Total mortality estimates for Spanish mackerel captured in the Gulf of Mexico commercial and recreational fisheries 1983 to 2011

Meaghan D. Bryan

SEDAR28-RD29

13 December 2012

Please cite as:

Bryan, M.D. 2012. Total mortality estimates for Spanish mackerel captured in the Gulf of Mexico commercial and recreational fisheries 1983 to 2011. SEDAR28-RD29. SEDAR, North Charleston, SC. 31 pp.

Total mortality estimates for Spanish mackerel captured in the Gulf of Mexico commercial and recreational fisheries 1983 to 2011

Meaghan D. Bryan
DOC/NOAA/NMFS
Southeast Fisheries Science Center
Miami, FL

August 2012

This report presents total mortality estimates for commercially and recreationally harvested Spanish mackerel for the Gulf of Mexico. Total mortality estimates were derived separately by fleet (i.e., commercial gill net, commercial line, and recreational). The approach made use of commonly used age and length based estimation methods including a traditional catch curve analysis, the Chapman-Robson catch curve analysis method (Chapman and Robson, 1960), and the Gedamke-Hoenig mean length estimator (Gedamke and Hoenig, 2006). The analyses made use of length sample and age observation data from the Southeast Fisheries Science Center's (SEFSC) Panama City Laboratory, the Trip Interview Program (TIP), the Marine Recreational Fisheries Statistical Survey (MRFSS/MRIP), and the Headboat Survey.

Data handling

The SEFSC's Panama City Laboratory provided data stratified by year, season, and fleet. Length composition data was obtained from the SEFSC TIP program and was stratified by year, season, and fleet in the same manner as the age composition samples. The fleets considered as part of this analysis were the gill net and line gear commercial fisheries, and the recreational fishery, which included the combined private angler, charter, and headboat sectors. Each length observation had a corresponding age estimate derived from otolith readings. The length data were binned in 2cm increments and were aggregated over time (years) to develop an age-length key for each species and fleet combination. Fleets were evaluated separately because of concerns relating to differential selectivities among fleets. The fleet-specific age-length keys yield the probability of fish falling within a certain length bin being of a particular age (i.e., the probability at age).

The fleet-specific age-length keys were then used to convert the TIP and MRFSS length data to age. The TIP and MRFSS length data were first binned in 2cm increments as was done with the Panama City Lab's age-length data. The annual numbers within each length bin were determined and multiplied by the corresponding vector of probabilities at age. This resulted in an annual estimate of the numbers at age for each fleet. All length measures used in this analysis were in millimeters fork length (FL).

Mortality Estimation

Catch curve analysis

Two catch curve models were used. First a linear regression was fit to the descending limb of the annual catch (in numbers) at age curve, where the slope of the line provided an estimate of annual total mortality. The second analysis was done using the Chapman-Robson method. The Chapman-Robson method estimates survival as:

$$S = \frac{T}{n+T-1} \quad (1)$$

where n is the number of fish observed on the descending limb of the catch curve and T is the total recoded age of fish on the descending limb. Ages were recoded, so that the age of full recruitment was set to zero. Age of first recruitment was identified by plotting the number of fish caught per age group. Age at first recruitment was three for the gill net fishery and one for the line and recreational fisheries. The maximum age was set to nine and represented a plus group of nine, 10, and 11 year olds. In general there were very few fished aged at 10 or11 years old for any of the three fleets.

Total mortality was then estimated from the survival estimate as:

$$Z = -log(S) \tag{2}$$

The standard error associated with Z was then calculated as:

$$SE_Z = \sqrt{\frac{(1-S)^2}{nS}} \tag{3}$$

Mean length estimator

Gedamke and Hoenig (2006) developed an extension of the Beverton-Holt length-based mortality estimator for use in non-equilibrium situations. The method requires minimal data inputs and utilizes information that is commonly available (e.g., length samples and von Bertalanffy growth parameters) and the approach allows for a broader application of a mean length analysis by removing the equilibrium assumption that is often difficult to meet in real world situations. The transitional form of the model also allows mortality estimates to be made within a few years of a change rather than having to wait for mean lengths to stabilize at their new equilibrium. In other words, as soon as a decline in mean lengths is detected, this model can estimate the new Z and quantify the magnitude and direction that mean length has changed over time.

The reader is referred to Gedamke and Hoenig (2006) for a detailed explanation of this method, but a brief description follows. The data requirements include estimates of the von Bertalanffy growth coefficient, asymptotic length, and a time series of mean lengths above a user defined length at full vulnerability value. Gedamke and Hoenig (2006) demonstrated the utility of the approach with simulated data and an application to the goosefish data from the Northeast Fisheries Science Center's (NEFSC) fall groundfish survey.

The following equation shows that the mean length of a population can be calculated d years after a single change in total mortality:

$$\bar{L} = L_\infty - \frac{Z_1 Z_2 (L_\infty - L_c)\{Z_1 + K + (Z_1 - Z_2) exp(-(Z_2 + K)d)\}}{(Z_1 + K)(Z_2 + K)\left(Z_1 + (Z_2 - Z_1) exp(-Z_2 d)\right)} \tag{4}$$

This equation allows for multiple changes in total mortality over time. The algorithm was programmed in AD Model Builder in a maximum likelihood framework and used to estimate total mortality rates from observed mean length data. The model is linked to Program R to conduct a grid search of potential years of change.

For the Spanish mackerel analyses, models were run starting with the simplest model (i.e., no change in total mortality) and then additional years of change were sequentially added. The additional years of change increases the complexity of the model, each year of change adds two parameters). Akaike information criterion with a correction for small sample size (AIC_c) was calculated for each model run. When comparing models, an AIC_c value that improved by 5 or more was deemed as providing strong support for the more complex model (Burnham and Anderson 2002).

The first step of applying this method is to determine the length at which fish become vulnerable to the fishing gear, L_c. L_c is assumed to be constant over time. The chosen value of L_c must be large enough, so that it is not confounded with changes in selectivity. Annual length-frequency and a cumulative length-frequency histograms were plotted for each species and fleet to visually choose L_c (see Figures 1-3 for the cumulative histograms). A range of L_c values were identified for each fleet. This was done to determine the sensitivity of the model to this chosen value.

Table 1 summarizes the L_c values and the von Bertalanffy growth parameters used for the analysis. The cumulative length-frequency plot for Spanish mackerel caught by the commercial gillnet fishery is misleading in terms of the choice of L_c (Figure 1). Figure 1 indicates that L_c for the commercial gillnet fishery is ~385mm FL. The annual length-frequency plots show that in most years L_c ~400mm FL (Figure 4). A size regulation of 12 inches FL was implemented in 1993. In 1993-1996, there was a shift in the length-frequency distribution towards larger fish (Figure 4). An L_c value of 385mm FL would, therefore, be confounded between selectivity and mortality. L_c values equal to 500mm FL, 550mmFL, and 575mm FL were chosen based on the annual length frequency plots and used to analyze the commercial gillnet fishery (Table 1). The annual sample sizes for the commercial line fishery were small; therefore, the cumulative length-frequency plot for the commercial line fishery was assumed representative of the annual length-frequencies and the following values, 545mm FL, 560 mm FL, and 585mm FL, were used for the analysis of this fishery (Table 1). The cumulative length-frequency plot for the recreational fishery is also somewhat missing leading with regard to the choice of L_c (Figure 3). In the majority of years the length-at-vulnerability is ~ 400mm FL, but after the implementation of the 12 inch FL size regulation there is a shift towards larger fish (Figure 5). In 1993-1996, the length-at-full vulnerability was equal to ~ 450mm - 500mm FL for the recreational fishery (Figure 5). The L_c values used in the analysis of the recreational fishery were 450mm FL, 500mm FL, and 550mm FL (Table 1).

The von Bertalanffy growth parameter values used to inform the model were those recommended by the data workshop life history work group for combined sexes, 0.61 for the von Bertalanffy growth coefficient and 601mm FL for the asymptotic length.

Results and discussion

Gill net fishery

Catch curve analyses

Annual total mortality estimates for the gill net fishery were similar between the two catch curve analytic approaches (Figure 6). Point estimates of total mortality from the regression method were between 0.59 and 1.16 (Figure 6). Point estimates from the Chapman-Robson method were between 0.6 and 1.05. Assuming that natural mortality is ~ 0.38, the average of the age-based natural mortality estimates that were recommended by the life history data working group, fishing mortality was between 0.21 and 0.78 and 0.22 and 0.67 for the regression and Chapman-Robson methods, respectively.

The total mortality estimates were initially estimated to be ~1 until 1992 (Figure 6). In 1993 a 12 inch size limit was implemented, which corresponds to declining estimates of total mortality between 1993 and 1995 (Figure 6). This period of lowered total mortality estimates was followed by an increase over the remaining years (Figure 6).

Mean length mortality estimator

Results from the mean length mortality estimator indicated that the model with the strongest support from AIC_c predicted that total mortality remained constant over time, irrespective of the L_c input value (Table 2, Figures 7 and 8). The point estimates of total mortality were larger for smaller L_c values; 0.658 (500mm), 0.337 (550mm), and 0.005 (575mm) (Table 2). Assuming natural mortality is ~ 0.38, the estimates of fishing mortality were 0.278 (L_c = 500mm) and essentially zero for L_c values of 550mm and 575mm. It should be mentioned that the L_c value, 575mm, closely approaches the recommended asymptotic length value, 601mm (a difference of 30mm or 1.2 inches), and in turn the annual mean lengths were similar to the assumed asymptotic length (Figures 7 and 8). This forced the model to estimate a negligible total mortality to explain a population saturated with larger (older individuals).

The total mortality estimates from the model run using an L_c input value equal to 550mm was 48% lower than the model run using an L_c input value equal to 450mm. The relative difference in the total mortality estimates resulting from the mean length estimator using 500mm as the L_c input value was between 0% and 45% lower than the estimates from the catch curve analysis. The relative difference in the total mortality estimates resulting from the from the mean length estimator using 550mm as the L_c input value was between 48% and 71% lower than the estimates from the catch curve analysis.

Line gear fishery

Catch curve analyses

Annual total mortality estimates from the regression based catch curve analysis ranged between 1.25 and 2.25 (Figure 9). The highest estimates of total mortality were seen in 1984 and 1997 (Figure 9). In comparison, the annual total mortality estimates from the Chapman-Robson method were close to one for the entire time series. The variance associated with the point estimates from the regression method was quite large and the error bars overlapped those associated with the Chapman-Robson method indicating that there were no significant differences between annual total mortality estimates (Figure 9).

Mean length mortality estimator

The most parsimonious mean length mortality model according to AIC_c criteria was one where total mortality remained constant over time, irrespective of the input L_c value applied to the model (Table 3). Estimates of total mortality were equal to 0.21, 0.11, and 0.001 for L_c values equal to 545mm FL, 560mm FL, and 585mm FL, respectively (Table 3). The total mortality estimates from the mean length estimator were significantly lower than those estimated by either catch curve analysis method (Figure 9). Assuming that natural mortality is equal to 0.38, the resulting fishing mortality estimates are negative values (i.e., F=0).

