A Consideration of Factors Potentially Affecting the National Marine Fisheries Service Bottom Trawl Survey Indices of Abundance for Mackerel

Jonathan J. Deroba
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1. Introduction
During the Atlantic mackerel *Scomber scombrus* Transboundary Resource Assessment Committee (TRAC) data review meeting, held October 22-23, 2009, some suggestions were made about how to best utilize the National Marine Fisheries Service (NMFS) spring and winter bottom trawl surveys. These suggestions included: 1) using a delta method for the estimation of annual indices of mackerel abundance, 2) considering the potential effects of temperature during each tow, whether each tow occurred during daytime or nighttime, timing of the survey in each season, and other characteristics of the survey, vessel, and gear (e.g., door changes), and 3) considering the hypothesis that low abundance of cod *Gadus morhua* may have led to mackerel occurring more frequently in demersal habitats and so changes in the catch per tow of the bottom trawl surveys may not reflect changes in mackerel abundance. Use of the delta method was suggested because this approach is better suited for data with a high proportion of zero observations than common alternatives (e.g., arithmetic or backtransformed means; Pennington 1996), and the mackerel survey data contained many tows that did not catch mackerel (see Deroba Notes on mackerel abundance indices from NMFS bottom trawl surveys). Considering the potential effects of temperature, daytime versus nighttime, etc., was motivated by the observation that these factors may affect the spatial and temporal distribution of the mackerel stock and therefore the availability and/or catchability of the surveys, as has been observed for other species and surveys. The recommendation to consider that mackerel may more frequently occur near the ocean floor in response to low cod abundance was motivated by some evidence that Atlantic herring *Clupea harengus* may be exhibiting this behavior.

The objectives of this research were to explore each of the suggestions above in greater detail. More specifically: 1) to evaluate the use of the delta method relative to other methods of estimating annual indices of abundance (e.g., arithmetic means), 2) to evaluate the effect of temperature, daytime versus nighttime, timing of the survey, etc., on mackerel indices of abundance, and 3) to evaluate whether mackerel may be occurring more frequently near the ocean floor in response to low cod abundance. Here and throughout, the phrase, "affecting the indices of abundance," should be interpreted as any trend in the indices of abundance induced by factors other than mackerel abundance. To some extent, objectives one and two were addressed simultaneously through the use of statistical models during the application of the delta method that standardized the mackerel survey data for some of the factors outlined in objective two. Objective three was addressed by looking for trends in the frequency of co-occurrence of cod and mackerel in the spring survey among years.

2. Methods
The data used in these analyses were the same as described in, "Notes on mackerel abundance indices from NMFS bottom trawl surveys," prepared by Jonathan J. Deroba for the October 2009 TRAC data review meeting (see Appendix). Data for the spring survey were from the years 1968-2008 and from survey strata 01010-01250, 01610-01760. Data for the winter survey were from the years 1992-2007

(the winter survey was not conducted after 2007) and from survey strata 01010-01030, 01050-01070, 01090-01110, 01130, 01140, 01160, 01610-01630, 01650-01670, 01690-01710, 01730-01750.

2.1. Delta method and considering factors that may affect the index of abundance

Application of the delta method involved developing statistical sub-models for two components; one component for standardizing the probability of non-zero mackerel catch per tow observations, and a second component for standardizing the positive mackerel catch per tow observations. Each sub-model was fit separately for the spring and winter bottom trawl surveys. The probability of non-zero mackerel catch per tow observations followed a binomial distribution, while the positive catch per tow observations were assumed to follow a lognormal distribution. An examination of the distribution of the log transformed positive catch per tow observations suggested that the assumption of lognormality was violated in each seasonal survey (Figure 1; Figure 2). However, preliminary analyses (results not shown) using other distributional assumptions (e.g., poisson, gamma) suggested that results were not sensitive to the assumed distribution and that the lognormal distribution had the best residual diagnostic plots of the distributions considered (residuals vs. fitted values; quantile-quantile plots; square root of standardized residuals vs. fitted values; and standardized residuals vs. leverage). So, conclusions are at least robust to the types of error distributions considered here.

2.1.1. Modeling the probability of a non-zero catch per tow observation

The fully saturated statistical sub-model for the probability of a non-zero catch per tow observation included fixed effects of year, stratum, year by stratum interaction, survey vessel (i.e., Delaware II or Albatross IV), time of day (i.e., Day or Night), and temperature. All effects were treated as categorical except for temperature, which was continuous. For the effect of time of day, daytime was defined as 0600 to 1830 during the spring survey and 0645 to 1715 during the winter survey, and nighttime otherwise in each season. Tows from both vessels were only available for one year during the winter survey, which was not enough data to reliably estimate vessel effects, and so vessel was not included in the full model for that season. Furthermore, temperature data were missing for some tows during the winter survey and so temperature was not included in the full model for that season. However, plots of catch per tow versus temperature in each year showed no trends (Figure 3), and during preliminary analyses with only tows that had temperature observations, temperature was not included in the final model after a model selection process (see below). So, results were likely robust to the exclusion of temperature from the full model for the winter survey. Parameters of this sub-model were estimated based on data for each tow, and observations were classified as “1” if at least one mackerel was caught or “0” if no mackerel were caught. The analysis assumed that the classified observations are independent Bernoulli random variables, with probability *p* of success of catching a mackerel for a given combination of year, stratum, year by stratum, survey vessel, time of day, and temperature as defined by effects in the full model. The number of non-zero catch per tow observations was modeled as binomial using a generalized linear model with a logit link function, logit[g()]. So, the fully saturated model for the logit[g()] of the probability $[p_i]$ of a non-zero catch for the *i*th observation from year *y*, stratum *s*, year by stratum combination *ys*, survey vessel *v*, time of day *d*, and temperature *T* was:

$$g(p_i) = \log_e\left(\frac{p_i}{(1-p_i)}\right) = \alpha_y + \zeta_s + \delta_{ys} + \omega_v + \tau_d + \beta T_i;$$

where α_y was the effect for year, ζ_s was the effect for stratum, δ_{ys} was the effect for the year by stratum interaction, ω_v was the effect for vessel, τ_d was the effect for time of day, and β was the slope parameter for the temperature coefficient. For the reasons above, the full model for the winter survey did not include ω_v and βT_i.

2.1.2. Modeling the positive catch per tow observations

The sub-model for the positive catch per tow observations was constructed using data for tows that caught at least one mackerel. The dependent variable was the $\log_e$ transformed catch per tow (*CPT*) from each, *i*th, observation, and the effects considered in the fully saturated model were the same as in the sub-model for the probability of a non-zero catch:

$$\log_e(CPT_i) = \mu + \alpha_{yz} + \zeta_s + \delta_{ys} + \omega_v + \tau_d + \beta T_i + \varepsilon_i$$

where μ was the overall intercept, α_{yz} was the effect for year and *z* distinguished this year effect from that of the model for the non-zero observations, ε_i was the unexplained residual error, and all other factors were defined as above. Again, the full model for the winter survey did not include ω_v and βT_i.

2.1.3. Model Selection

For each of the sub-models in each season described above, effects in the fully saturated models were evaluated for inclusion in a final model using Akaike's information criteria (AIC). All possible combinations of effects were evaluated and the final model in each case was the model with the lowest AIC value. The year effect was not subject to the model selection process and was always retained in the final model because the objective was to estimate an annual index of abundance.

2.1.4. Estimating annual indices of abundance and a comparison to alternatives

The annual indices of abundance for each seasonal survey using the delta method described above were estimated using a combination of year effect estimates from the final sub-models for the probability of a non-zero catch per tow observation and the positive catch per tow observations. The annual indices, I_y, were estimated as:

$$I_y = \left(\frac{e^{\log_e(\alpha_y)}}{1 + e^{\log_e(\alpha_y)}}\right)\left(e^{\log_e(\alpha_{yz})}\right).$$

The annual indices of abundance, I_y, were qualitatively compared to two other methods of estimation, an arithmetic mean and back-transformed geometric mean for each year (see NMFS SURVAN documentation, Appendix A – SURVAN Notation and Equation List). The different methods were compared qualitatively by looking for inconsistent trends among years in the indices of abundance estimated using each method. Inconsistencies would suggest that the effects retained in the final models of the delta method may have affected the indices of abundance; although the trends from the delta method may have also been affected by the unbalanced design of the data (Table1; Table 2; Table 3; Table 4). By revealing which effects may be "important", this methodology partially addressed objectives one and two (see introduction). Additional analyses to address objective two, on other factors that may affect catch per tow or the annual indices of abundance, were considered below. For ease of comparison, the annual indices of abundance from each method were "re-scaled to one" by dividing the index in each year by the mean among all years for each method of estimation.

2.2. Additional analyses considering factors that may affect the index of abundance

In addition to the model selection process described above, several other analyses were conducted to evaluate whether factors other than changes in mackerel abundance may be affecting the annual indices of abundance. Additional analyses evaluated: 1) time of day of the tow (i.e., Day versus Night), 2) timing of the survey in each season, 3) vessel changes among years, 4) door changes among years, and 5) net changes among years. Time of day was further considered by estimating the arithmetic and back-transformed geometric means separately for daytime and nighttime tows, which were defined for each season as above, for each year (see NMFS SURVAN documentation, Appendix A – SURVAN Notation and Equation List). Furthermore, the proportion of tows taken during the daytime and nighttime was also calculated in each year. If the relative scale or trends through time in the arithmetic and/or back-transformed geometric means differed, then time of day may have been affecting the annual indices of abundance. However, if the proportion of tows taken during the daytime and nighttime remained approximately equal among years, then any differences among the scale or trends would have “averaged” out and time of day may not have affected the indices of abundance. Thus, both a difference in scale or trend among years and a systematic trend in the proportion of tows between day and night were necessary for time of day to be concluded as potentially affecting the indices of abundance (i.e., neither is sufficient by itself for time of day to be “important”). The timing of the survey in each season was evaluated by looking for trends among years in the mean Julian date of each survey. A trend among years would suggest that the timing of the survey has changed systematically and so may be affecting the indices of abundance. The absence of a trend in the timing of the survey among years may still affect the indices of abundance if mackerel availability at the time of the survey has changed over time (e.g., due to changes in timing of migration), but this alternative was not evaluated. Evaluating vessel, net, and door changes among years required multiple paired observations for each type of vessel, net, or door in use. Where enough of such data existed, analyses had already been done. So, additional analysis of these potential factors was conducted via a review of relevant literature.

2.3. Considering that mackerel may have shifted depth distribution in response to low cod abundance
To evaluate whether mackerel may be shifting their depth distribution in response to the presence or absence of cod, the frequency of co-occurrence of cod and mackerel in the spring survey was examined for trends among years. More specifically, trends in the proportion of tows in each year that caught both cod and mackerel were examined among years. If mackerel shifted their depth distribution to near the ocean floor as cod abundance declined, then the proportion of tows that caught both cod and mackerel may have declined among years. Other trends among years would not suggest any hypothesis over another. Additionally, trends in the proportion of tows in each year that caught mackerel but not cod were examined among years. If mackerel shifted their depth distribution to near the ocean floor as cod abundance declined, then the proportion of tows in each year that caught mackerel and not cod may have increased among years. Other trends among years would suggest that mackerel have not shifted their depth distribution to near the ocean floor in response to low cod abundance. The analyses described in this section were limited to the spring survey because the index of abundance from that season suggested a larger increase in mackerel abundance in recent years than the winter survey and the discussion of this topic at the TRAC mackerel data meeting in October focused on the spring survey.

