight time were similar. Thus, it is possible that if this hurricane event had not transpired, the biomass of menhaden observed over the course of the northern survey may have been even greater. A further factor is that commercial spotter pilots in the South would be expected to focus more on areas where higher densities are to be expected than on performing effectively random surveys of these regions.
- *Factors biasing the ratio upward*: There are two ways in which double-counting might impact the ratio estimate. First, although we attempted to reduce any potential double counting by augmenting our flight patterns (see aerial survey flight logistics for details), we cannot rule out this possibility. For example, there may be some double counting as the surveys that took place in late September to early October may have observed the same schools of menhaden, on different sampling dates, as they slowly migrated south. Secondly, since the spotter pilots operate mainly during the peak of the fishery, while the New England survey occurred later in the year, some fish from the fishery area might have moved northward in the intervening period to become potentially sightable in the New England surveys. Furthermore, the contributions from the Southern New England and the Virginian Ocean regions dominate in computing the New England:South biomass ratio, and both are sensitive to the areal extents assumed for these regions. For example if the Virginian Ocean region is taken to extend to 12 rather than 8 nm from the coast, the ratio drops from 2.57 to 1.77. In addition, including Long Island sound may have resulted in overestimation of the ratio in this analysis. This is because this region includes part of a single flight path that was used in the initial stages of the survey in an attempt to both identify the range of menhaden schools from shore as well as to determine the area that could be flown during each flight (see Transects and Spotter planes in the Materials and Methods section). If part of this flight is removed, and the eastern perimeter is subsequently reduced (there were no sightings of menhaden), the New England:South biomass ratio drops to 1.39.

- *Biases whose direction is unclear*: A key assumption made is that of comparability of sighting efficiency in the New England survey and south spotter operations, i.e. effectively that the two manifest the same effective search half width *w*. There are likely to be differences, as well as differences amongst regions and even amongst flights in a region as a result of variations in environmental conditions. There is no immediate basis to conclude whether these differences mean that the ratio estimate of 2.57 is biased high or biased low, or by how much. In addition, we were forced to make assumptions with regard to the menhaden spotter pilot flight times in the three southern regions. It is possible in some cases that spotter pilots observed part of the ocean as well as part of the bay, but since the bay regions make relatively little contribution to the overall biomass in the south (see Table 2), the rato estimate seems unlikely to be overly sensitive to this.

Implications

Results from what should be seen as primarily a feasibility exercise, for future more carefully designed surveys, are naturally coarse and uncertain. Nevertheless these results do suggest that the biomass of menhaden to the north of the area where the fishing takes place is at least as large as that in the fishing area, and possibly substantially larger. Though only limited ageing results were obtained for the fish in the New England area, these confirmed existing impressions that these fish tend to be older than the fish available to the fishery. This older and larger fish stock may represent an enormous reproductive potential (e.g. Jennings and Reynolds 2001) that is currently not incorporated into stock assessments.

The BAM estimates menhaden biomass to be low and fishing mortality on 3+ fish to be very high, but is based on the assumption of asymptotically flat selectivity at age for (at least one component of) the fishery. An alternative explanation is that the apparent high total mortality reflected by the catch-at-age composition is instead (at least in part) a reflection of emigration of older fish to outside of the fishing area, and consequently that biomass is higher and fishing mortalities are lower than indicated by this model when selectivity is assumed to be asymptotically flat.

The results from the aerial survey, though coarse, provide qualitative support for this alternative, as they suggest a much greater proportion of 3+ menhaden in the population as a whole than estimated by the BAM. Importantly the New England:South biomass ratio provides a basis to estimate the extent of doming in selectivity in the BAM by calibrating this ratio against the proportion of fish that the doming implies to be outside the fishing grounds and not available to the fishery.