It is suggested that the reader look at the cumulative length frequency curve (Figure 2). One will notice that the majority of observations are to the left of L_c input values. Reducing L_c to a value lower than 545mm was not considered as the resulting estimates of Z would have been confounded with changes in selectivity. The L_c input values used for the analysis effectively reduce the number of annual length observations to very few and causing the annual mean length estimates to be approximately equal to the asymptotic length and constant over time. Figure 10 shows the fit of the mean length estimator when the Lc input value was equal to 560mm. The mean lengths are generally within 25mm of the asymptotic length. This was also true for the other model runs (not shown here). Given that the mean lengths were similar to the asymptotic length, the model was forced to estimate a low total mortality value to explain how the population remained at a very high annual mean length.

Recreational fishery

Catch curve analyses

Point estimates of annual total mortality from the regression based catch curve analysis ranged between 0.65 and 1.0 resulting in fishing mortality estimates between 0.27 and 0.62 (Figure 11). Point estimates from the Chapman-Robson method ranged between 0.5 and 0.8 resulting in fishing mortality estimates between 0.12 and 0.42 (Figure 11). Total mortality estimates were higher before 1985 than after for both catch curve analyses (Figure 11).

Mean length mortality estimator

The number of predicted changes in total mortality for the recreational fishery was dependent on the L_c input value (Table 4). The most parsimonious model, when an L_c input value equal to 450mm was used, predicted two changes in total mortality; this was strongly supported by AIC_c criteria (Table 4). Mortality was predicted to change in 1985 where the total mortality estimate was 0.998 prior to 1985, 0.640 between 1985 and 2003, and 0.899 after 2003 (Table 4). This corresponds to a general increase in mean size that starts in 1985, mean length stabilizing in 1995, and mean length declining in 2003 (Figure 12a). This likely represents a shift in selectivity rather than mortality. The number of larger individuals in the TIP samples increased between 1987 and 2003. It should be noted that during this period of time a 12 inch size limit was implemented, which may have caused a shift in selectivity to avoid catching sub-legal fish. The L_c value, 450mm, represents the lower bound of the sensitivity range evaluated and may be confounded with selectivity given there are one or two years where L_c is higher. The result, therefore, may reflect a change in selectivity rather than mortality.

When an L_c input value of 500mm was used, model selection criteria strongly supported models predicting two and three changes in total mortality (Table 4). Given that the AICc values for these models were close in value, the most parsimonious model is one that predicted two changes in total mortality (Table 4, Figure 12b). Prior to 1988 total mortality was estimated to be equal to 0.567, between 1988 and 1991 the total mortality was estimated to be equal to 0.001, and after 1991 the total mortality was estimated to be 0.550 (Table 4). Conversely the model predicting no change in total mortality was most strongly supported when an L_c input value of 575mm was used (Table 4). The model run using an L_c input value equal to 575mm resulted in annual mean lengths that were similar or above the asymptotic length input value. This forced the model to estimate a low total mortality value to explain a population saturated with larger (older individuals).

Conclusions

The morality estimates from the catch curve analysis methods and the mean length estimator provide a range of total mortality estimates characterized by considerable uncertainty. Each analytic approach used assumed that the age-at-recruitment (catch curve analysis) and the length-at-recruitment are constant over time. Given the implementation of a size regulation in 1993, it would be expected that these assumptions would be violated. This assumption made it difficult to choose a length-at-recruitment that was not confounded with selectivity and not so large that the mean length time series remained at the asymptotic length. A length-at-recruitment value approximating the asymptotic length led to total mortality estimates that indicated the Spanish mackerel population experienced minimal mortality. Although the mean length estimator was the preferred analytical method because it does not assume equilibrium conditions the problems with changing selectivity and an asymptotic length value that approximates a reasonable length-at-recruitment value indicates that the mortality estimates from this analysis should be interpreted cautiously.

The catch curve analyses also assume that the age-of –recruitment is constant. A size regulation was implemented in 1993, with this size regulation it would be expected that the age-at-recruitment would change towards older individuals. The variability in the age-length relationship was quite large, therefore, the age-at-recruitment input values used may encompass the shift towards larger individuals, but would also encompass smaller individuals. This may potentially bias the total mortality estimates towards larger values due to confounding with changing selectivity. It is therefore recommended that the total mortality estimates be interpreted with caution and in consideration of this caveat.

References

Burnham , K.P. and D.R. Anderson. 2002. Model selection and multi-model inference: A practical information-theoretic approach.

Chapman, D. G. and D. S. Robson. 1960. The analysis of a catch curve. Biometrics 16:354{368.

Gedamke, T., and J.M. Hoenig. 2006. Estimating Mortality from Mean Length Data in Nonequilibrium Situations, with Application to the Assessment of Goosefish (Lophius americanus). Trans. Amer. Fish. Soc. 135:476-487.

Table 1. Summary of the length at full vulnerability values (L_c) and the von Bertalanffy growth parameters applied to the mean length estimation approach.

Fleet	L_c (mm FL)	von Bertalanffy growth coefficient	Asymptotic length (mm FL)
Gill net	500	0.61	601
	550		
	575		
Line gear	545	0.61	601
	560		
	585		
Recreational	450	0.61	601
	500		
	550		

Table 2. AIC_c results and total mortality estimates for the model runs for the commercial gill net fishery under three different length at full vulnerability, L_c, values. vBk is the von Bertalanffy growth coefficient, Linf is the asymptotic length, Npar is the number of parameters, Nobs is the number of observations, AIC_c is the Akaike Information Criteria with correction for small sample size, LLike is the log-likelihood, Z is total mortality, and Z1, Z2, and Z3 are total mortality estimates for time periods 1, 2, and 3. *Smallest AICc value. ** $\Delta_{AIC} < 2$ indicating substantial support for the model (Burnham and Anderson, 1998).

Fleet	Lc	vBk	Linf	# of Changes	Npar	Nobs	AIC_c	Δ_{AIC}	LLike	Z	Z1	Change Year1	Z2	Change Year2	Z3	Change Year3	Z4
Gill net	500	0.61	601	0**	2	24	193.008	0.547	94.218	0.658	-	-	-	-	-	-	-
				1	4	24	196.514	4.053	93.205	-	0.590	2003	0.715	-	-	-	-
				2*	6	24	192.461	0.000	87.760	-	0.699	1994	0.001	1996	0.693	-	-
				3	8	24	198.263	5.802	86.332	-	0.694	1994	0.001	1996	3.108	1998	0.682
Gill net	550	0.61	601	0*	2	22	152.698	0.000	74.033	0.337	-	-	-	-	-	-	-
				1	4	22	158.047	5.349	73.847	-	0.329	2008	0.425	-	-	-	-
				2	6	22	162.849	10.151	72.625	-	0.382	1994	0.001	1996	0.347	-	-
				3	8	22	170.654	17.956	71.788	-	0.317	1992	0.661	1994	0.001	1996	0.344
Gill net	575	0.61	601	0*	2	21	144.393	0.000	69.863	0.005	-	-	-	-	-	-	-
				1	4	21	149.301	4.908	69.401	-	0.001	1995	0.271	-	-	-	-
				2	6	21	156.507	12.114	69.254	-	0.001	2004	1.947	2006	0.001	-	-
				3	8	21	166.507	22.114	69.254	-	0.001	1987	0.001	2004	1.947	2006	0.001

Table 3. AIC_c results and total mortality estimates for the model runs for the commercial line gear fishery under three different length at full vulnerability (L_c) values. vBk is the von Bertalanffy growth coefficient, Linf is the asymptotic length, Npar is the number of parameters, Nobs is the number of observations, AIC_c is the Akaike Information Criteria with correction for small sample size, LLike is the log-likelihood, Z is total mortality, and Z1, Z2, and Z3 are total mortality estimates for time periods 1, 2, and 3. *Smallest AICc value. ** Δ_{AIC} < 2 indicating substantial support for the model (Burnham and Anderson, 1998).

Fleet	Lc	vBk	Linf	# of Changes	Npar	Nobs	AIC_c	Δ_{AIC}	LLike	Z	Z1	Change Year1	Z2	Change Year2	Z3	Change Year3	Z4
Line	545	0.61	601	0*	2	25	259.93	0.00	127.69	0.21	-	-	-	-	-	-	-
				1	4	25	265.06	5.13	127.53	-	0.09	1985	0.28	-	-	-	-
				2	6	25	271.44	11.51	127.39	-	0.012	1987	1.65	1989	0.23	-	-
				3	8	25	279.72	19.79	127.36	-	0.003	1987	2.58	1989	0.001	1992	0.24
Line	560	0.61	601	0*	2	24	253.58	0.00	124.50	0.11	-	-	-	-	-	-	-
				1	4	24	259.01	5.43	124.45	-	0.05	1983	0.17	-	-	-	-
				2	6	24	265.42	11.84	124.24	-	0.001	1987	2.77	1989	0.09	-	-
				3	8	24	274.07	20.49	124.24	-	0.001	1987	2.72	1989	0.13	2005	0.001
Line	585	0.61	601	0*	2	24	268.08	0.00	131.75	0.001	-	-	-	-	-	-	-
				1	4	24	273.61	5.53	131.75	-	0.001	1983	0.001	-	-	-	-
				2	6	24	280.45	12.37	131.75	-	0.001	1983	0.001	1985	0.001	-	-
				3	8	24	289.11	21.03	131.75	-	0.001	1983	0.001	1985	0.001	1987	0.001

Table 4. AIC_c results and total mortality estimates for the model runs for the recreational fishery under three different length at full vulnerability (L_c) values. vBk is the von Bertalanffy growth coefficient, Linf is the asymptotic length, Npar is the number of parameters, Nobs is the number of observations, AIC_c is the Akaike Information Criteria with correction for small sample size, LLike is the log-likelihood, Z is total mortality, and Z1, Z2, and Z3 are total mortality estimates for time periods 1, 2, and 3. *Smallest AICc value. ** Δ_{AIC} < 2 indicating substantial support for the model (Burnham and Anderson, 1998).

