Abundance Indices of King Mackerel, *Scomberomorus cavalla*, Collected in Fall SEAMAP Groundfish Surveys in the Western U.S. Gulf of Mexico (1972-2007)*

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Introduction and Methodologies

One of the most important objectives of fishery-independent surveys is to make inference about the size (in numbers and/or biomass) and age structure of targeted populations. Annual abundance indices based on such surveys are usually derived from catch or catch-per-unit-effort (CPUE) data and are a vital part of current management regimes of many fisheries. Collection, analysis and dissemination of such information are paramount functions of NOAA Fisheries.

King mackerel, *Scomberomorus cavalla*, have been intensely exploited by both recreational and commercial fishermen since the mid 1950's and early 1960's, respectively. This species has been managed by a joint fishery management plan of the Gulf of Mexico and South Atlantic Fishery Management Councils since 1983. From the inception of the SEDAR process in 2003, king mackerel has been a priority species (Merriner 2003). The purpose of this document is to provide annual abundance indices of king mackerel to the SEDAR 16 Data Workshop for possible use in stock assessment. Data were collected during Fall SEAMAP Groundfish Surveys (hereafter referred to as groundfish surveys) conducted by NOAA Fisheries in the U.S. Gulf of Mexico from 1972-2007.

Fish in many cases are overdispersed as a result of behavior and/or physical oceanographic processes, resulting in catch data which is not normal. Therefore, samples taken from such overdispersed populations contain many small or zero values and few very large values, and simple estimates of mean abundance from sample data may either be too low if many low values are included or too high if very large values are included. Model-based estimators have been popularized since they may reduce the likelihood of false conclusions about trends in abundance (McConnaughey and Conquest 1992). They may also produce estimators with better precision (Pennington 1983, 1996; Lo *et al*. 1992).

One model-based alternative to the arithmetic mean of the sample is the delta-lognormal method (Lo *et al*. 1992). The index computed by this method is a mathematical combination of yearly abundance estimates from two distinct generalized linear models: a binomial (logistic) model which describes proportion of positive abundance values (i.e. presence/absence) and a lognormal model which describes variability in only the nonzero abundance data (Lo *et al*. 1992).

The delta-lognormal index of relative abundance (I_y) as described by Lo *et al*. (1992) can be estimated as

(1) $I_y = c_y p_y$,

where c_y is the estimate of mean CPUE for positive catches only for year y; p_y is the estimate of mean probability of occurrence during year y. Both c_y and p_y can be estimated using generalized linear models. Data used to estimate abundance for positive catches (c) and probability of occurrence (p) are assumed to have a lognormal distribution and a binomial distribution, respectively, and can be modeled using the following equations:

(2) $$\ln(\mathbf{c}) = \mathbf{X\beta} + \boldsymbol{\varepsilon}$$

and

(3) $$\mathbf{p} = \frac{e^{\mathbf{X\beta}+\boldsymbol{\varepsilon}}}{1+e^{\mathbf{X\beta}+\boldsymbol{\varepsilon}}}$$, respectively,

where **c** is a vector of the positive catch data, **p** is a vector of the presence/absence data, **X** is the design matrix for main effects, **β** is the parameter vector for main effects, and **ε** is a vector of independent normally distributed errors with expectation zero and variance σ^2.

The variables c_y and p_y can be estimated as least-squares means for each year along with their corresponding standard errors, SE(c_y) and SE(p_y). From these estimates, I_y can be calculated, as in equation (1), and its variance calculated as

(4) $$V(I_y) \approx V(c_y)p_y^2 + c_y^2 V(p_y) + 2c_y p_y \mathrm{Cov}(c,p),$$

where

(5) $$\mathrm{Cov}(c,p) \approx \rho_{c,p}\left[\mathrm{SE}(c_y)\mathrm{SE}(p_y)\right],$$

and $\rho_{c,p}$ denotes correlation of c and p among years.

The survey methodologies and descriptions of the data sets used herein have been previously presented in detail by Nichols (2004, SEDAR7-DW1). The basic structure of the modern groundfish surveys (i.e. 1987-present; see SEDAR7-DW1) follows a stratified random station location assignment with strata derived from depth zones (5-6, 6-7, 7-8, 8-9, 9-10, 10-11, 11-12, 12-13, 13-14, 14-15, 15-16, 16-17, 17-18, 18-19, 19-20, 20-22, 22-25, 25-30, 30-35, 35-40, 40-45, 45-50 and 50-60 fathoms), shrimp statistical zones (between 88° and 97° W longitude, statistical zones from west to east: 21-20, 19-18, 17-16, 15-13 and 12-10), and time of day (i.e. day or night). In order to incorporate the early groundfish surveys data (i.e. 1972-1986), the data were post stratified into the aforementioned strata used in the modern survey. These strata served as the variables in each submodel of the delta-lognormal approach. The submodels of the delta-lognormal model were built using a backward selection procedure based on type 3 analyses with an inclusion level of significance of $\alpha = 0.05$. Binomial submodel performance was evaluated using AIC, while the performance of the lognormal submodel was evaluated based on analyses of residual scatter and QQ plots. King mackerel CPUE (number of fish per trawl-hour) was modeled using this approach. Finally, a length frequency histogram was developed to determine which portion of the stock was represented in these analyses.