The Future

A clear and immediate need for the future is a synoptic survey to cover both the southern fishing grounds and the regions to the north at a time corresponding to peak fishing activities. Perpendicular distances to sighting need to be measured to enable estimation of effective search half width. Coupled to a careful survey trackline design which provides equal coverage probability (or at least calculable coverage probability) within pre-defined survey regions, would allow for more sophisticated analyses in the future and much more robust estimation of the ratio of the biomass to the north compared to that within the fishing area, and hence provide a better basis to calibrate the extent of doming in the BAM catch selectivities. In turn this would allow much improved estimates of biomass, fishing mortality and reference points to be made.

On a longer time scale, regular continuation of such surveys would provide a much needed fishery independent index of abundance for the Atlantic menhaden resource as a whole. Such surveys should be coupled to activities to estimate age composition by region and to calibrate observer estimates of school biomass, as well as to study the effects of the depth distribution of the fish and of environmental conditions on sight ability to shed light on the likely value of *g(0)* and its variability.

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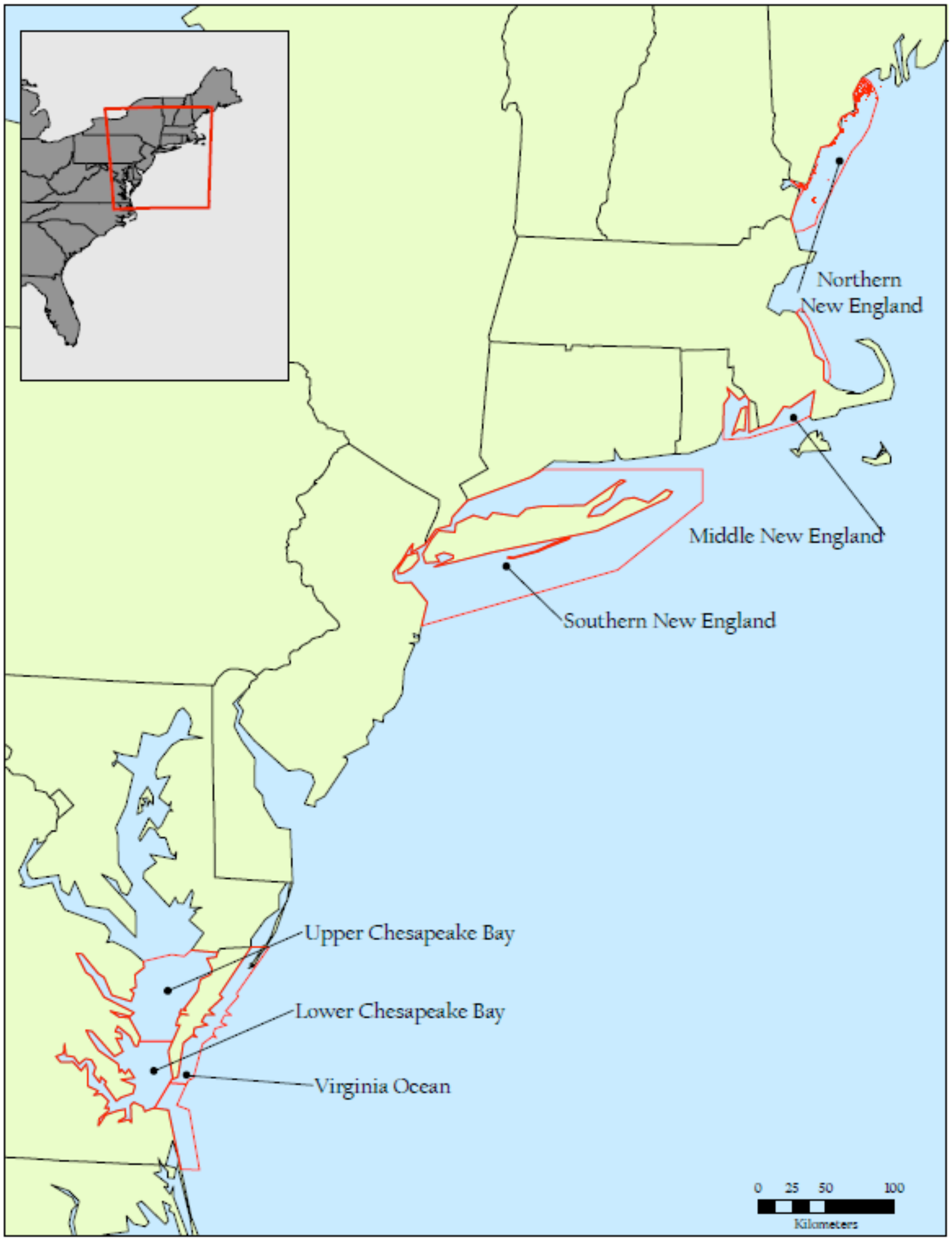