Fleet	Lc	vBk	Linf	# of Changes	Npar	Nobs	AIC_c	Δ_{AIC}	LLike	Z	Z1	Change Year1	Z2	Change Year2	Z3	Change Year3	Z4
Rec	450	0.61	601	0	2	31	222.497	18.198	109.034	0.718	-	-	-	-	-	-	-
				1	4	31	211.566	7.267	101.014	-	0.665	2003	0.894	-	-	-	-
				2*	6	31	204.299	0.000	94.399	-	0.995	1985	0.640	2003	0.899	-	-
				3**	8	31	204.584	0.285	91.019	-	0.707	1982	1.923	1984	0.639	2003	0.899
Rec	500	0.61	601	0	2	31	232.156	3.968	113.864	0.506	-	-	-	-	-	-	-
				1*	4	31	228.188	0.000	109.325	-	0.459	2003	0.703	-	-	-	-
				2**	6	31	229.888	1.700	107.194	-	0.567	1988	0.001	1991	0.550	-	-
				3**	8	31	228.929	0.741	103.192	-	0.565	1988	0.028	1991	0.521	2008	0.970
Rec	550	0.61	601	0**	2	31	268.325	1.726	131.948	0.084	-	-	-	-	-	-	-
				1*	4	31	266.599	0.000	128.530	-	0.001	1983	0.303	-	-	-	-
				2	6	31	271.034	4.435	127.767	-	0.001	1995	1.774	1998	0.196	-	-
				3	8	31	277.654	11.055	127.554	-	0.001	1996	2.867	1998	0.001	2002	0.280

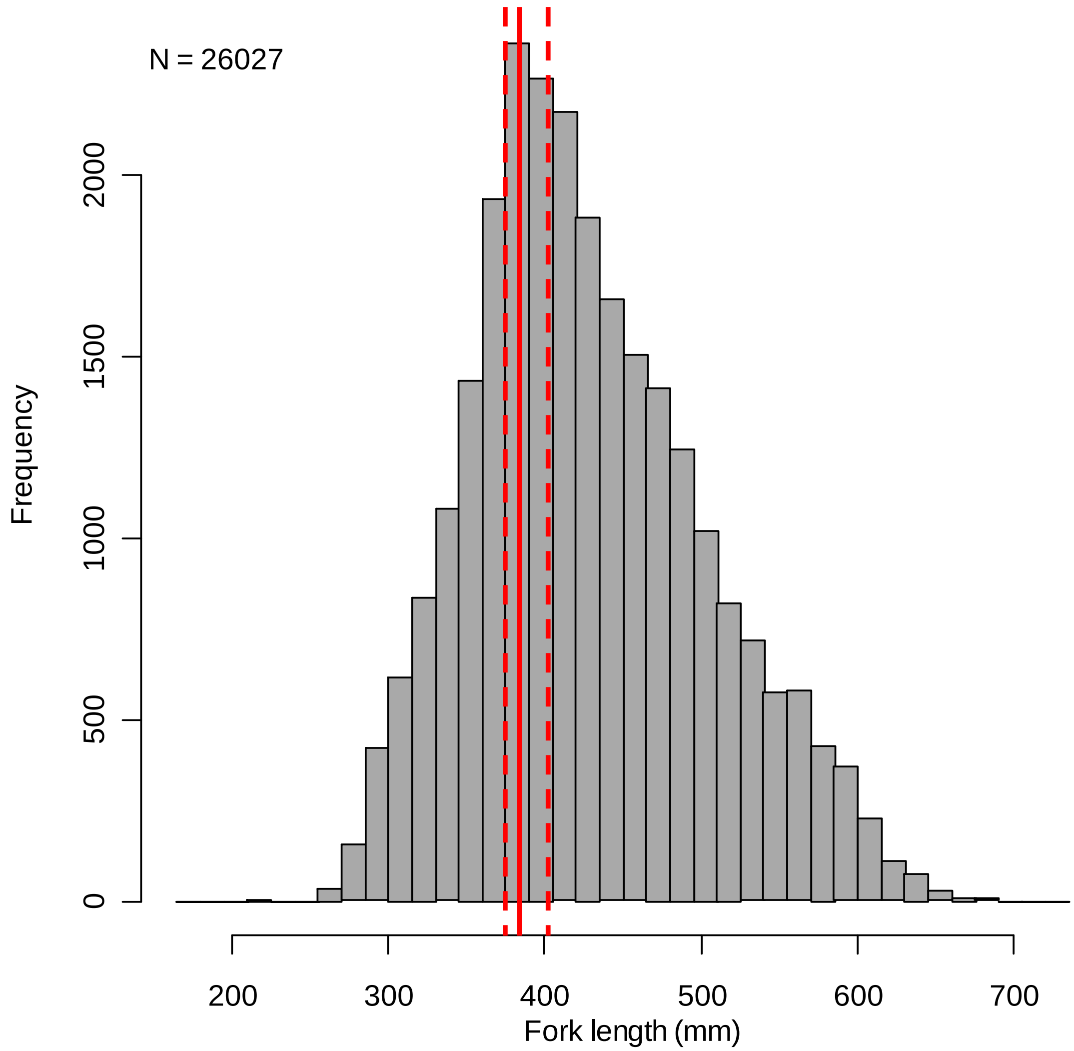


Figure 1. Cumulative length-frequency histogram for Spanish mackerel captured in the Gulf of Mexico. Data were obtained from the TIP database and represent the commercial gill net fishery. Length bins are in increments of 15mm FL. The red line signifies the length bin with the highest frequency of observations from which L_c is based.

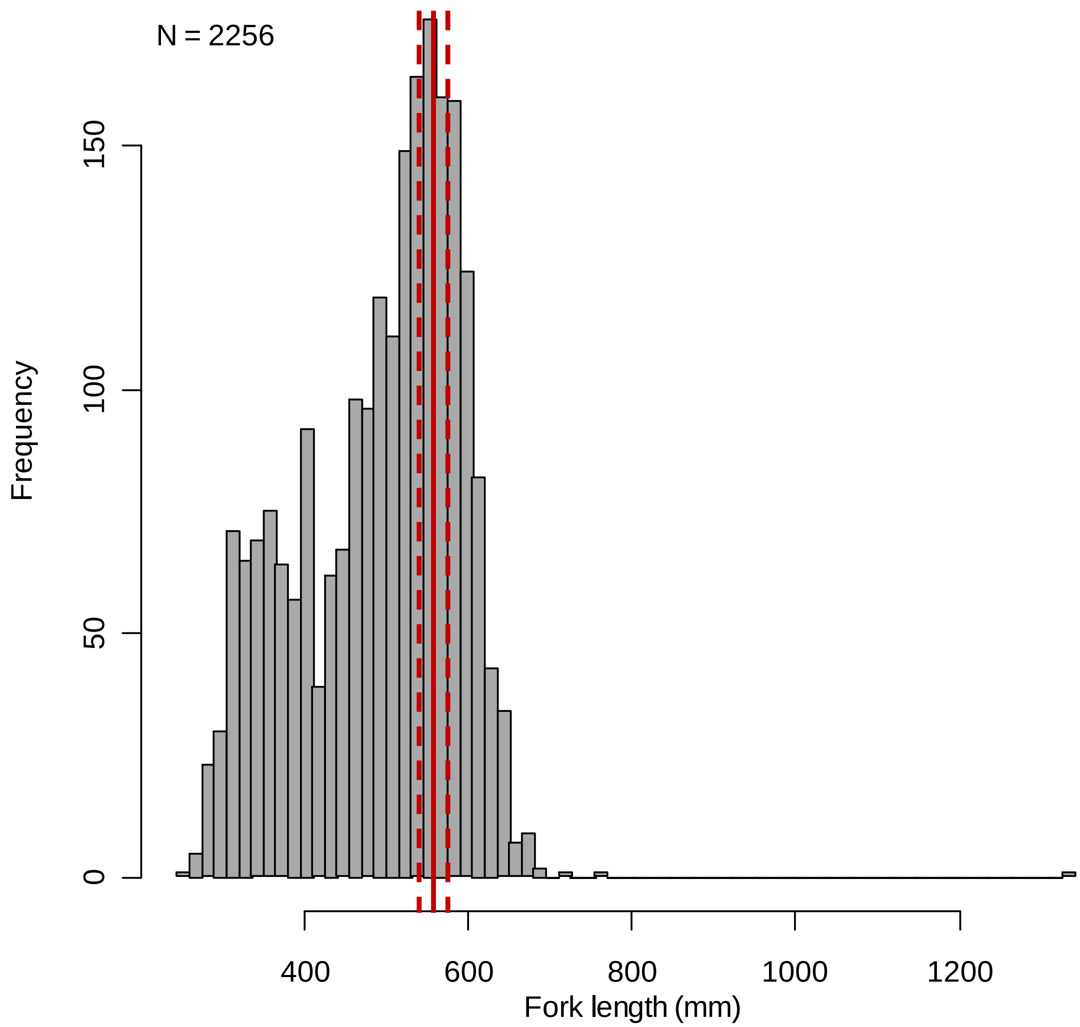


Figure 2. Cumulative length-frequency histogram for Spanish mackerel captured in the Gulf of Mexico. Data were obtained from the TIP database and represent the commercial line gear fisheries. Length bins are in increments of 15mm. The red line signifies the length bin with the highest frequency of observations from which L_c is based.

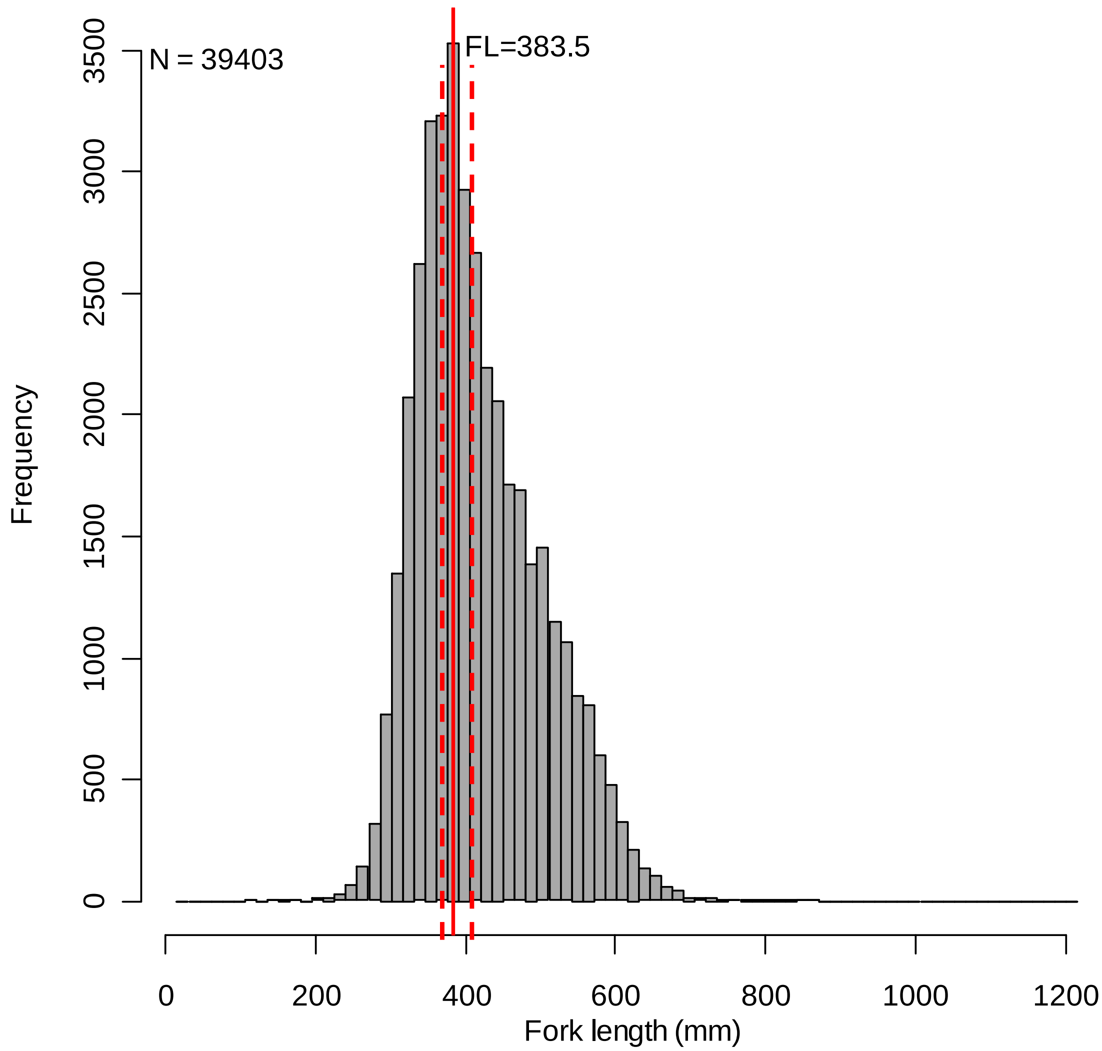


Figure 3. Cumulative length-frequency histogram for Spanish mackerel captured in the Gulf of Mexico. Data were obtained from the MRFSS and Headboat databases and represent the recreational fishery. Length bins are in increments of 15mm. The red line signifies the length bin with the highest frequency of observations from which L_c is based.