3. Results

3.1. Model selection results for each sub-model
The final models for the spring and winter survey sub-models for the probability of a non-zero catch per tow observation shared several of the same effects. The final model for the spring survey sub-model was:

$$g(p_i) = \log_e\left(\frac{p_i}{(1-p_i)}\right) = \alpha_y + \zeta_s + \omega_v + \tau_d + \beta T_i \; ;$$

and the final model for the winter survey sub-model was:

$$g(p_i) = \log_e\left(\frac{p_i}{(1-p_i)}\right) = \alpha_y + \zeta_s + \tau_d$$

Similarly, the final models for the spring and winter survey sub-models for the positive catch per tow observations also shared some of the same effects. The final model for the spring survey sub-model was:

$$\log_e(CPT_i) = \mu + \alpha_y + \zeta_s + \omega_v + \tau_d + \varepsilon_i$$

and the final model for the winter survey sub-model was:

$$\log_e(CPT_i) = \mu + \alpha_y + \zeta_s + \varepsilon_i.$$

3.1.1. A comparison of alternative methods for estimating annual indices of abundance

The trend among years in the annual indices of abundance was generally the same among the three methods of estimation (i.e., the arithmetic mean, back-transformed geometric mean, and delta approach) in each season. In the spring, the indices of abundance generally increased through the 1990s and varied without trend for the remainder of the time series (Figure 4). Although each method of estimation shared the same general trends among years, individual years and short-term trends occasionally differed between the delta approach and the arithmetic mean, while the delta approach and the back-transformed geometric mean were more similar (Figure 4). In the winter, the indices of abundance generally varied without trend with the exception of increases in 2003 and 2005 (Figure 5). All three methods of estimation were generally similar for the winter survey (Figure 5). Due to the general similarity between the delta method and the other methods of estimation in each season, the effects retained in the final models were likely not affecting the indices of abundance.

3.2. Additional analyses considering factors that may affect the index of abundance

3.2.1. Time of day of the tow

In the spring survey, daytime tows generally had higher mean catches in each year than nighttime tows, but the general trend among years between the two times of day was similar (Figure 6). The proportion of tows occurring during each time of day varied without trend around 50% through the entire time series (Figure 7). Since the proportion of tows occurring during each time of day in each year was about 50% and did not trend among years, time of day was likely not affecting the spring survey index of abundance. In the winter survey, no time of day had consistently higher or lower mean catches than the other time of day, and mean catches between daytime and nighttime tows were similar in scale (Figure 8). The general trend among years between the two times of day was similar (Figure 8). The proportion of tows occurring during each time of day varied without trend just below 50%, with more tows occurring during the nighttime through the entire time series (Figure 7). Since the mean catches and trend among years were generally similar between each time of day, and the proportion of tows occurring during each time of day was about 45% in each year and did not trend among years, time of day was likely not affecting the winter survey index of abundance.

3.2.2. Timing of the survey in each season

The mean Julian date of the spring and winter surveys varied without trend among years (Figure 9). So, the timing of the survey in each season was likely not affecting the indices of abundance, unless mackerel availability to the surveys has changed among years.

3.2.3. Vessel, door, and net changes –results from the literature

The 12th Stock Assessment Workshop (SAW; 1991) found no significant difference between the number or weight per tow of mackerel caught by the Delaware II and the Albatross IV. However, sample sizes for mackerel were low (n=15). Little or no data existed for evaluating the effect of net or door changes on mackerel catches. However, the 12th SAW (1991) found no significant effect of door changes on the catch of Atlantic herring, a species often assumed to be similar to mackerel. Using data from 22 species, but no data on mackerel, Sissenwine and Bowman (1978) found that time of day (i.e., whether tows were taken during the day or night) explained more variation in catch than net type, although results varied for individual species.

3.3. Considering that mackerel may have shifted depth distribution in response to low cod abundance
The proportion of tows in each year that caught both cod and mackerel varied without trend among years, while the proportion of tows in each year that caught mackerel but not cod increased from the 1980s to 2000, and varied without trend for the remainder of the time series (Figure 10). Increases in the proportion of tows in each year that caught mackerel but not cod from the 1980s to 2000 were not of sufficient magnitude to lend strong support for the hypothesis that mackerel have shifted their depth distribution in response to low cod abundance. So, these results are inconclusive.

4. Discussion and Conclusions
Preliminary results suggested that the trends among years in the indices of abundance were robust to assumptions about the form of the error distribution in the sub-models for positive catch per tow observations, and Punt et al. (2000) found similar results for an analysis of school shark *Galeorhinus galeus* off the coast of southern Australia. Consequently, the trends among years in the indices of abundance were also likely robust to the degree of violations of the assumptions about the form of the error distribution in this study. This conclusion, however, may not be general.

Factors in the final models for the spring and winter surveys in this study were similar to analyses done on commercial and survey data from other fisheries. For example, Battaile and Quinn (2004) found a significant effect of time of day (i.e., daytime or nighttime) when standardizing catch per effort data from the eastern Bering Sea trawl fishery for walleye Pollock *Theragra chalcogramma*, with higher catch rates observed during daytime than during nighttime. Battaile and Quinn (2004) suggested that the difference was attributable to greater catchability of walleye Pollock during daylight, when the fish exhibit schooling behavior, than during nighttime, when the fish spread out to forage, and a similar mechanism may also explain time of day differences for mackerel. Similarly, using data from a bottom trawl survey in the Gulf of St. Lawrence, Benoit and Swain (2003) found significant differences in catchability between daytime and nighttime for several pelagic species, including mackerel. Temporal factors on broader scales such as month and year have also been found to be significant in other studies (e.g., Maunder and Punt 2004; Deroba and Bence 2009). Vessel has also been included in models for catch per effort standardization, including some analyses of survey data, as in this study (Maynou et al. 2003; Battaile and Quinn 2004; Bishop et al. 2004; Cooper et al. 2004; Helser et al. 2004). For example, Cooper et al. (2004) and Helser et al. (2004) found that vessel and interactions with vessel should be included in the final models used to standardize U.S. West Coast groundfish bottom trawl surveys. The consistent inclusion of a vessel effect suggests that this factor serves as a catch-all for boat characteristics that are not included in the models (Battaile and Quinn 2004). However, specific characteristics of vessels are also often included in models of commercial fishery catch per effort data (Punt et al. 1996; Maynou et al. 2003; Battaile and Quinn 2004; Deroba and Bence 2009).

The trend in the indices of abundance estimated using arithmetic means, back-transformed geometric means, and the delta method was generally similar among years. This result was especially true for the back-transformed geometric mean and the delta method. Consequently, the choice of which method to use for stock assessment may be of small consequence, although definitive conclusions are not possible until the stock assessment models are evaluated for their sensitivity to the indices of abundance. However, the delta method could be argued to be superior based on the prior evidence that the delta method was more appropriate for data with a high proportion of zeros (Pennington 1996; Ortiz et al. 2000). Conversely, a strong argument could be made for use of the back-transformed geometric mean, which provides nearly the same trends, has a long history, and is easier to estimate (e.g., does not require two sub-models). The similar trend in the annual indices of abundance provided by the three methods of estimation in this study is not a general result. In some cases, a standardization process like the delta method developed here can lead to a different trend in the annual index of abundance (e.g., Maynou et al. 2003; Battaile and Quinn 2004; Deroba and Bence 2009), and this should be evaluated on a case by case basis. Furthermore, even in cases when different methods of estimation provide nearly the same trends in annual indices of abundance, standardization processes can provide more accurate estimates of uncertainty (e.g., standard errors) for each year, and this can be especially important when estimates of uncertainty are used to weight the importance of catch per effort indices in stock assessment models, which can improve stock assessment accuracy (Maunder and Starr 2003; Helser et al. 2004) and should be considered for most stock assessments.

Most factors evaluated in this study were shown not to affect the indices of abundance, or in the case of net and door changes, not enough data were available for analyses. Even those factors retained in the final models of the delta approach did not lead to a much different trend in the annual indices of abundance, likely because they "averaged out", as in the case of daytime versus nighttime tows. These results are likely not general, however, and should be considered on a case by case basis. For mackerel, the assumption must be made that vessel, net, and door changes are not affecting the indices of abundance, unless a study is directed to specifically address these possible issues.

The results of this study were inconclusive as to whether mackerel have shifted their depth distribution in response to low cod abundance, but did not add to the body of evidence in support of that hypothesis. Furthermore, studies directed at the shifting depth distribution of prey species (e.g., Atlantic herring) often considered similar to mackerel have not controlled for the confounding effects of changes in fishing mortality, density, predator-prey dynamics, or the "one-way trip" of cod to low abundance from which the population has not returned. Mackerel also differ from similar prey species because they lack a swim bladder, and so may not respond to low predator abundance in the same way as other similar prey species. Lastly, mackerel are preyed on by several other demersal predators beside cod (e.g., spiny dogfish, goosefish), and those predator populations are at relatively high abundance. Why mackerel would shift their depth distribution in response to the low abundance of one predator while ignoring the presence of several other predators is not clear. The hypothesis that mackerel have shifted their depth distribution in response to low cod abundance is still viable and could be considered in future research that considers the above confounding factors. Until such studies are conducted, however, the assumption must be made that indices of abundance from NMFS bottom trawl surveys are not being affected by systematic shifts in depth distribution of mackerel.

5. Acknowledgements

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6. References

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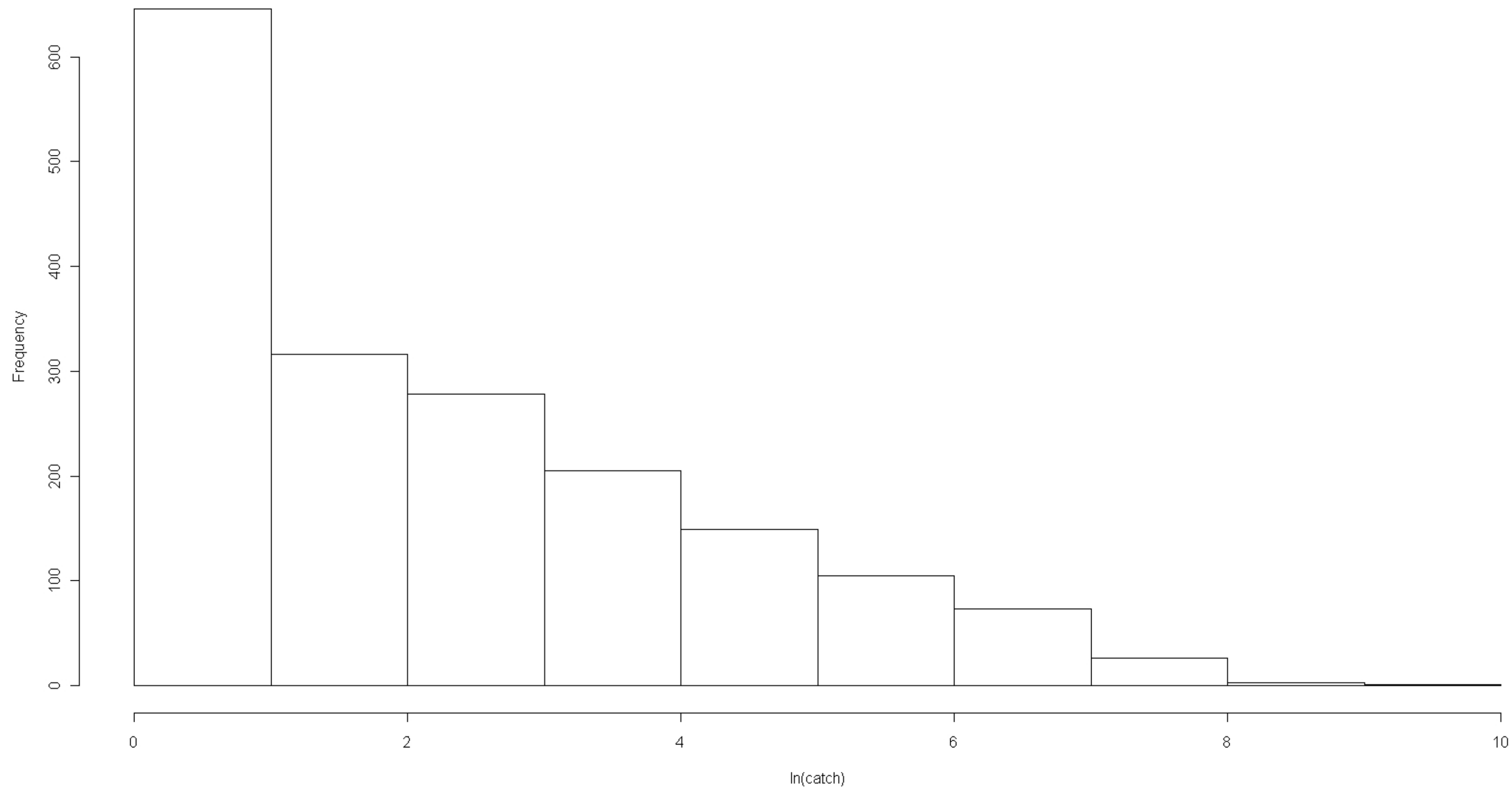


Figure 1. Frequency distribution of $\log_e$ transformed positive mackerel catch per tow observations from the National Marine Fisheries Service spring bottom trawl survey during 1968-2008.