Figure 1. Map of the individual Northern areas surveyed in New England and observed by spotter pilots in the Chesapeake Bay (Virginia) region.

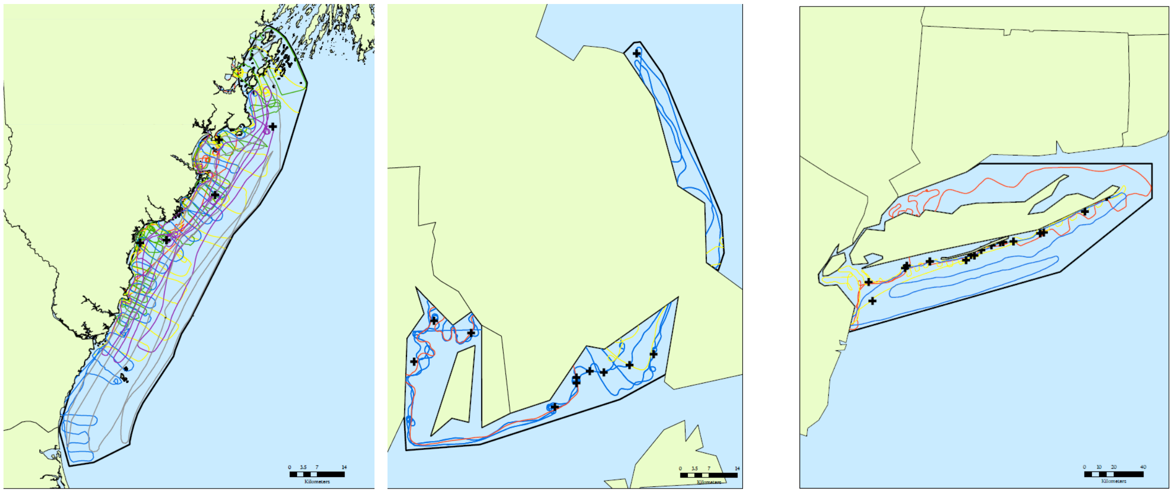
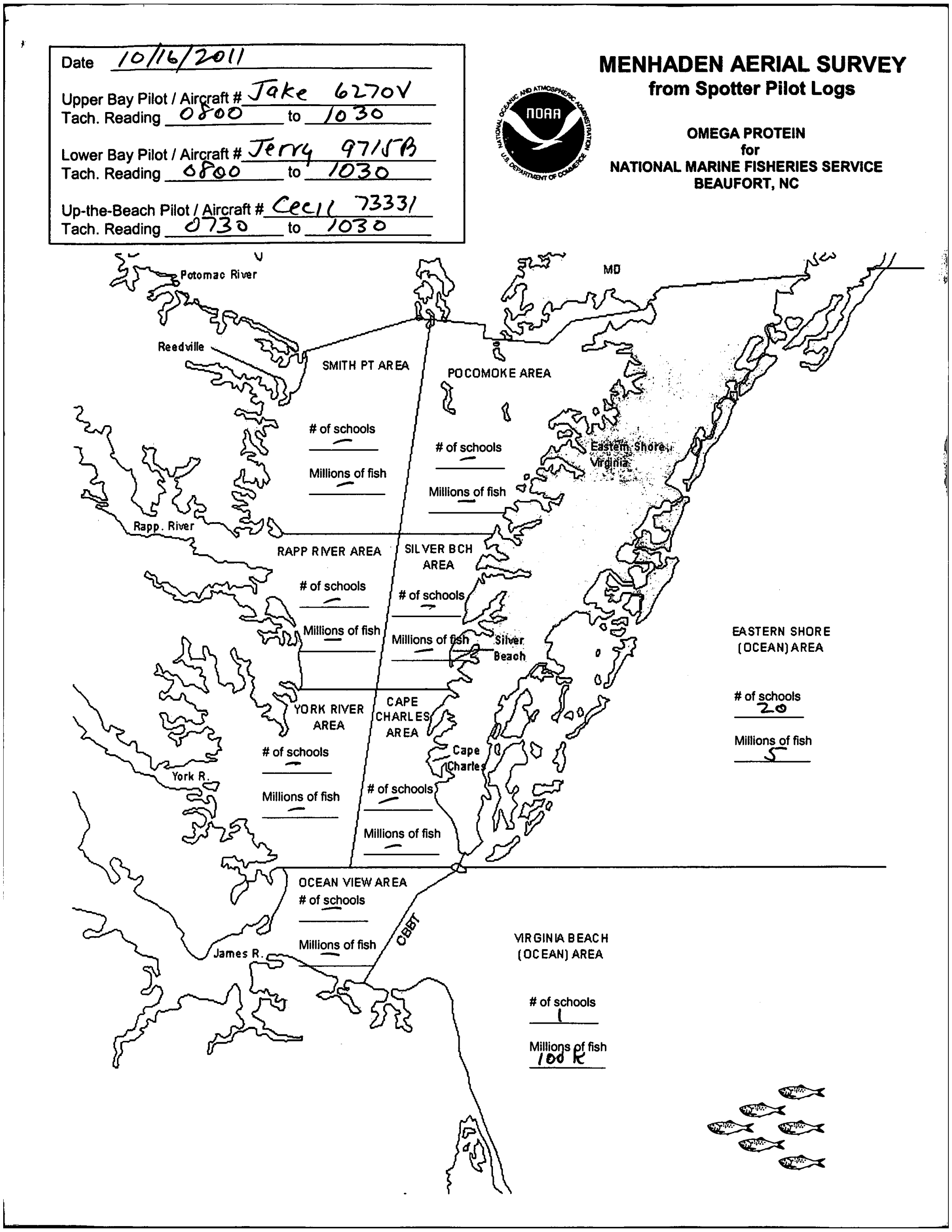