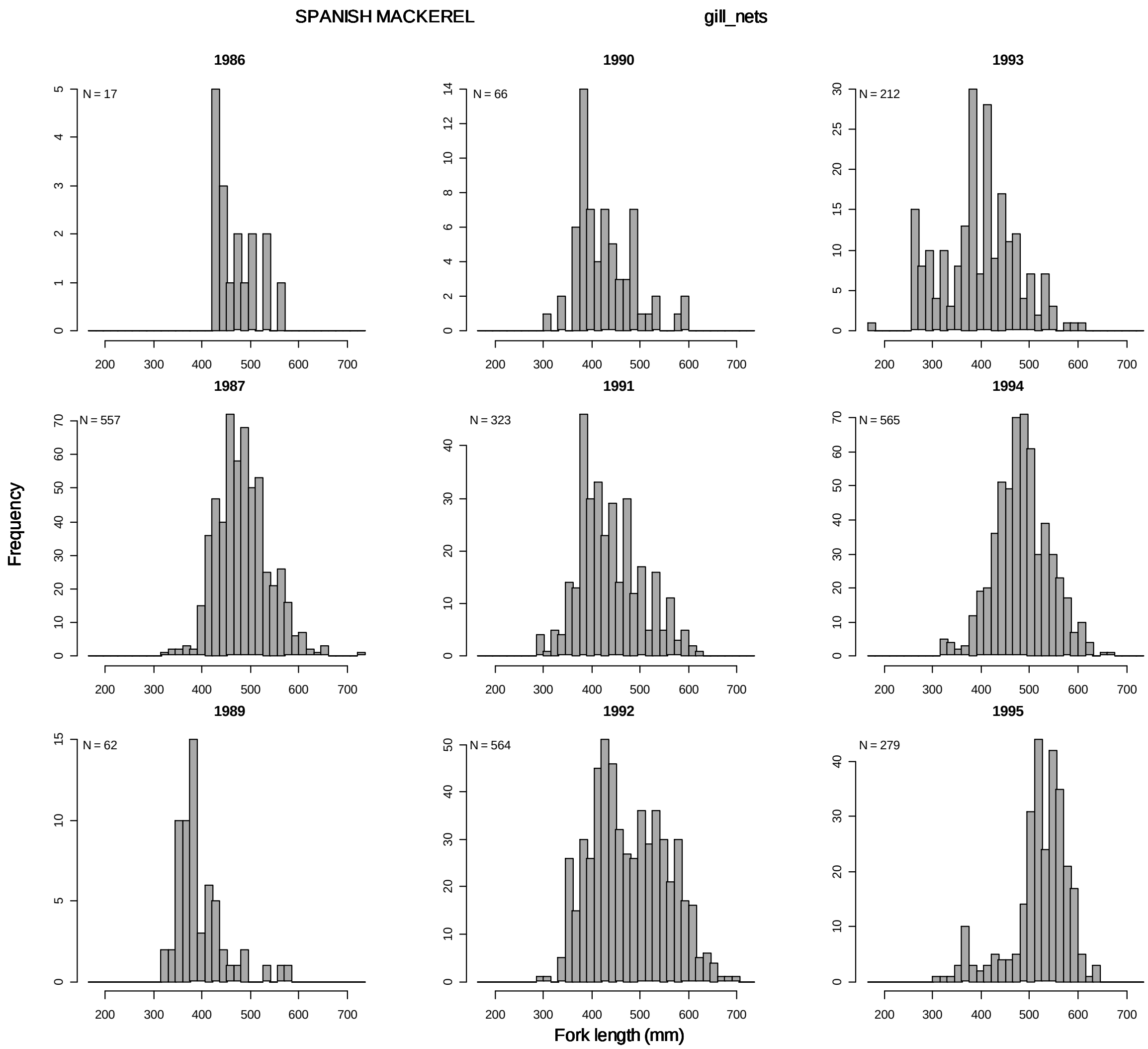


Figure 4. Annual length frequency histograms for Spanish mackerel captured by the commercial gillnet fishery in the Gulf of Mexico. Length bins are in increments of 15mm. Years 1986-1995 are shown here. Years are chronologically ordered by column.

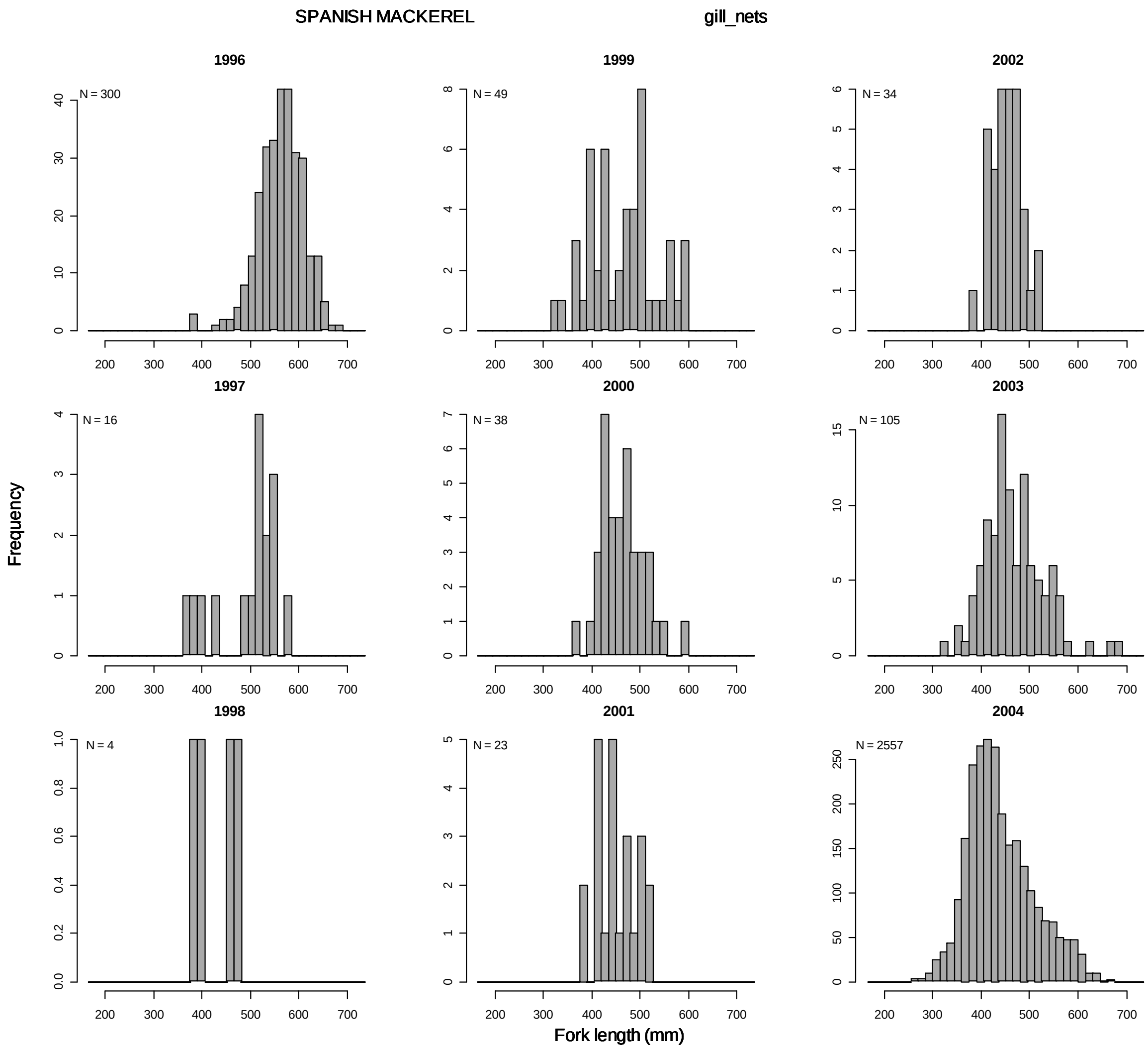


Figure 4 continued. Years 1996-2004 are shown here. Years are chronologically ordered by column.