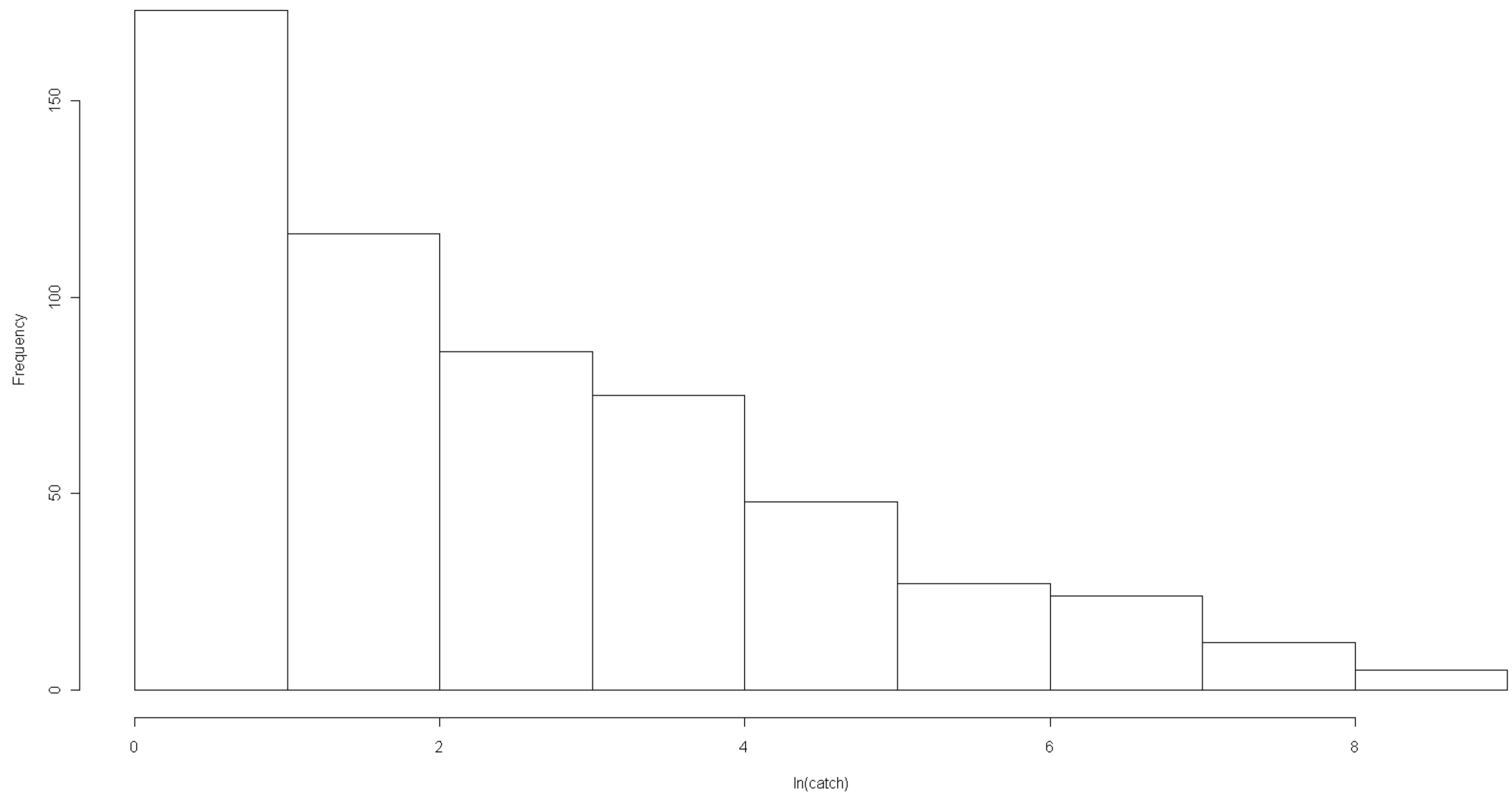


Figure 2. Frequency distribution of $\log_e$ transformed positive mackerel catch per tow observations from the National Marine Fisheries Service winter bottom trawl survey during 1992-2007.

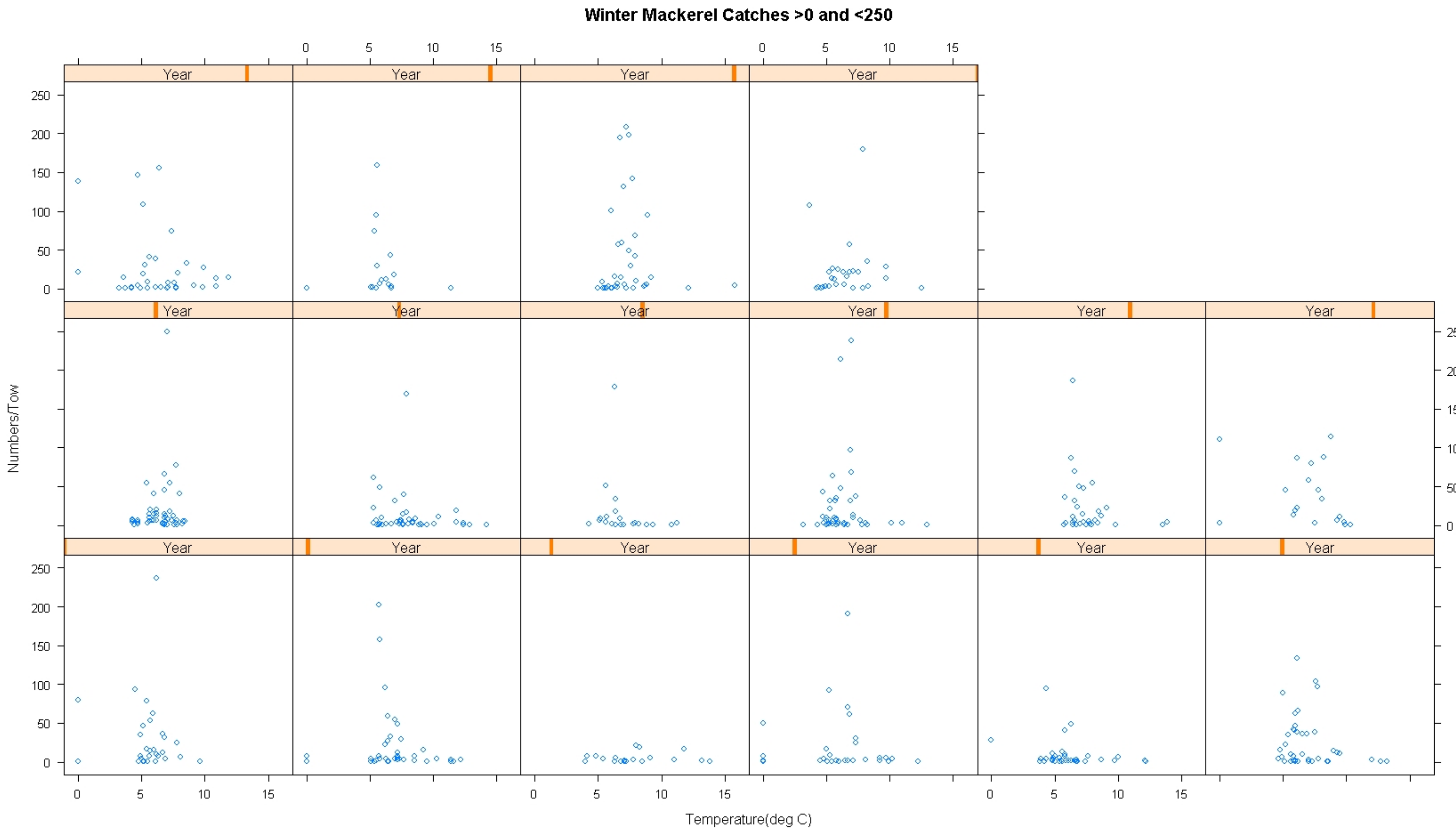


Figure 3. Temperature versus number of mackerel per tow during 1992-2007 from the National Marine Fisheries Service winter bottom trawl survey. Only tows that caught at least one mackerel and less than 250 mackerel are included so that the scale of each panel is such that trends can be inferred.