Figure 2. Map indicating individual aerial survey flights conducted in each of the three truncated New England areas (left to right): northern New England (dark red spots slightly offshore indicate islands); middle New England, and southern New England. Dark crosses indicate individual schools observed.



Date 10/16/2011

Upper Bay Pilot / Aircraft # Jake 6270V
Tach. Reading 0800 to 1030

Lower Bay Pilot / Aircraft # Jerry 9715B
Tach. Reading 0800 to 1030

Up-the-Beach Pilot / Aircraft # Cecil 73331
Tach. Reading 0730 to 1030

MENHADEN AERIAL SURVEY
from Spotter Pilot Logs

OMEGA PROTEIN
for
NATIONAL MARINE FISHERIES SERVICE
BEAUFORT, NC

SMITH PT AREA
# of schools —
Millions of fish —

POCOMOKE AREA
# of schools —
Millions of fish —

RAPP RIVER AREA
# of schools —
Millions of fish —

SILVER BCH AREA
# of schools —
Millions of fish —

YORK RIVER AREA
# of schools —
Millions of fish —

CAPE CHARLES AREA
# of schools —
Millions of fish —

OCEAN VIEW AREA
# of schools —
Millions of fish —

EASTERN SHORE (OCEAN) AREA
# of schools 20
Millions of fish 5

VIRGINIA BEACH (OCEAN) AREA
# of schools 1
Millions of fish 100 K

Figure 3. NMFS spotter log indicating the four regions (Smith Point, Pocomoke, Rappahannock River and Silver Beach) in the upper Chesapeake Bay and three (York River, Cape Charles, and Ocean View) in the lower Chesapeake Bay and two (Eastern Shore and Virginia Beach) in the Virginia Ocean.