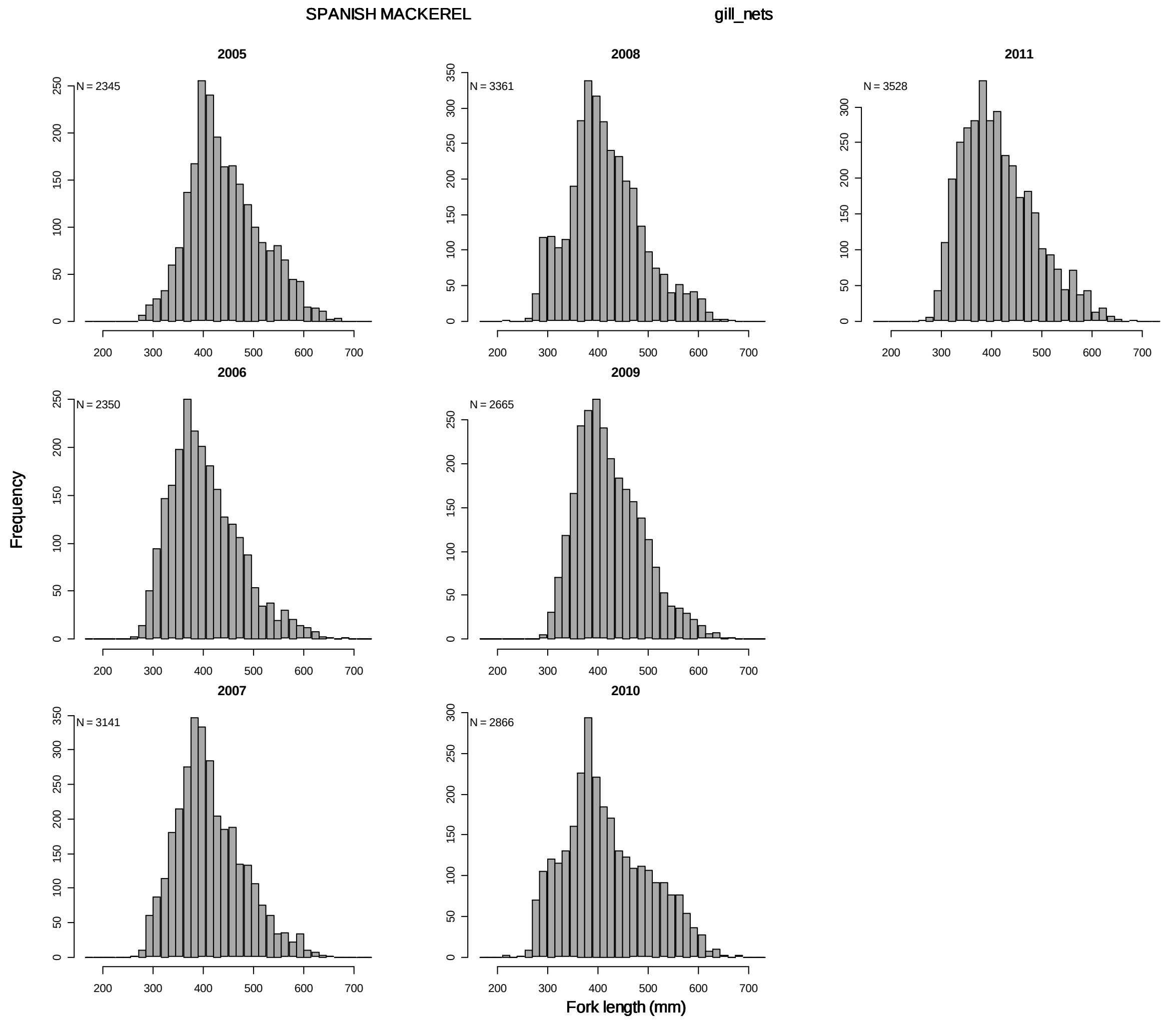


Figure 4 continued. Years 2005-2011 are shown here. Years are chronologically ordered by column.

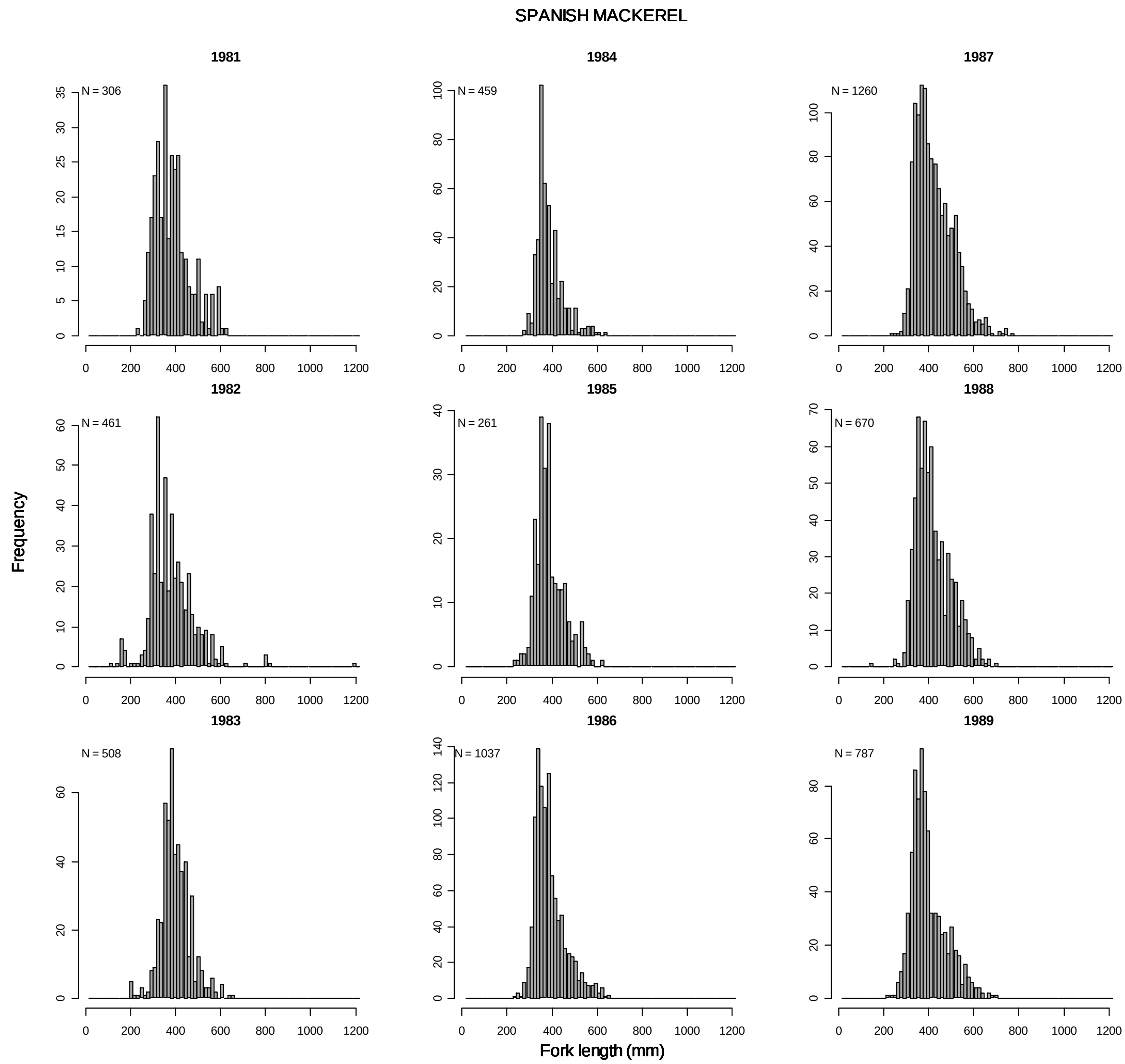


Figure 5. Annual length frequency histograms for Spanish mackerel captured by the recreational fishery (data from MRFSS and Headboat survey) in the Gulf of Mexico. Length bins are in increments of 15mm. Years 1981-1989 are shown here. Years are chronologically ordered by column.

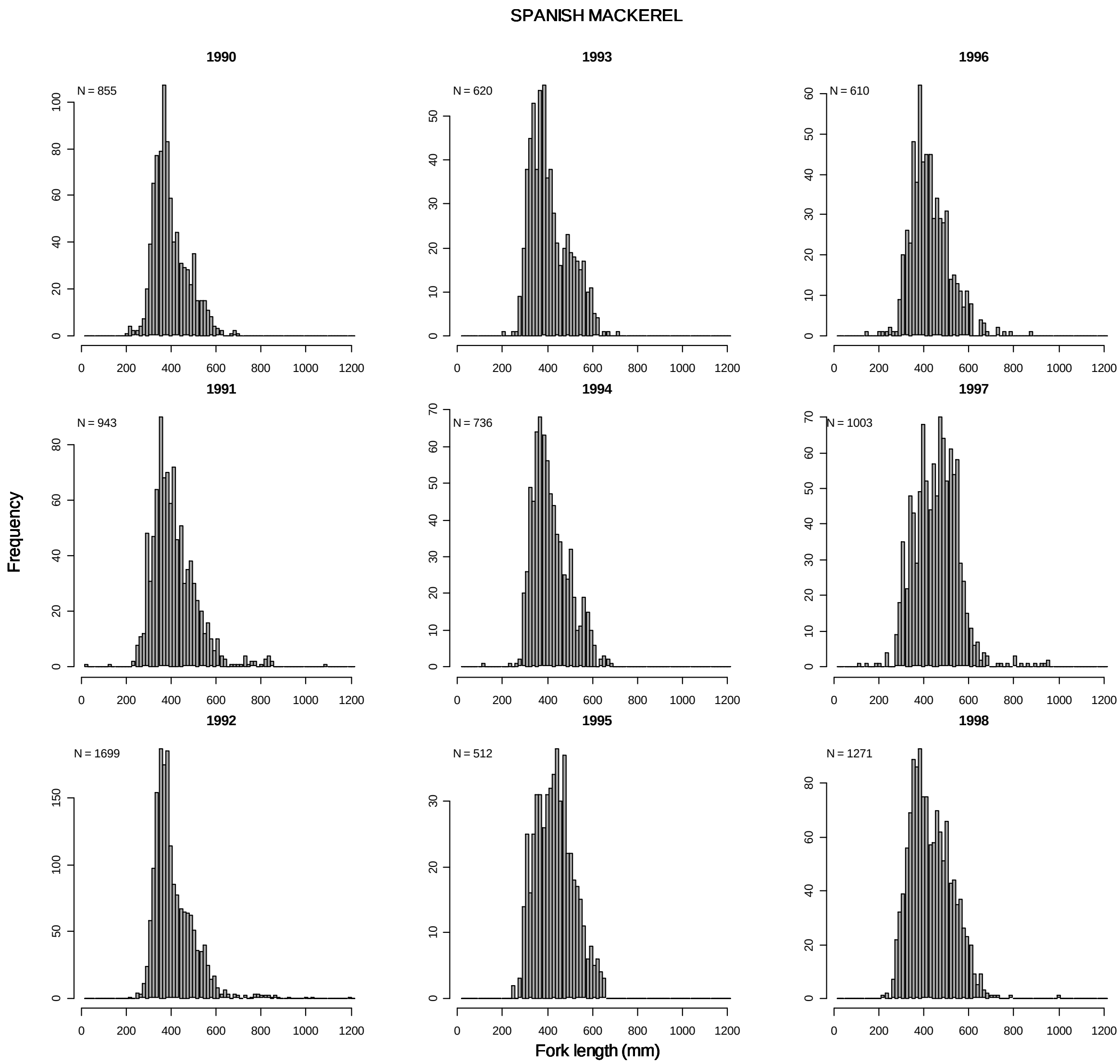


Figure 5 continued. Years 1990-1998. Years are chronologically ordered by column.