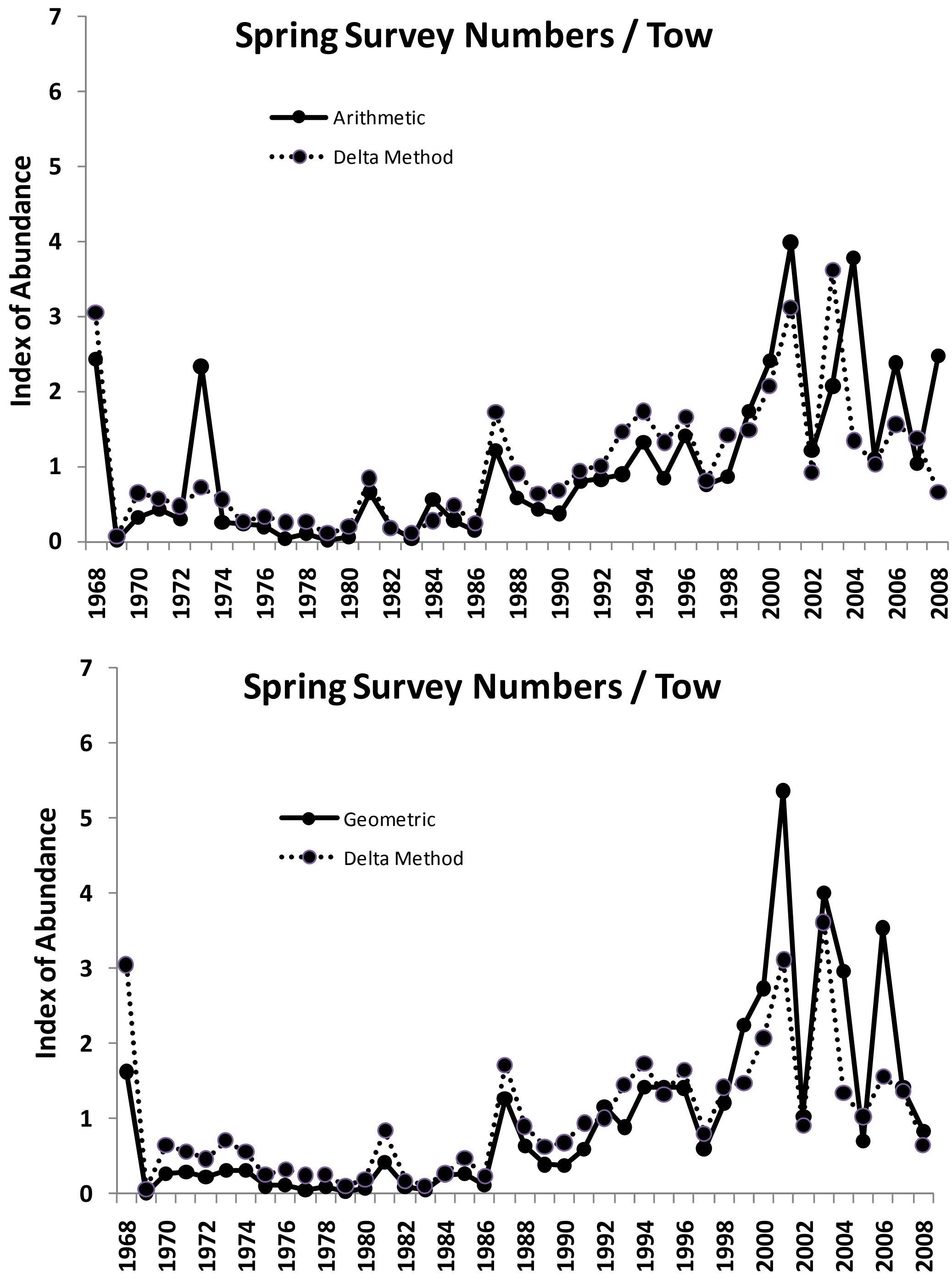


Figure 4. Arithmetic mean (top panel), back-transformed geometric mean (bottom panel), and model based delta method estimates of indices of abundance (both panels; see text for details) for mackerel in the National Marine Fisheries Service spring bottom trawl survey during 1968 to 2008. For ease of comparison, the annual indices of abundance from each method were "re-scaled to one" by dividing the index in each year by the mean among all years for each method of estimation.

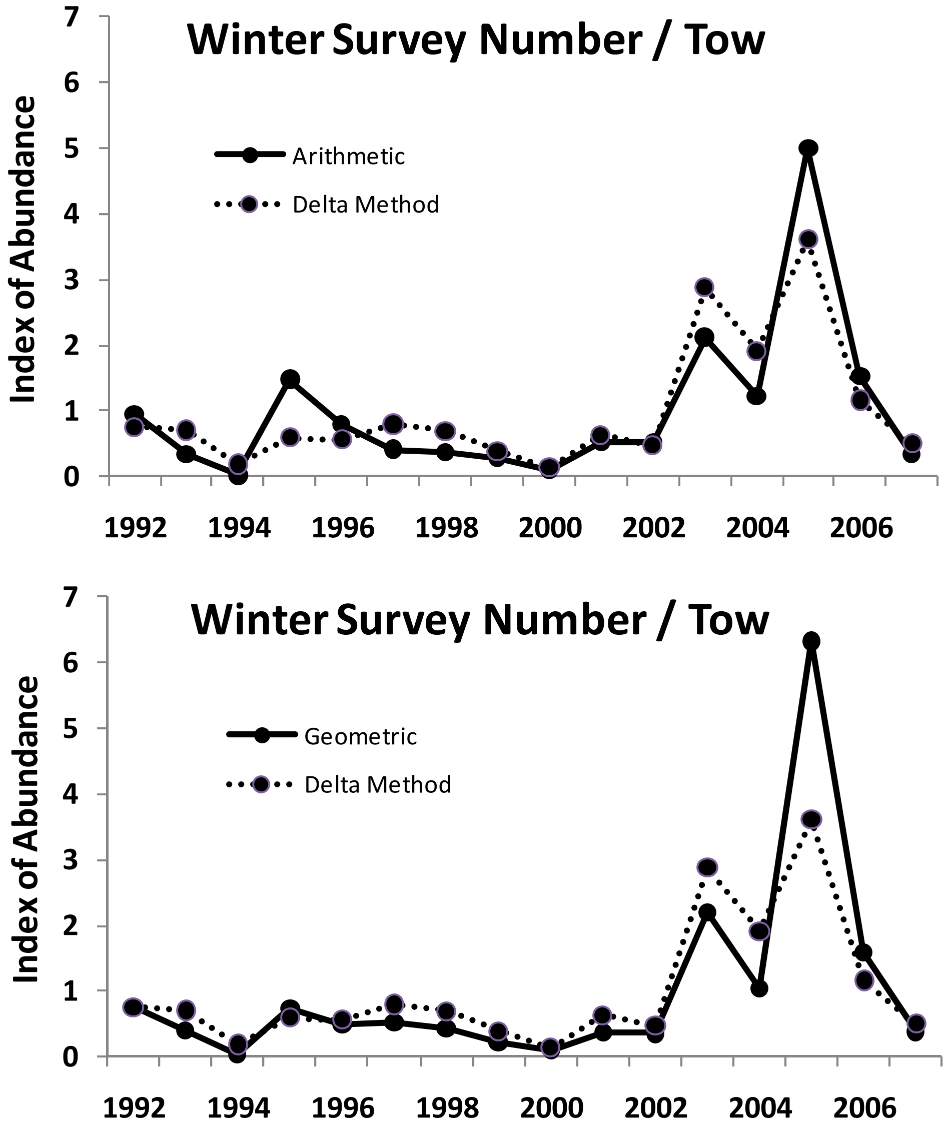


Figure 5. Arithmetic mean (top panel), back-transformed geometric mean (bottom panel), and model based delta method estimates of indices of abundance (both panels; see text for details) for mackerel in the National Marine Fisheries Service winter bottom trawl survey during 1992 to 2007. For ease of comparison, the annual indices of abundance from each method were "re-scaled to one" by dividing the index in each year by the mean among all years for each method of estimation.

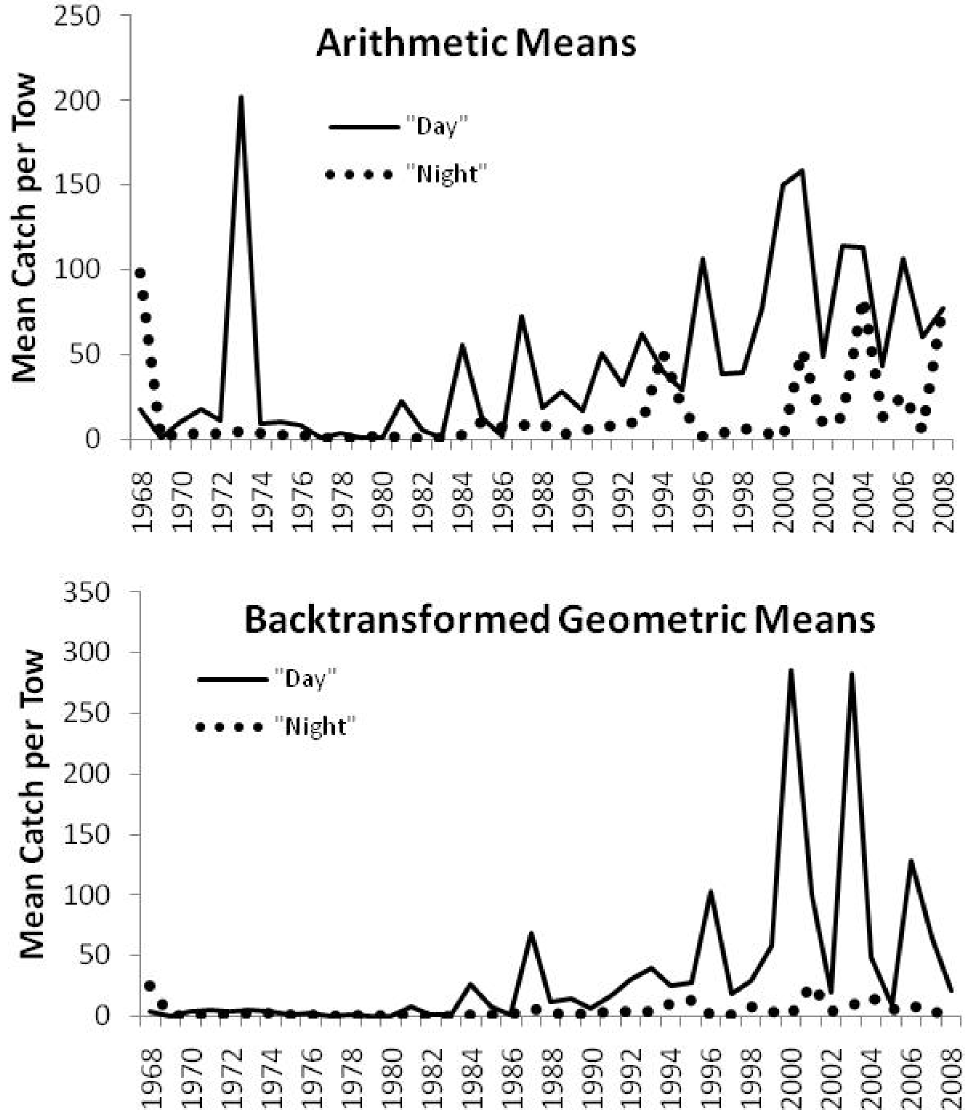


Figure 6. Arithmetic means (top panel) and back-transformed geometric means (bottom panel) for mackerel in the National Marine Fisheries Service spring bottom trawl survey during 1968 to 2008, for tows during the daytime and nighttime (see text for definitions).

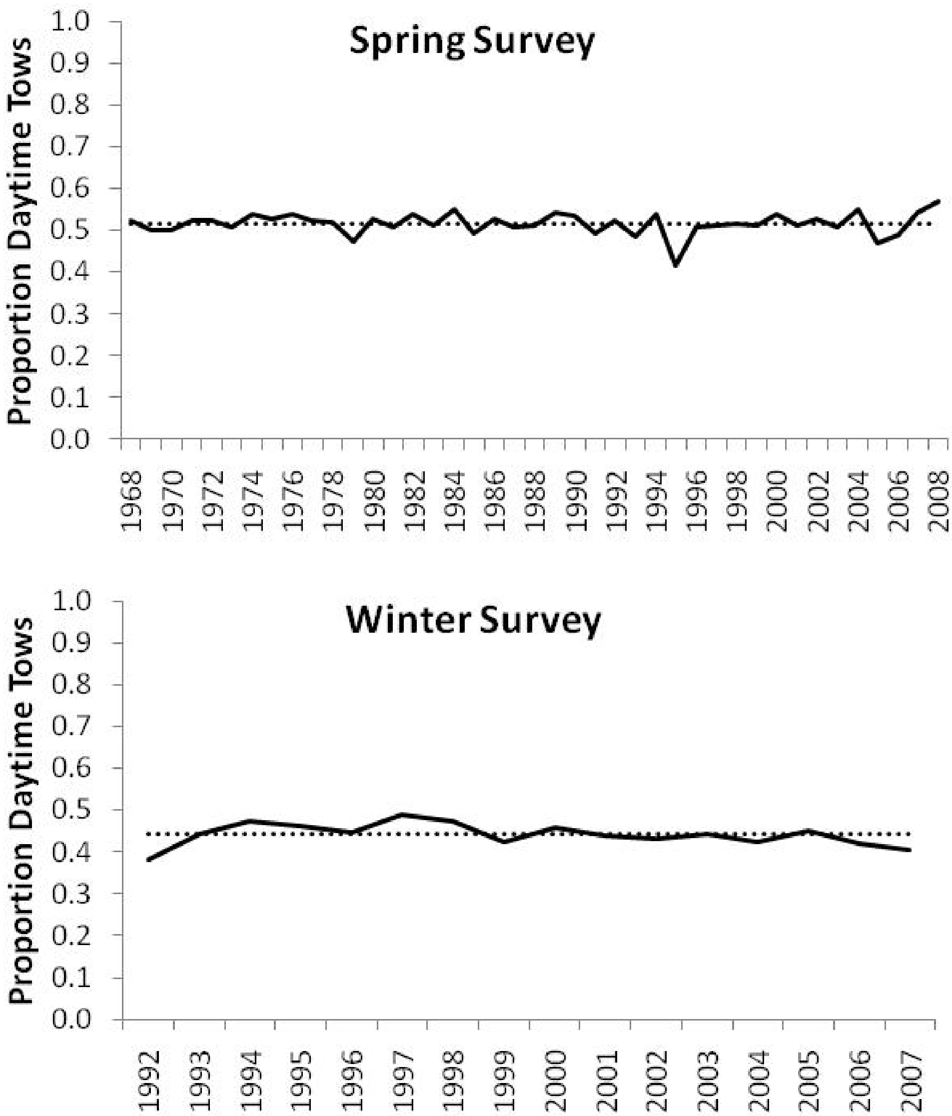


Figure 7. The proportion of tows that occurred during the daytime (see text for definition) for the National Marine Fisheries Service spring bottom trawl survey during 1968 to 2008 (top panel) and winter bottom trawl survey during 1992 to 2007 (bottom panel). Dashed lines are the means for the time series in each panel.