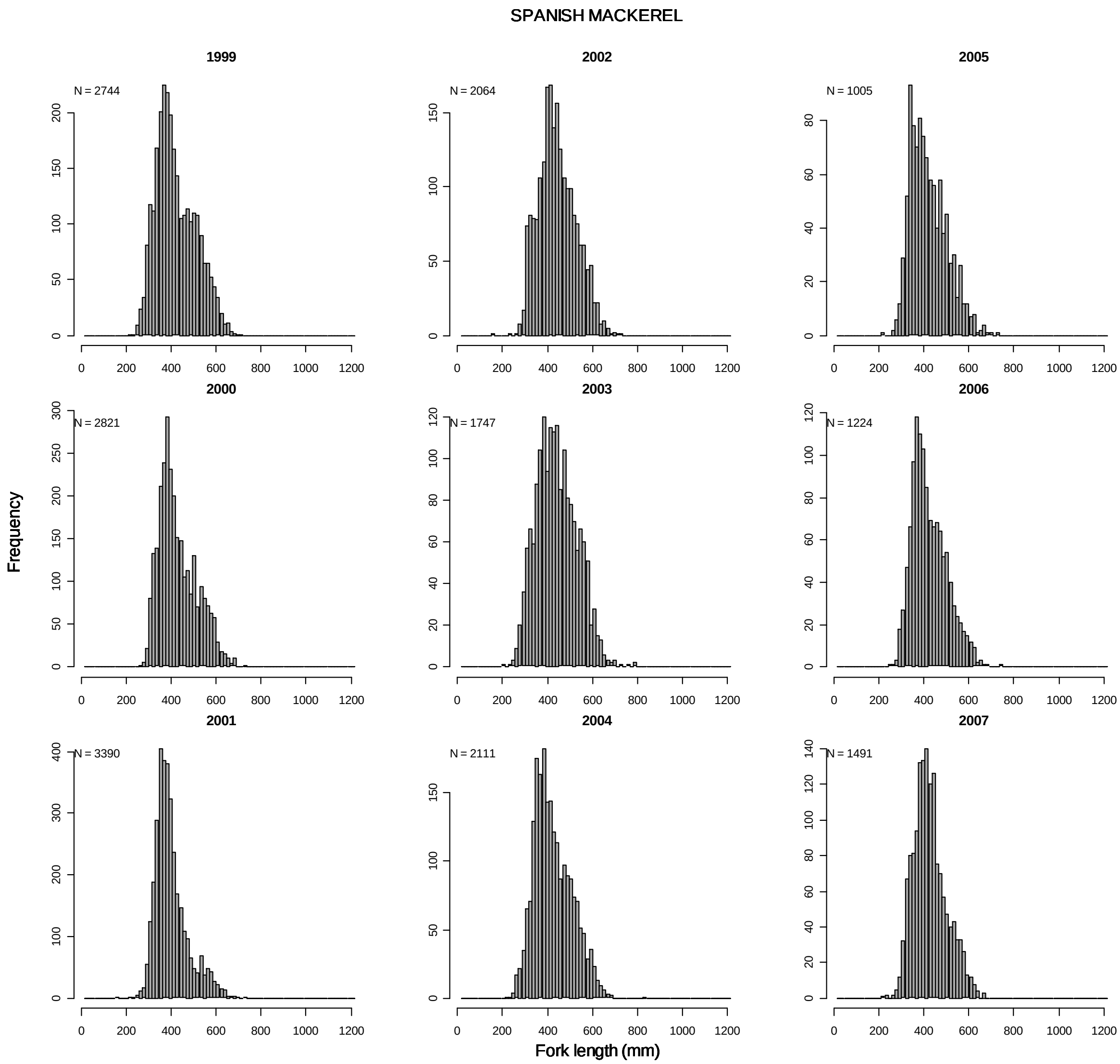


Figure 5 continued. Years 1999-2007. Years are chronologically ordered by column.

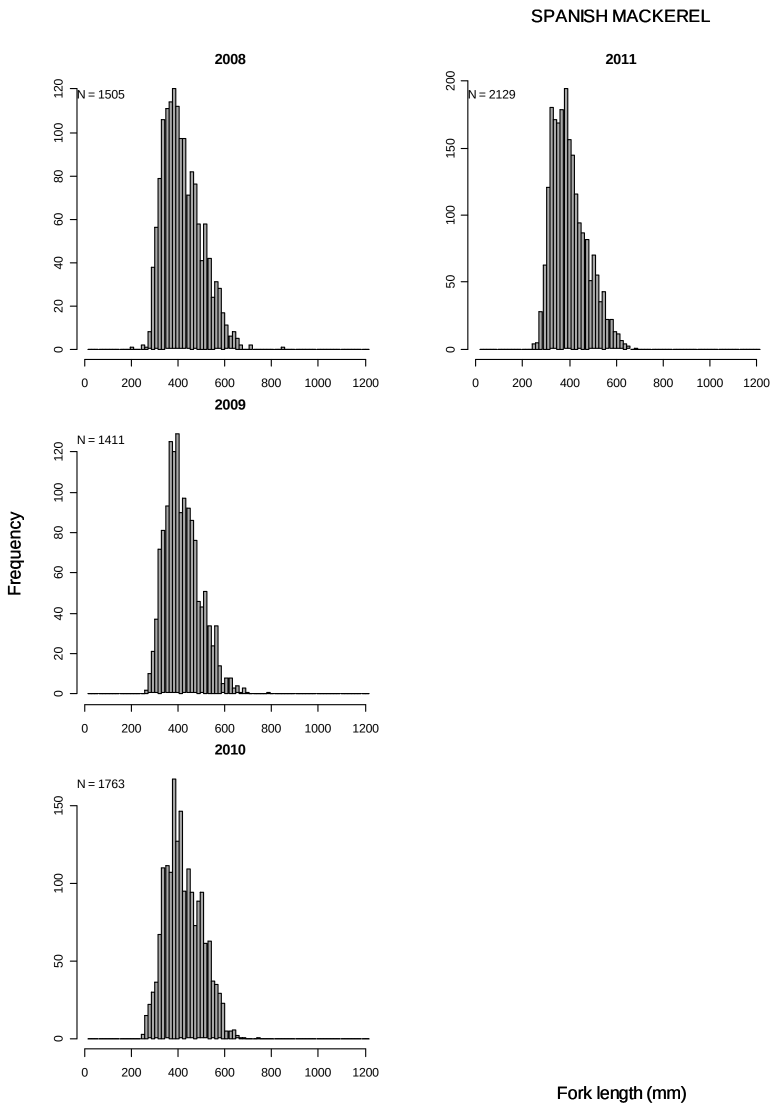


Figure 5 continued. Years 2008-2011. Years are chronologically ordered by column.

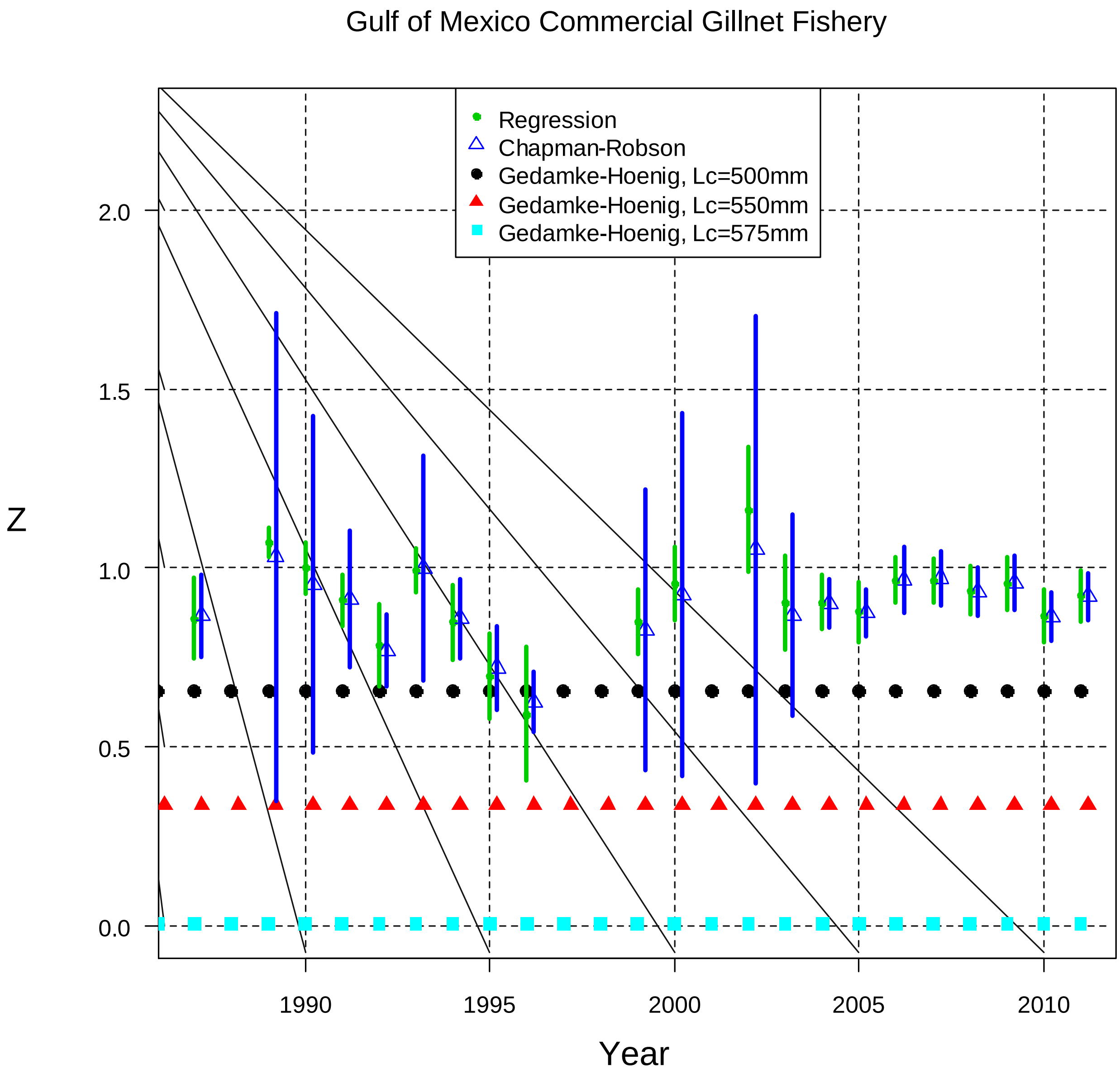


Figure 6. Annual total mortality estimates for three different methods: 1) regression method, 2) Chapman – Robson catch curve analysis, and 3) the mean length estimator for Spanish mackerel captured in the Gulf of Mexico by the gill net fishery**.**

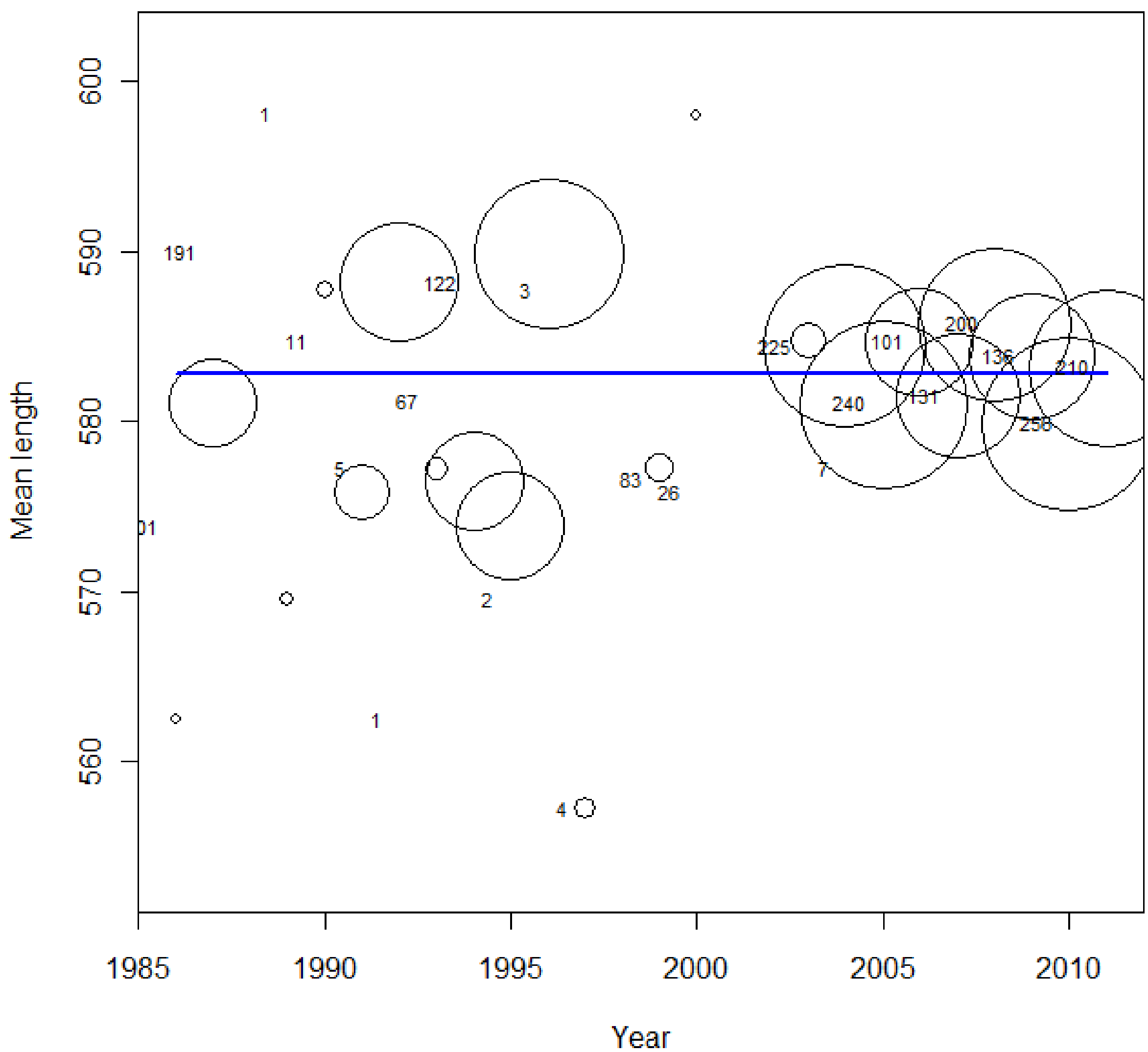
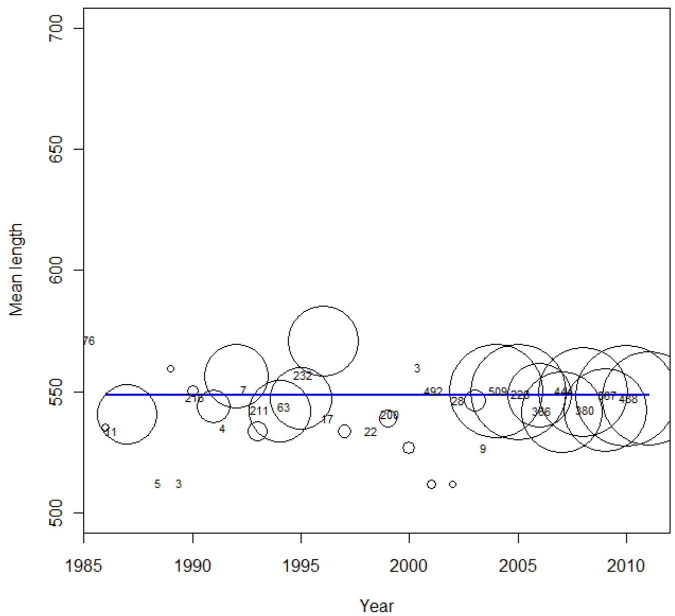


Figure 7. Annual mean length time series for Spanish mackerel captured by the Gulf of Mexico commercial gill net fishery. Annual mean length was calculated with an assumed value of length at full vulnerability, *Lc*, equal to 550mm FL. The model fit is represented by the solid blue line and is shown for a model predicting two changes in mortality in 1993 and 1996.

a)



b)

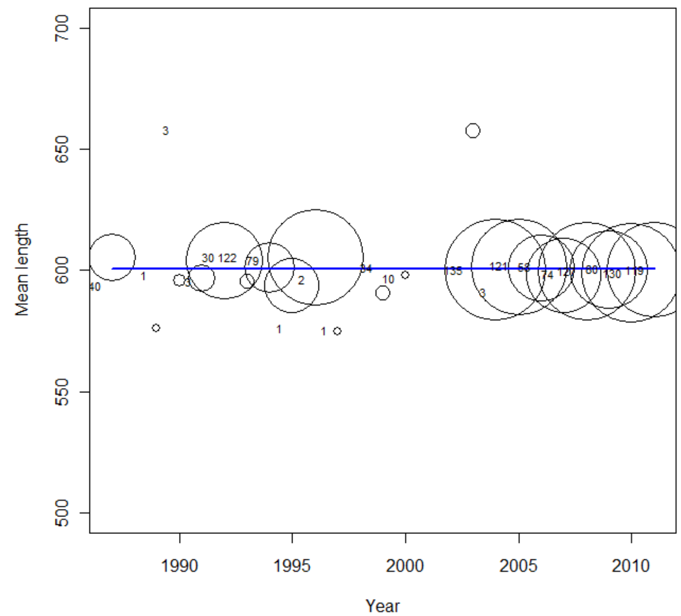


Figure 8. Annual mean length time series for Spanish mackerel captured by the Gulf of Mexico gill net fishery. Annual mean length was calculated with an assumed value of length at full vulnerability, *Lc*, equal to a) 500mm FL and b) 575mm FL. The solid blue line represents the model fit. Bubble size indicates the annual number of interviews used to calculate the observed mean length.

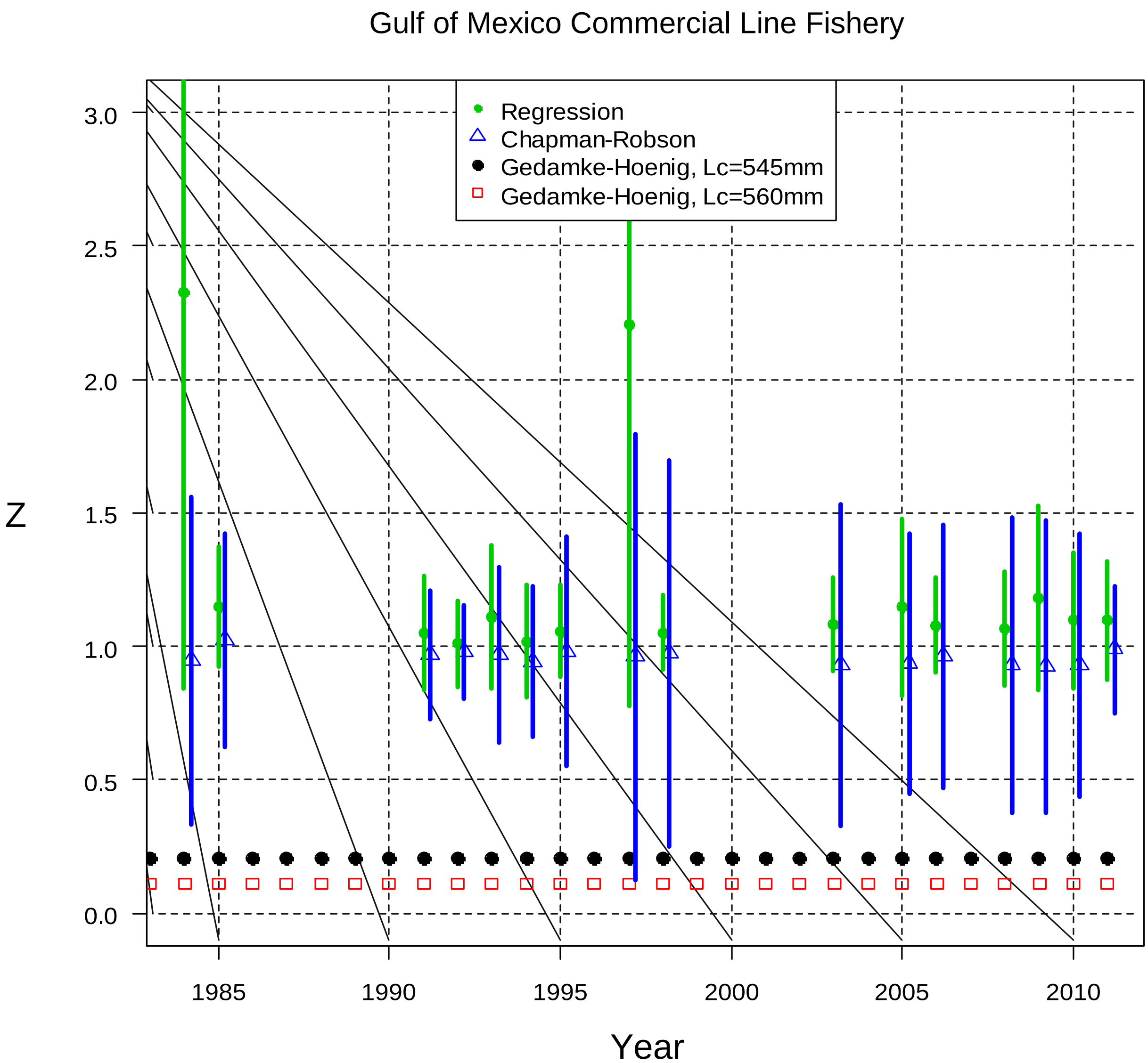


Figure 9. Annual total mortality estimates for three different methods: 1) regression method, 2) Chapman – Robson catch curve analysis, and 3) the mean length estimator for Spanish mackerel captured in the Gulf of Mexico by the commercial line fishery.