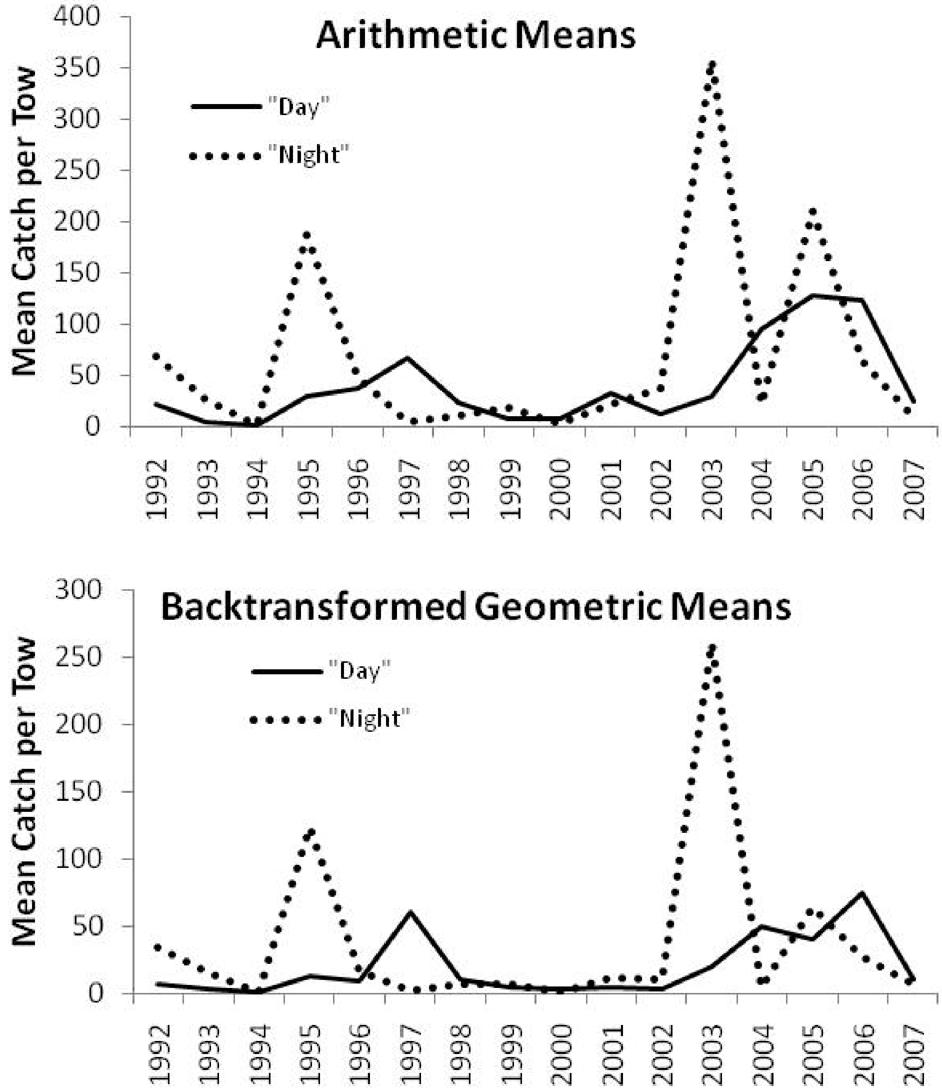


Figure 8. Arithmetic means (top panel) and back-transformed geometric means (bottom panel) for mackerel in the National Marine Fisheries Service winter bottom trawl survey during 1992 to 2007, for tows during the daytime and nighttime (see text for definitions).

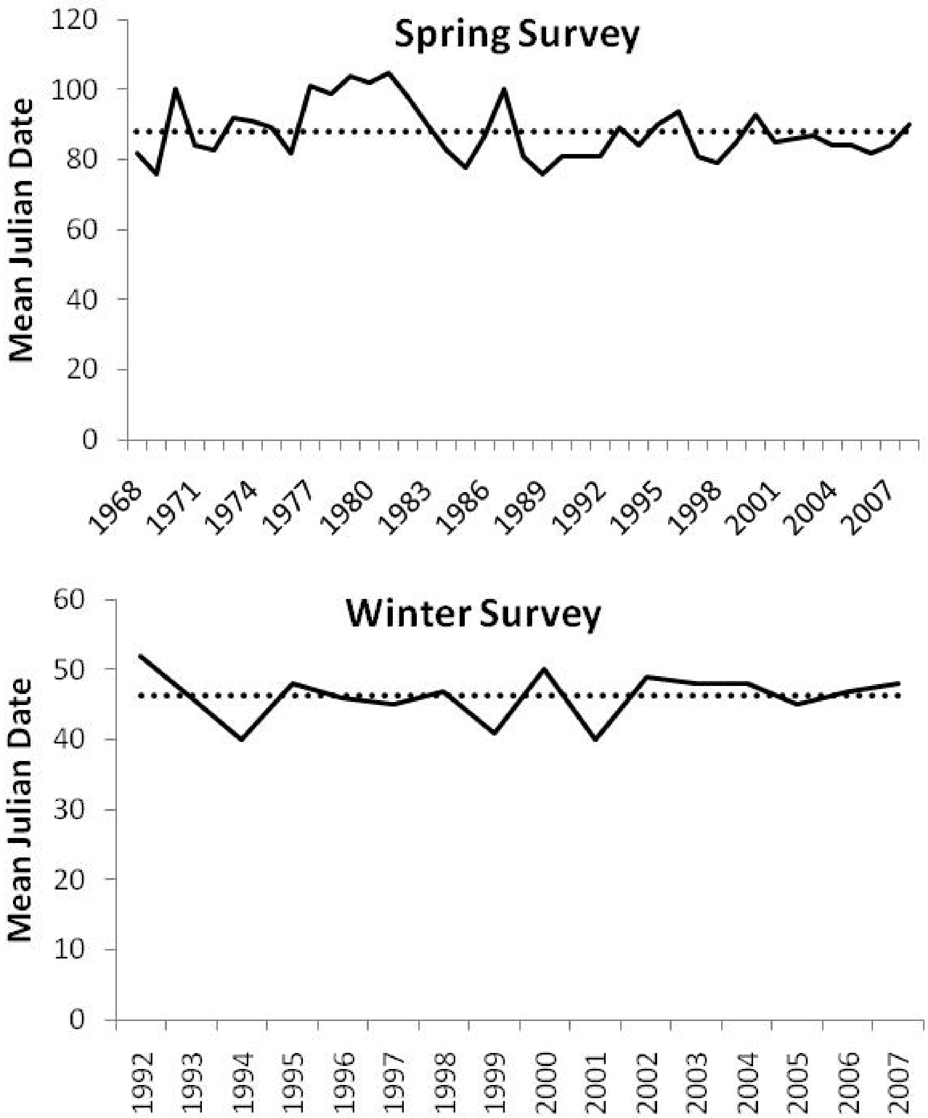


Figure 9. Mean Julian date of the National Marine Fisheries Service spring bottom trawl survey during 1968 to 2008 (top panel) and the winter bottom trawl survey during 1992 to 2007 (bottom panel). Dashed lines are the means for the time series in each panel.

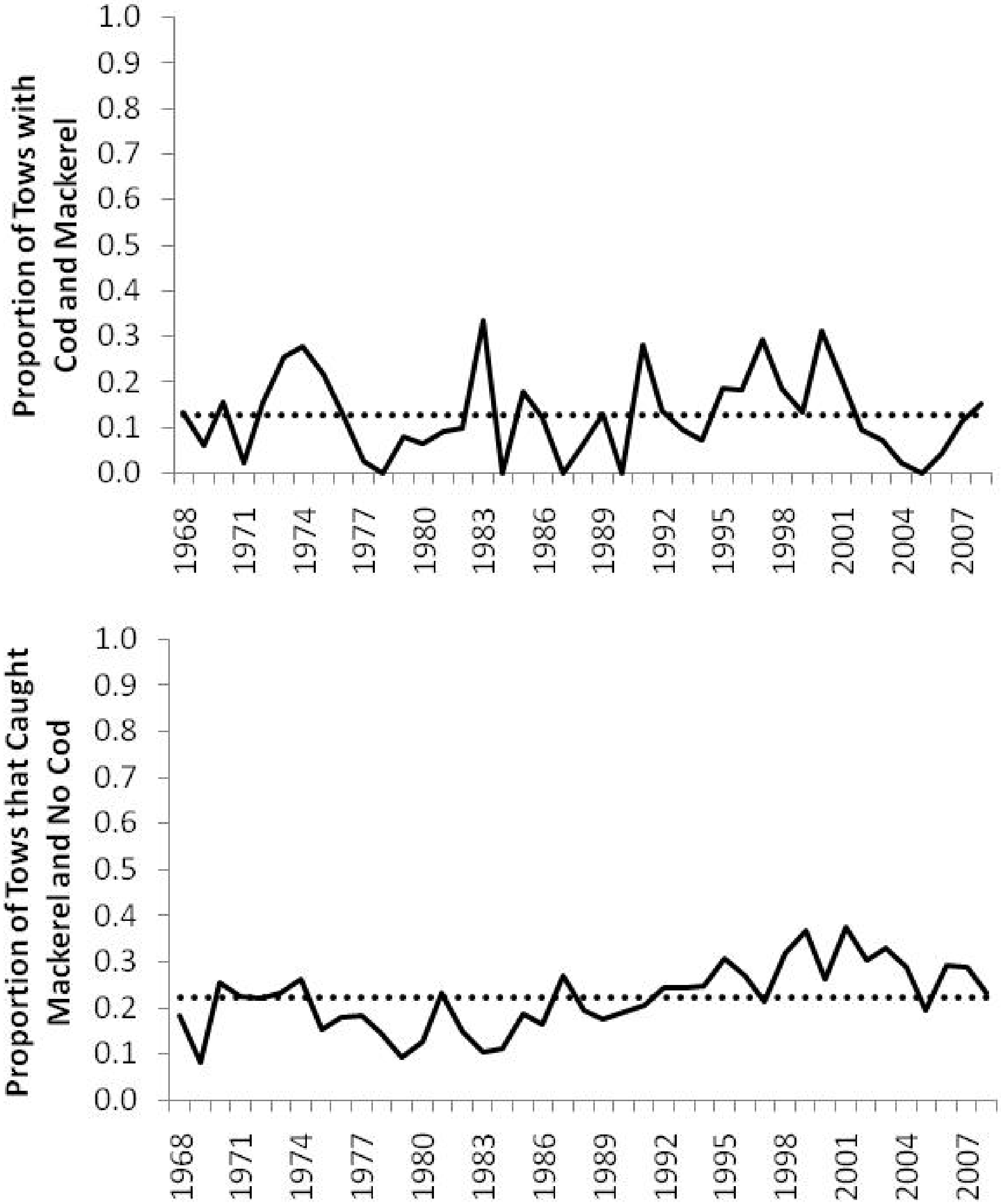


Figure 10. The proportion of tows that caught both cod and mackerel (top panel) and the proportion of tows that caught mackerel and no cod (bottom panel) from the National Marine Fisheries Service spring bottom trawl survey during 1968 to 2008. Dashed lines are the means for the time series in each panel.

Table 1. The number of tows in each stratum from the National Marine Fisheries Service spring bottom trawl survey during 1968 to 2008.

Year	Number of Tows in Each Stratum																																							
	1010	1020	1030	1040	1050	1060	1070	1080	1090	1100	1110	1120	1130	1140	1150	1160	1170	1180	1190	1200	1210	1220	1230	1240	1250	1610	1620	1630	1640	1650	1660	1670	1680	1690	1700	1710	1720	1730	1740	1750	1760
1968	6	5	4	4	4	6	4	3	4	6	4	3	7	4	4	9	4	3	8	6	4	4	6	6	4	3	2	2	2	8	4	2	2	7	4	3	3	6	4	3	
1969	7	7	3	3	5	8	3	3	5	8	3	3	9	4	3	14	4	3	8	6	4	4	5	6	4	3	2	2	2	8	3	2	2	7	4	2	2	5	4	2	
1970	7	9	6	3	5	9	4	3	5	10	4	3	9	4	3	10	4	3	8	5	4	4	5	6	4	3	2	2	2	6	4	1	2	7	5	3	2	6	5	4	
1971	8	7	3	3	5	11	3	3	6	9	3	3	9	4	3	12	4	2	9	6	5	3	5	7	4	4	2	2	2	8	3	2	2	6	5	2	2	6	5	1	
1972	7	8	5	4	5	9	4	3	5	8	4	4	8	4	3	13	4	3	9	6	4	5	5	7	4	4	2	2	2	8	3	1	2	7	4	2	2	6	4	2	
1973	16	14	6	3	10	16	3	3	5	8	3	3	9	4	3	10	4	3	9	6	4	4	5	6	4	3	2	2	2	7	3	2	2	6	4	2	1	9	6	2	
1974	7	6	3	3	4	8	3	3	4	8	3	3	8	3	3	10	3	3	9	6	5	2	5	6	3	1	1	1	1	3	3	1	1	5	4	2	2	5	4	2	
1975	6	8	3	3	6	9	3	2	5	7	3	3	9	4	3	10	4	3	9	6	4	4	5	6	4					1	3	2	2	4	4	2	2	6	4	2	2
1976	8	7	3	2	5	9	3	3	5	10	3	3	9	4	3	10	3	2	9	6	4	4	6	6	3	5	2	2	2	9	3	2	2	9	4	3	2	7	5	2	
1977	7	7	3	3	5	8	3	2	6	9	3	3	9	5	3	9	4	2	9	6	4	4	6	7	3	5	2	2	1	9	3	2	2	10	4	2	2	8	5	2	
1978	8	8	3	1	7	10	3	4	5	8	3	2	9	5	3	12	4	3	9	6	4	5	6	9	4	4	2	2	2	7	4	1	2	7	4	2	2	6	4	2	
1979	7	7	2	3	10	8	3	3	15	8	3	3	18	4	3	20	4	3	18	12	8	8	10	12	7	3	2	2	1	6	4	2	1	6	6	2	3	5	5	2	
1980	7	7	3	2	17	28	3	3	18	20	3	2	8	4	3	10	5	2	9	6	4	4	5	6	2	3	2	2	2	7	3	2	2	6	4	2	2	5	4	2	
1981	8	7	3	1	3	8	3	2	5	8	3	3	9	4	2	10	4		9	6	4	4	4	6	4	3	2	1	3	7	3	1	2	6	4	3	1	5	4	2	2
1982	7	7	3	3	5	8	3	3	5	8	3	3	9	4	3	10	4	3	9	6	4	4	5	6	5	3	2	2	2	7	3	2	2	6	4	2	2	5	4	2	
1983	7	7	3	3	4	8	3	3	5	8	3	3	9	4	3	10	4	2	9	6	4	4	5	6	3	3	2	2	1	7	3	2	2	6	4	2	2	5	4	2	
1984	7	7	3	3	4	9	3	3	5	7	3	2	9	4	3	11	4	3	9	6	4	4	5	6	4	3	2	2	2	7	3	2	2	6	4	2	2	5	4	2	
1985	7	5	3	2	5	8	3	3	6	7	4	2	9	5	2	10	4	2	9	6	3	5	4	5	2	3	2	2	2	7	4	1	2	7	4	2	2	5	4	2	
1986	7	7	3	3	5	8	3	3	5	8	3	3	8	4	3	10	4	3	9	6	4	4	5	6	4	3	2	2	2	7	4	1	2	6	4	2	2	5	4	2	
1987	7	7	4	3	5	8	3	1	5	8	3	3	9	4	3	10	4	3	9	6	4	4	5	6	4	4	2	2	2	6	3	2	2	6	4	2	2	5	5	2	
1988	7	7	2	1	6	8	2	1	5	8	2	1	9	3	1	10	3	1	9	6	4	4	4	6	4	3	2	2	1	7	3	2	1	6	4	3		5	4	2	1
1989	7	7	2	1	5	8	2	1	5	8	2	1	9	3	1	10	3	1	9	6	4	4	4	6	2	3	2	2	1	7	3	2	1	6	2	2	1	5	4	2	
1990	7	7	2	1	5	8	2	1	5	8	2	1	9	3	1	10	3		9	6	4	4	5	6	4	3	2	2	1	7	3	2	1	6	2	2	1	5	4	2	1
1991	7	7	2	1	5	8	2	1	5	8	2	1	9	3	1	10	3	1	9	6	4	4	5	6	3	3	2	2	1	7	3	2	2	6	4	2	1	5	4	2	
1992	7	7	2	1	4	8	2	1	5	8	2		9	3	1	10	3	1	9	6	4	4	4	6	4	3	2	2		7	3	2	1	6	4	2	1	5	4	2	1
1993	7	7	2	1	4	8	2	1	5	8	2		9	3	1	10	3	1	9	6	4	4	6	6	3	3	2	2		7	3	2	1	6	4	2	1	5	4	2	1
1994	7	7	2	1	5	8	2	1	5	8	3		9	3	1	10	3	1	9	6	4	4	4	6	3	3	2	2	1	7	3	2	1	6	4	2	1	5	4	2	1
1995	7	7	2	1	5	8	2	1	5	8	2	1	9	3	1	9	3	1	9	6	4	4	4	6	3	3	2	2	1	7	3	1	1	6	4	2	1	5	4	2	
1996	8	7	2	1	4	8	2	1	5	8	2	1	9	3	1	10	3	1	9	6	4	4	4	4	2	4	3	3	2	8	4	3	1	7	5	3	2	6	4	2	
1997	7	7	2	1	5	8	2	1	5	8	2		9	3	1	10	3	2	9	6	4	4	5	6	3	3	2	2	1	7	3	2	1	6	4	2		5	4	2	1
1998	7	7	2	1	5	8	2	1	5	8	2	1	9	3	1	10	3	1	9	6	4	4	5	9	4	3	2	2	1	7	3	2	1	6	4	2	1	5	4	3	
1999	7	7	2	1	5	8	2	1	5	8	2	1	9	3	1	10	3	1	9	6	4	4	5	6	4	3	2	2	1	7	3	2	1	6	4	2	1	5	4	2	
2000	7	7	2	1	5	8	2	1	5	8	2	1	9	3	1	10	3	1	9	6	4	4	5	6	4	3	2	2	1	7	3	2	1	6	4	2	1	5	4	2	
2001	7	7	2	1	5	8	1	1	5	8	3	1	9	3	1	10	3	1	9	6	4	4	5	6	4	3	2	2	1	7	3	2	1	6	4	2	1	5	4	2	
2002	7	7	2	1	5	8	2	1	5	8	2	1	9	3	1	10	3	1	9	6	3	4	5	6	4	3	2	1	2	7	3	2	1	6	4	2	1	5	4	2	
2003	6	6	2	1	5	8	2	1	5	8	2	1	9	3	1	10	3	1	9	4	4	4	5	6	3	3	2	2	1	6	3	2	1	5	4	2	1	4	3	2	
2004	7	7	2	1	5	8	2	1	5	8	2	1	9	3	1	10	3	1	9	6	4	4	5	6	4	3	3	1	1	7	3	2	1	6	4	2	1	5	4	2	
2005	7	7	2	1	5	8	2	1	5	8	2	1	9	3	1	10	3	1	9	6	4	4	5	6	3	3	2	2	1	7	3	2	1	6	4	2	1	5	4	2	
2006	7	7	2	1	5	8	2	1	5	8	2	1	9	3	1	10	3	2	9	6	4	4	5	6	4	3	2	2	1	7	3	2	1	6	4	2	1	5	4	3	
2007	7	7	4	3	5	8	2	1	5	8	2	1	9	3	1	20	3	2	9	6	4	4	5	6	3	3	2	2	1	7	3	4	3	6	4	4	3	5	4	4	
2008	7	7	1	1	5	8	2	1	5	8	2	1	9	3	1	20	3	1	9	6	4	4	3	6	4	3	2	2	1	7	3	2	1	6	4	2	1	5	4	2	

Table 2. The number of positive mackerel tows in each stratum from the National Marine Fisheries Service spring bottom trawl survey during 1968 to 2008.