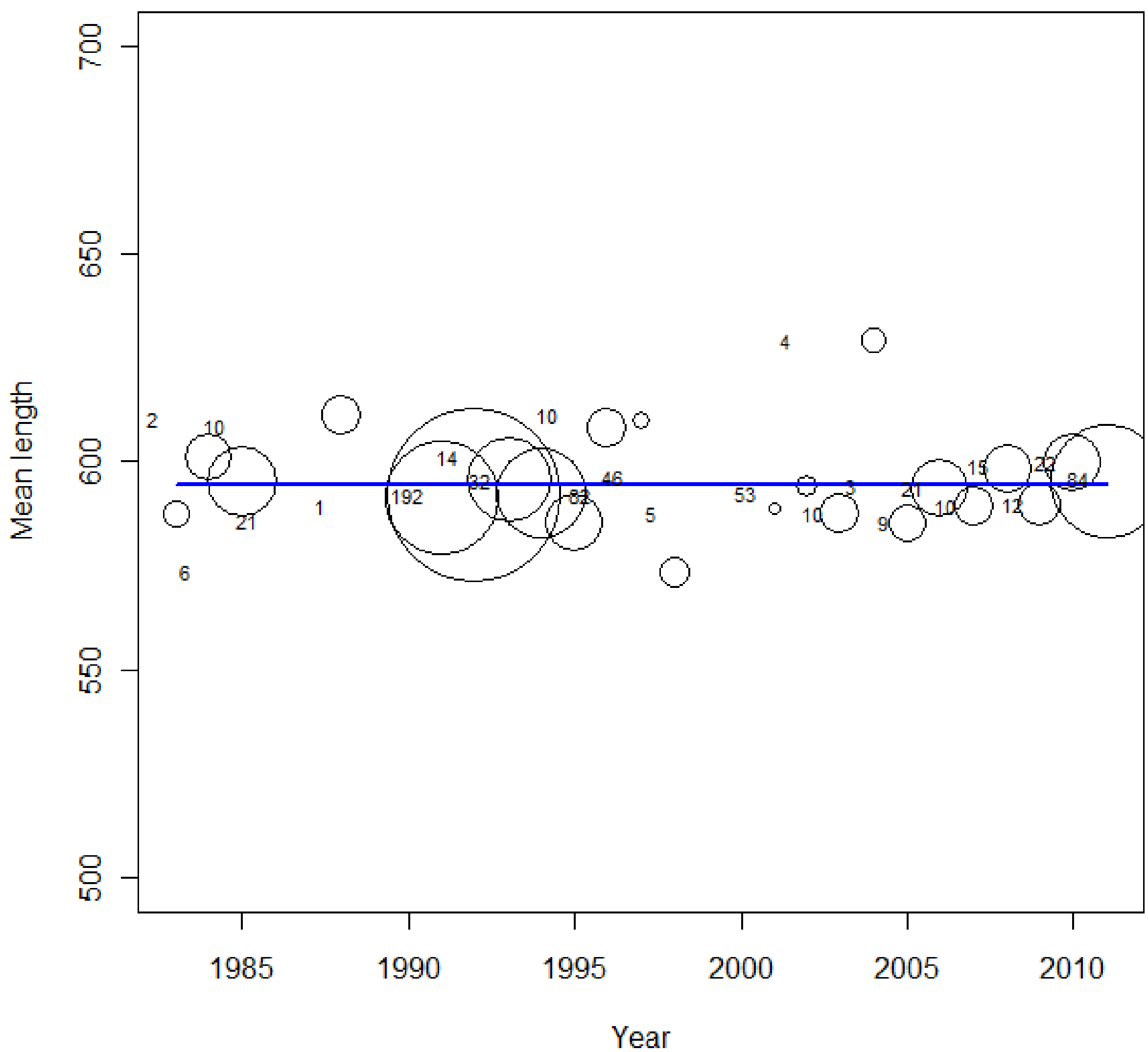


Figure 10. Annual mean length time series for Spanish mackerel captured by the Gulf of Mexico line gear fisheries. Annual mean length was calculated with an assumed value of length at full vulnerability, *Lc*, equal to 560mm FL. The model fit is represented by the solid blue line and is for a model that predicts total mortality is constant over time.

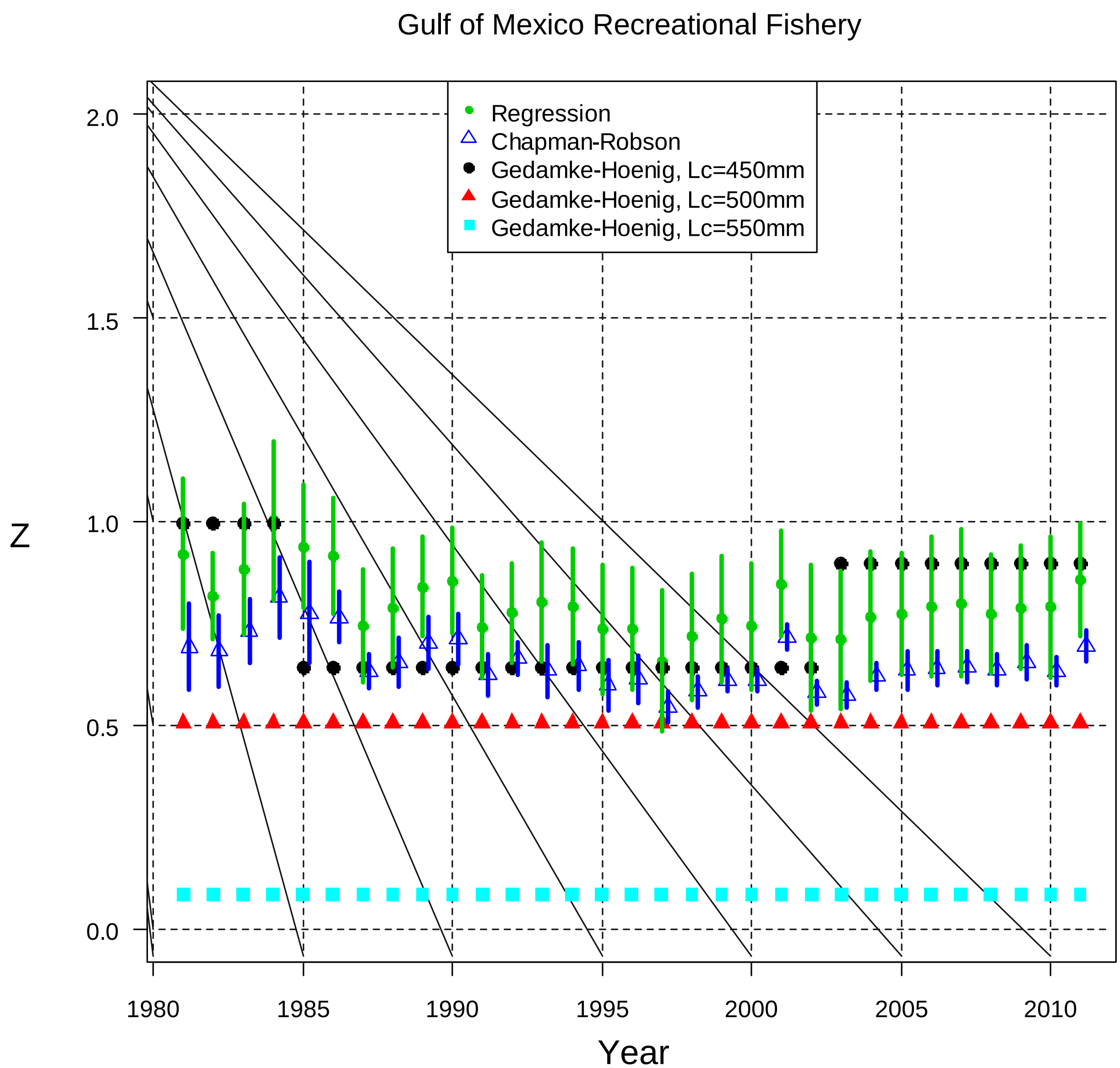


Figure 11. Annual total mortality estimates from three methods: 1) regression, 2) Chapman – Robson catch curve analysis, and 3) Gedamke-Hoenig mean length estimator (three values of L_c) for Spanish mackerel captured in the Gulf of Mexico by the recreational fishery. The recreational data represents private boats, charter boats, and headboats.

a) b) c)

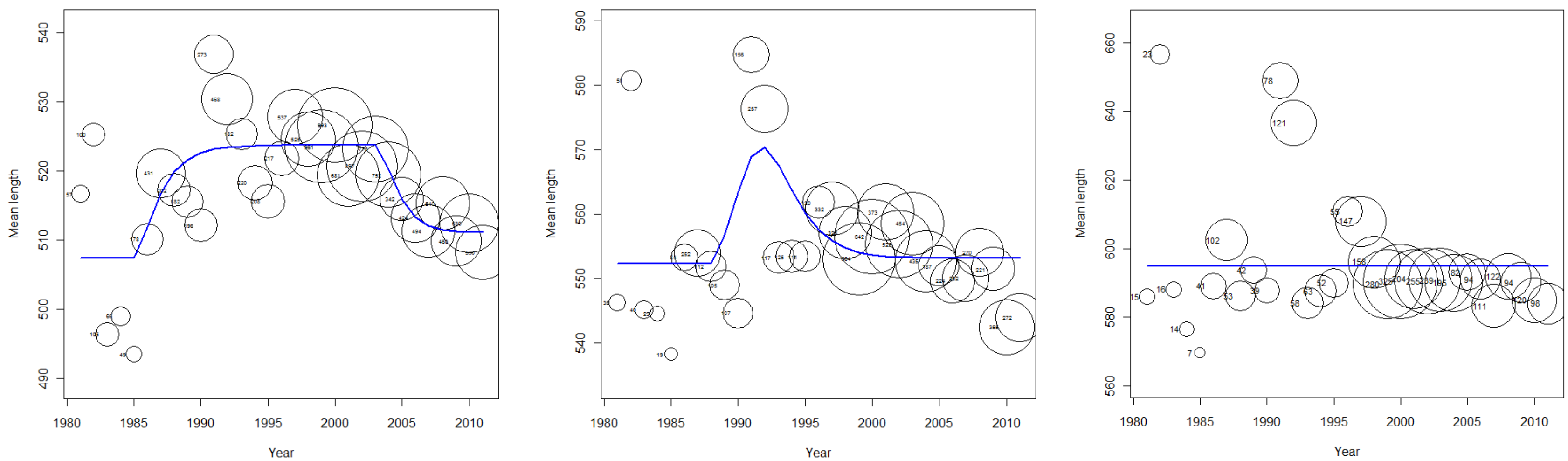


Figure 12. Annual mean length for Spanish mackerel captured by the Gulf of Mexico recreational fishery. Annual mean length was calculated with an assumed value of length at full vulnerability, *Lc*, equal to a) 450mm FL, where the most parsimonious model with stong support predicted two changes in total mortality, b) 500mm FL, where the most parsimonious model with stong support predicted two changes in total mortality, and c) 550mm FL, where the most parsimonious model with strong support predicted no change in total mortality. The solid blue line represents the model fit.