	Number of Positive Tows in Each Stratum																																							
Year	1010	1020	1030	1040	1050	1060	1070	1080	1090	1100	1110	1120	1130	1140	1150	1160	1170	1180	1190	1200	1210	1220	1230	1240	1250	1610	1620	1630	1640	1650	1660	1670	1680	1690	1700	1710	1720	1730	1740	1750	1760
1968		1	1	0	0	2	2	0	0	0	2	0	3	1	0	0	0	0	0	0	0	0	0	0	0	3	2	0	0	7	2	2	0	1	4	2	0	0	3	0	
1969		0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	2	0	2	2	0	0	1	0	1	1	0	0	1	1	
1970		4	5	0	0	4	4	0	0	2	4	3	1	4	0	2	0	0	0	0	0	0	0	0	0	2	0	0	0	1	2	0	0	2	4	2	1	3	2	2	
1971		6	3	2	0	1	2	2	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	1	2	1	2	2	0	3	2	1	1	4	1	
1972		2	3	2	2	6	3	2	0	5	2	1	1	3	0	3	1	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	2	0	1	0	2	3	2	
1973		2	4	2	0	8	3	2	0	1	1	1	4	4	0	0	2	1	0	0	0	0	0	0	0	1	1	0	0	4	2	0	0	3	2	1	0	7	4	2	
1974		5	3	1	2	4	2	1	0	7	3	3	6	1	2	2	1	0	1	1	2	0	0	1	0	0	0	0	0	1	0	0	0	2	0	0	0	2	1	1	
1975		3	2	2	1	3	1	0	0	6	1	1	4	1	1	0	0	0	1	0	0	0	0	0	0					0	0	0	0	0	1	1	0	0	1	0	1
1976		3	2	2	3	0	2	0	0	1	0	0	4	2	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	3	0	0	0	5	3	1	1	0	1	0	
1977		4	2	2	0	0	2	1	0	0	1	2	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	3	1	0	0	3	1	2	1	0	4	2	
1978		0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0	3	2	1	2	4	2	1	2	0	1	2	
1979		2	0	1	0	2	1	0	0	0	2	0	3	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	2	0	0	0	0	3	1	1	0	3	2	
1980		1	0	1	0	3	2	1	0	2	3	1	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	4	4	2	
1981		4	3	0	0	3	3	1	0	0	3	2	0	3	1	2	1		0	0	0	0	0	0	0	1	0	0	0	3	0	0	0	3	1	1	0	3	3	1	1
1982		3	1	0	1	5	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	2	0	0	4	1	2	
1983		1	0	0	0	1	1	0	2	4	0	0	5	0	0	0	2	0	1	0	1	0	1	0	1	0	0	0	0	1	0	0	0	2	0	0	0	1	0	0	
1984		5	2	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	1	0	0	0	2	1	0	
1985		1	2	0	0	5	1	0	0	2	0	0	2	4	0	0	0	0	0	1	1	0	1	0	1	0	0	0	0	5	0	0	0	3	1	0	0	4	3	0	
1986		4	1	1	0	2	2	0	0	3	1	0	1	0	0	2	0	0	1	0	0	0	1	0	1	0	1	0	0	3	0	0	0	2	0	0	0	4	2	0	
1987		4	1	1	0	3	2	0	0	2	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	4	1	0	0	4	1	0	0	5	2	1	1	1	5	1	
1988		7	1	0	2	6	1	0	0	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	1	0		0	3	0	0
1989		4	0	0	0	3	0	0	0	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	6	0	0	0	5	2	0	
1990		4	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	6	1	1	0	4	3	0	0
1991		4	0	0	2	5	0	0	0	5	0	0	6	0	0	0	0	0	0	0	1	0	2	3	0	0	0	0	0	2	0	0	0	4	0	0	0	5	2	0	
1992		7	0	0	0	3	2	1	0	4	0		2	0	0	1	0	0	0	0	0	0	0	0	2	1	0	0		3	1	0	0	5	1	0	0	5	2	0	0
1993		4	2	1	0	1	2	0	0	1	2		3	3	0	1	1	0	0	1	0	1	0	0	0	1	0	1		3	2	1	0	0	3	2	0	1	4	0	1
1994		4	2	0	0	2	2	0	0	3	1		3	2	0	2	1	0	0	0	0	0	1	0	0	3	0	0	0	6	1	0	0	2	3	0	0	1	3	0	0
1995		4	1	0	4	5	1	1	0	5	0	0	2	0	0	0	0	0	4	1	1	2	3	0	0	0	0	0	0	5	0	0	0	6	2	0	0	5	0	1	
1996		5	1	0	0	2	2	0	0	4	1	0	2	0	0	2	0	0	4	3	1	3	2	1	0	1	0	0	0	5	1	0	0	4	4	0	0	2	3	1	
1997		3	0	0	5	7	0	1	2	2	2		5	0	0	0	3	0	1	1	0	0	5	0	1	0	0	0	0	3	0	0	0	2	0	0		2	0	0	0
1998		4	0	0	2	6	0	0	2	7	1	0	4	0	0	0	0	0	5	3	1	1	4	3	1	1	0	0	0	6	0	0	0	2	0	0	0	4	3	0	
1999		7	2	0	4	6	1	0	1	6	1	0	6	2	0	1	0	0	3	3	2	0	3	0	1	0	0	0	0	4	0	0	0	6	0	0	0	4	2	1	
2000		6	0	0	0	6	0	0	2	3	0	0	5	0	0	0	0	0	6	5	2	0	4	4	1	0	0	0	0	3	0	0	0	3	2	1	0	4	1	0	
2001		5	0	0	0	6	1	1	0	8	1	0	5	0	0	4	2	0	4	4	1	1	5	5	3	0	0	0	0	3	0	0	0	3	1	1	1	4	3	0	
2002		4	1	0	3	4	0	0	3	8	0	0	6	1	1	0	1	0	2	0	1	0	2	0	2	0	0	0	0	2	1	0	0	3	0	0	0	1	1	0	
2003		6	2	1	0	4	2	0	0	5	2	0	1	2	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	5	2	0	0	4	4	0	0	3	3	2	
2004		5	1	0	0	3	1	0	0	3	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	3	3	1	0	5	3	0	0	4	4	1	
2005		6	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	5	1	0	0	3	4	0	0	2	3	2	
2006		5	0	0	3	4	0	0	1	3	0	0	1	1	0	1	0	0	0	1	1	0	0	0	0	1	0	0	0	4	0	0	0	6	3	0	0	5	3	0	
2007		7	0	1	1	7	0	0	1	3	0	0	3	1	0	0	0	0	1	1	0	1	4	6	1	0	0	0	0	5	0	0	0	4	3	0	0	1	4	1	
2008		6	0	0	2	6	1	0	0	4	0	0	1	0	0	0	0	0	1	3	1	4	0	1	0	0	0	0	0	1	0	0	0	2	0	0	0	5	1	2	

Table 3. The number of tows in each stratum from the National Marine Fisheries Service winter bottom trawl survey during 1992 to 2007.

Year	Number of Tows in Each Stratum																							
	1010	**1020**	**1030**	**1050**	**1060**	**1070**	**1090**	**1100**	**1110**	**1130**	**1140**	**1160**	**1610**	**1620**	**1630**	**1650**	**1660**	**1670**	**1690**	**1700**	**1710**	**1730**	**1740**	**1750**
1992	9	7	3	7	9	2	5	6	2	7	1	5	4	1	1	7	2	2	8	4	2	5	4	2
1993	8	7	2	4	9	3	3	8	2	9	3		5	2		9	3	1	10	5	2	6	5	2
1994	6	5	2	3	5	1	4	8	2	7	2	1	3	1	2	5	1	2	5	4	1	3	4	1
1995	8	7	2	5	9	2	5	8	2	9	3	9	4	2	1	8	4	2	8	4	2	5	4	2
1996	8	8	3	5	10	2	4	10	3	7	4	2	4	2	2	9	4	3	9	5	3	6	5	3
1997	7	7	2	5	9	2	6	8	2	9	3	5	4	2	2	8	3	3	8	4	2	5	4	2
1998	8	7	3	4	9	3	5	8	3	9	4	10	4	2	3	9	3	3	8	4	3	5	4	3
1999	8	7	3	5	8	3	5	9	3	9	4	8	4	2	3	9	3	3	8	4	3	5	4	3
2000	8	8	4	5	10	4	3	7	4	4	2		5	3	3	10	4	4	9	5	4	3	5	4
2001	8	8	4	7	12	4	7	12	4	9	4	6	6	2	2	12	4	4	9	5	4	5	5	5
2002	8	8	4	7	11	4	5	12	4	8	4		7	5	3	12	4	4	9	5	4	5	5	5
2003	4	4	2	4	5	2	3	6	2				7	3	3	10	3	4	6	4	4	3	3	4
2004	6	7	4	4	11	4	5	10	4	4	4		7	3	4	10	4	4	6	5	4	4	5	4
2005	5	5	3	3	7	3	4	7	3	2			6	1	2	8	3	3	7	4	3	4	5	3
2006	7	7	3	9	11	3	4	8	4	2	1		5	4	1	11	3	3	8	4	3	5	4	4
2007	6	7	4	4	10	4	5	9	3				7	3	3	13	4	4	9	5	4	5	5	4

Table 4. The number of positive mackerel tows in each stratum from the National Marine Fisheries Service winter bottom trawl survey during 1992 to 2007.

Year	**Number of Positive Tows in Each Stratum**																							
	1010	**1020**	**1030**	**1050**	**1060**	**1070**	**1090**	**1100**	**1110**	**1130**	**1140**	**1160**	**1610**	**1620**	**1630**	**1650**	**1660**	**1670**	**1690**	**1700**	**1710**	**1730**	**1740**	**1750**
1992	5	5	0	2	5	0	0	3	1	1	0	0	0	0	0	2	0	0	3	0	0	5	1	0
1993	1	6	0	0	2	1	0	6	2	1	2		0	0		4	0	0	6	0	0	4	3	1
1994	2	2	0	0	0	0	0	5	0	1	1	0	0	0	0	2	0	0	2	1	0	2	1	0
1995	6	5	0	5	7	1	1	1	0	0	0	0	0	0	0	1	0	0	3	0	0	4	0	0
1996	4	4	0	0	4	0	0	3	0	3	0	2	1	0	0	8	1	0	2	1	0	5	3	0
1997	3	2	1	2	7	0	1	4	0	4	1	1	0	0	0	5	0	0	4	0	0	4	1	1
1998	5	6	0	0	7	0	0	3	0	5	0	0	0	0	0	8	0	0	8	0	0	5	2	0
1999	1	5	1	3	7	1	1	5	0	5	0	2	0	0	0	2	0	0	3	0	0	4	1	1
2000	4	3	0	2	3	0	0	3	0	0	0		0	0	0	1	0	0	2	1	0	2	1	0
2001	4	2	0	1	8	1	2	11	0	5	0	2	0	0	0	3	0	0	2	2	0	3	2	0
2002	7	2	0	5	8	1	0	4	0	3	0		0	0	0	0	0	0	0	0	0	2	1	1
2003	0	4	0	0	2	1	0	1	2				0	0	0	1	0	0	1	1	0	3	3	3
2004	3	6	2	1	9	4	0	0	2	1	1		0	0	0	5	1	0	1	3	1	1	1	0
2005	2	3	0	0	0	0	0	0	0	0			3	0	0	2	1	0	5	1	0	4	4	1
2006	7	4	0	9	7	0	2	1	0	1	0		1	0	0	1	0	0	6	0	0	5	0	0
2007	2	4	0	3	8	1	1	7	0				0	0	0	0	0	0	0	0	0	3	1	0

Appendix -II

Appendix

Notes on mackerel abundance indices from NMFS bottom trawl surveys

Jonathan J. Deroba

2009

Fall Survey

The fall survey was not used in the last assessment because few mackerel were sampled in this survey and a large proportion of the stock may be distributed in Canadian waters during this time of year and so were unavailable to the survey (SAW 42 2005). Yearly indices of abundance were estimated using this survey from 1963 to 2008 so that it's utility could be reexamined relative to other indices of abundance (Tables , Figures). All inshore and offshore (i.e., coded 01 or 03) survey strata were qualitatively examined for the number of non-zero tows and proportion of zero tows in each stratum among years. Based on this examination, only strata with "sufficient" data were retained for use in the development of the index and other calculations (e.g., proportion of zero tows in each year among strata). The strata retained were: 01010-01030, 01050-01070, 01090-01110, 01130-01140, 01160, 01190-01210, 01230-01270, 01320-01340, and 01360-01420. The proportion of zero tows in each year among retained strata was calculated, and was usually higher than either the winter or spring surveys (Figure). The proportion of zero tows in each year was stable during 1963-2008 and averaged 89% (Figure). Yearly indices were calculated using an arithmetic mean, geometric mean, and delta approach, and these three methods will be compared to help determine the most appropriate transformation (Indices through 2008.docx).

Winter Survey

Yearly and age-specific indices of abundance were estimated using the winter bottom trawl survey from 1992-2007. The survey strata used to develop this index were the same as in the prior assessment: 01010-01030, 01050-01070, 01090-01110, 01130, 01140, 01160, 01610-01630, 01650-01670, 01690-01710, 01730-01750. The proportion of zero tows in each year among strata was stable during 1992-2007 and averaged 69% (Figure 17). Year specific age-length keys during 1992-2005 were the same as in the prior assessment (Overholtz personal communication) and used combined data among winter and spring survey samples, and some commercial data (SAW42 2005). For length bins for which no ages were estimated (i.e., “holes” in the age-length key), a one was entered in the age-length key into the most likely age for that length bin based on age estimates in surrounding length bins (Table 18). Year specific age-length keys during 2006-2007 used combined data between winter and spring survey samples. “Holes” in the age-length key were patched in the same way as the age-length keys during 1992-2005. The age-length keys in each year were used to expand the yearly indices of abundance into age and year specific indices of abundance, as in prior assessments (Tables 16-17). Yearly indices were calculated using an arithmetic mean, geometric mean, and delta approach, and these three methods will be compared to help determine the most appropriate transformation (Figures 14-16). The winter survey was not conducted after 2007.

Spring Survey

Yearly and age-specific indices of abundance were estimated using the spring bottom trawl survey from 1968-2008. The survey strata used to develop this index were the same as in the prior assessment: 01010-01250, 01610-01760. The proportion of zero tows in each year among strata was stable during 1968-2008 and averaged 74% (Figure 17). The age-length keys used to develop the age-specific indices from 1968-1991 were not available and age data in the SVDBS database are sparse for some years in that range. So, at this time any new assessments may have to rely on age-specific index values reported for the last assessment (SAW42 2005). Alternatively, the age-length keys that were used during 1968-1991 could be inferred (“backed-out”) from those values reported in the last assessment, but this option has not yet been thoroughly explored. Year specific age-length keys during 1992-2005 were the same as in the prior assessment (Overholtz personal communication) and used combined data among winter and spring survey samples, and some commercial data (SAW42 2005). For length bins for which no ages were estimated (i.e., “holes” in the age-length key), a one was entered in the age-length key into the most likely age for that length bin based on age estimates in surrounding length bins (Table 18). Year specific age-length keys during 2006-2007 used combined data between winter and spring survey samples. “Holes” in the age-length key were patched in the same way as the age-length keys during 1992-

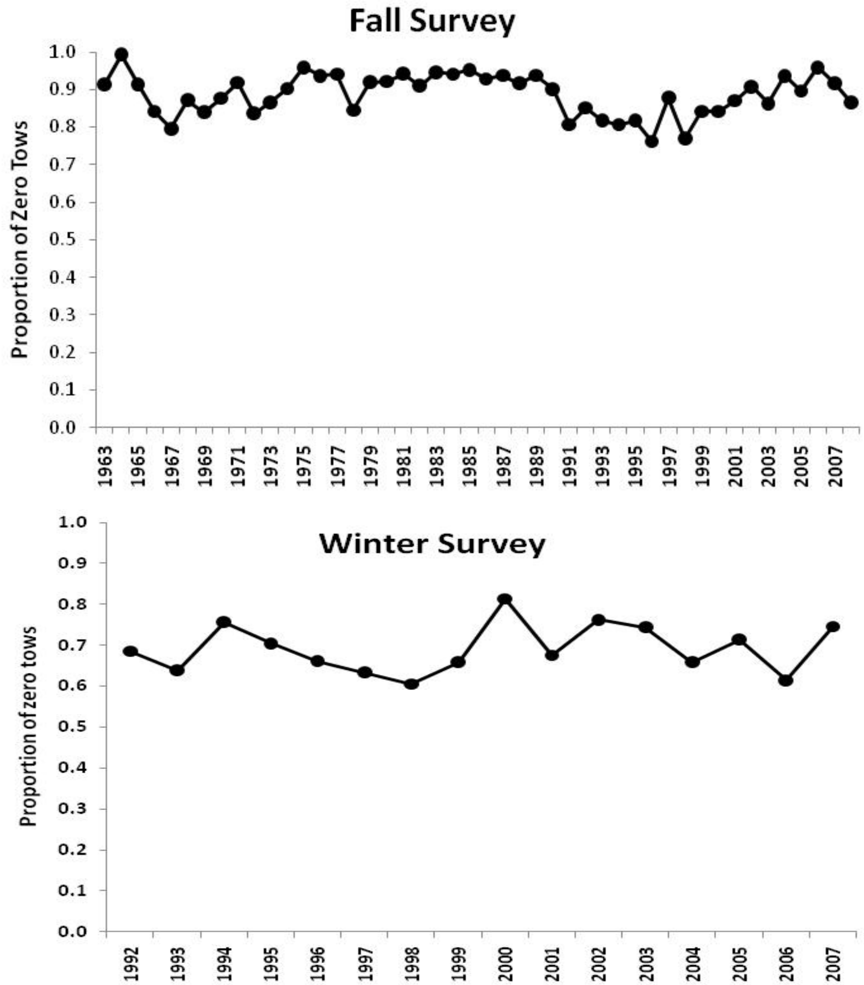
2005. The age-length key for 2008 used only data from the 2008 spring survey because the winter survey was not conducted after 2007. The age-length keys in each year were used to expand the yearly indices of abundance into age and year specific indices of abundance, as in prior assessments (Tables 16-17). Yearly indices were calculated using an arithmetic mean, geometric mean, and delta approach, and these three methods will be compared to help determine the most appropriate transformation (Indices through 2008.docx).

Miscellaneous Notes

The fall, winter, and spring yearly indices of abundance shared the same general trends, but the fall and spring indices were generally more variable than the winter index (Figures 14-16). The yearly indices of abundance estimated using an arithmetic mean, geometric mean, and delta approach shared the same general trends for each season (Figures 14-16). However, in the winter and spring surveys, the geometric mean was less variable and had less 'extreme' values than the arithmetic mean or delta approach. This result was caused by the arithmetic mean and delta approach being more sensitive to a few unusually high catch values in some years (results not shown) than the geometric mean. So, the extreme values and higher variation in the yearly indices estimated using the arithmetic mean and delta approach are likely not indicative of changes in abundance, and therefore the geometric mean may be preferred. This pattern was less evident in the fall survey, perhaps because mackerel are less available to the survey during this time of year and so few unusually high catches are ever recorded.

The yearly proportion of zeros tows was greater than 53% in all years for all surveys (i.e., fall, winter, and spring) and was generally greater than 60%. With 'zero-inflated' distributions like these, all three methods of estimating the yearly indices (i.e., arithmetic mean, geometric mean, and delta approach) may be inappropriate. Future research could be focused on developing an index that is more robust to a large proportion of zero observations. For example, the delta method (different from the delta approach mentioned above) is an option that estimates an index of abundance using a multiple step process. First, the probability of observing a non-zero catch in each year is modeled, likely with logistic regression. Second, the mean of the non-zero catches in each year is estimated, likely using a log transformation or some standardization process. Third, the yearly index of abundance is estimated by multiplying (adding in log space) the two components from steps one and two.

This essentially weights the means of the non-zero catches in each year by the probability of obtaining a positive catch. This method has been used to estimate an index of abundance for siscowet lake trout in Lake Superior using bycatch data from a survey designed to sample lean lake trout (Mata 2009).



Fall Survey
Proportion of Zero Tows
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
Winter Survey
Proportion of zero tows
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007

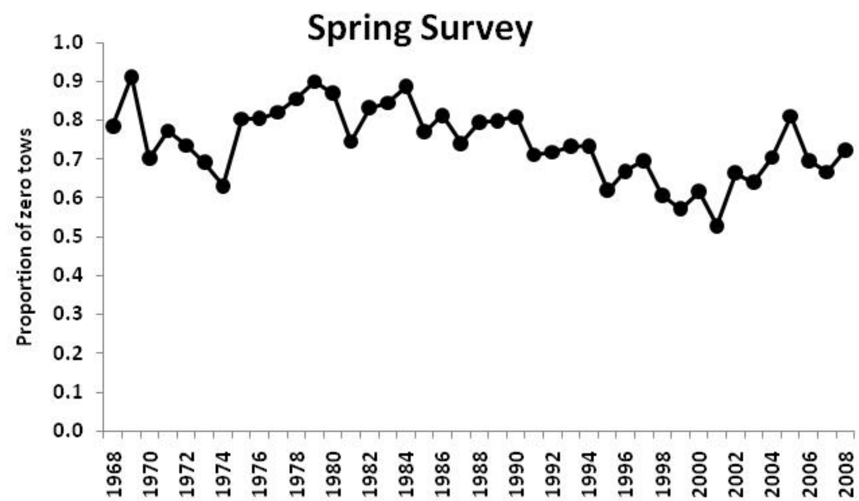
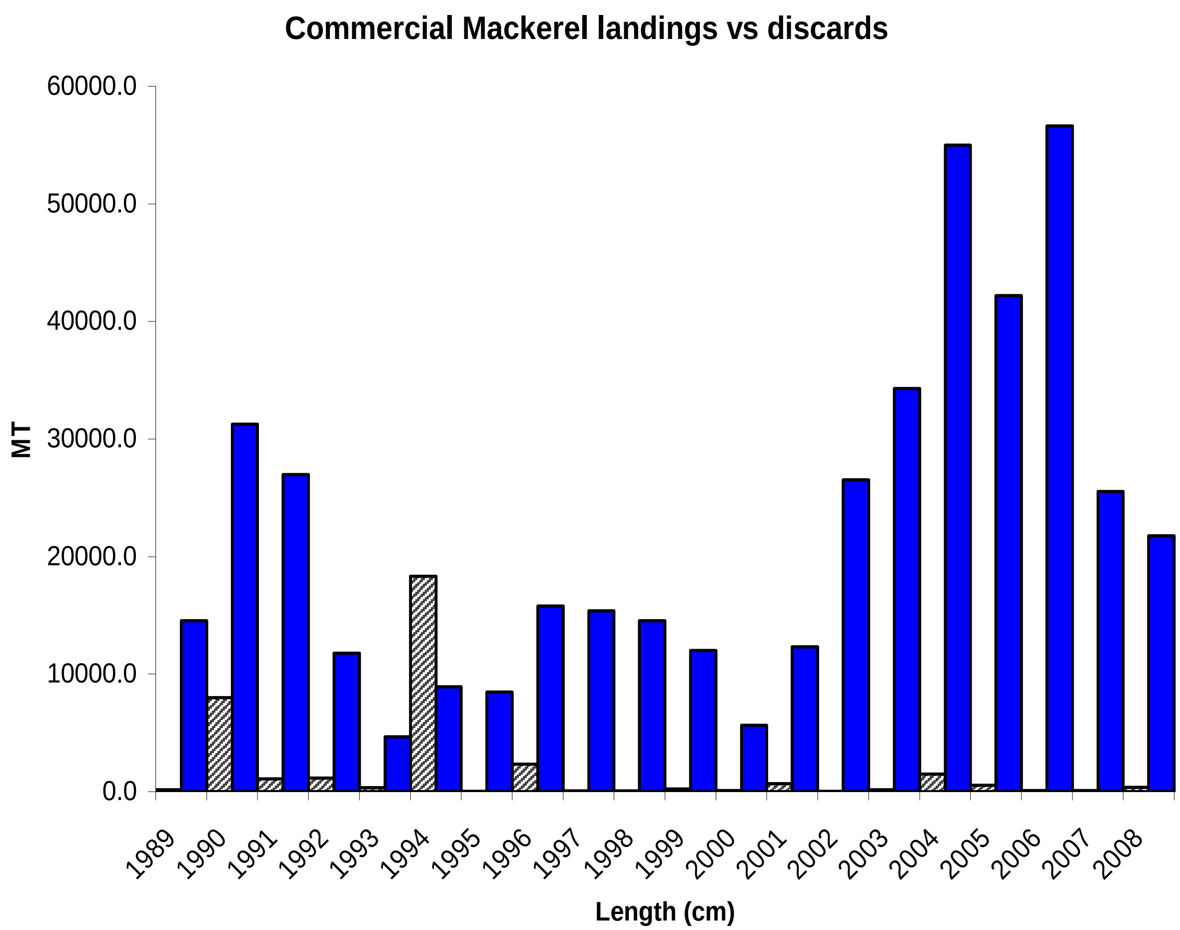


Figure 1. Proportion of zero tows for mackerel in each year from the fall, winter, and spring NMFS bottom trawl surveys.



Supplemental Figure 1. Commercial USA Atl. Mackerel landings vs USA discards.