Results and Discussion

Table 1 summarizes the data used in these analyses. The number of stations sampled per survey year ranged from 144 in 1980 to 304 in 1985. The number of specimens collected per year ranged from 0 to 215, and ranged in length from 64 to 777 mm fork length with an overall mean fork length of 249 mm. Before 1988 king mackerel specimens were rarely measured for length. Figure 1 is a length frequency histogram of king mackerel collected in this survey. According to findings summarized by Brooks and Ortiz, 2004 (SEDAR5-AW1), the mean size of age-0 king mackerel in the Gulf of Mexico is approximately 517 mm fork length. Because 99% of king mackerel collected and measured in the survey exhibit fork lengths of 500 mm or less the indices developed from this survey, index the abundance of age-0 king mackerel in the western Gulf of Mexico.

The variables that were retained in the binomial submodel were year, shrimp statistical zone, and depth zone. Table 2 summarizes the parameters used in the binomial submodel and their significance. The binomial submodel had an AIC = 35950.1, which was the lowest of the model runs. For the lognormal submodel, the time of day variable was dropped from the model while the statistical zone and depth zone variables were retained (Table 3). Figure 2 indicates the distribution of the residuals of the lognormal submodel is approximately normal.

Table 4 and Figure 3 summarize indices of age-0 king mackerel (number per trawl-hour) developed from the delta-lognormal model. Index values were highest in the later years of the survey and much lower during the early years, and in all but four years between 1972 and 1983, there were no king mackerel observed during the groundfish surveys.

The initial increase of index values during the mid 1980s occurred around the same time as the implementation of king mackerel management (1983). The highest annual value during the 1990s occurred in 1993 in association with the 100-year flood of the Mississippi River (Rabalais *et al.* 1997). Grimes (2001) reports that hydrodynamic convergence associated with the Mississippi River plume could enhance primary and secondary production, and larval fish production, feeding, growth and predation, subsequently enhancing recruitment. Therefore, due to the unusually large plume associated with the 100-year flood of 1993, a greater number of larvae could have survived to be captured in groundfish surveys.

Effort of the shrimp fishery (units in vessel-weeks) in the western Gulf of Mexico as described by Nichols (2004, SEDAR7-DW3) was included in Figure 3. The largest annual increase in an index value, which occurred in 2003, was associated with the largest annual decrease in shrimp fishery effort. The shrimp fishery effort continued to decline in 2005, due to the effects of Hurricane Katrina on the shrimp fleet, while values of age-0 king indices remain the highest of the time series.

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Table 1. Summary of the data used in these analyses.

Survey Year	Number of Stations	Number Collected	Number Measured	Minimum Fork Length (mm)	Maximum Fork Length (mm)	Mean Fork Length (mm)	Standard Deviation
1972	153	76	0				
1973	173	0	0				
1974	149	19	0				
1975	280	0	0				
1976	189	0	0				
1977	155	0	0				
1978	192	5	0				
1979	152	14	0				
1980	144	0	0				
1981	176	0	0				
1982	160	0	0				
1983	146	0	0				
1984	147	20	0				
1985	304	28	7	64	161	129	38
1986	230	12	0				
1987	151	2	0				
1988	216	33	21	87	340	204	66
1989	220	30	19	115	400	200	100
1990	228	35	18	221	437	328	55
1991	220	21	10	315	593	406	85
1992	213	31	13	119	193	144	23
1993	221	151	47	108	408	263	73
1994	213	60	29	181	418	304	56
1995	195	45	10	108	720	273	175
1996	203	22	13	124	330	237	74
1997	191	54	27	122	368	211	80
1998	195	47	20	160	356	259	48
1999	233	42	19	138	432	284	87
2000	214	74	28	111	441	270	112
2001	234	61	32	124	392	260	88
2002	202	24	15	245	377	297	30
2003	227	209	92	131	777	208	77
2004	170	102	73	132	451	260	76
2005	226	215	69	137	536	235	81
2006	194	131	46	86	458	187	79
2007	174	194	97	159	392	267	60
Total Number of Year	Total Number of Stations	Total Number Collected	Total Number Measured			Overall Mean ForkLength (mm)	
36 years	7090	1757	705			249	

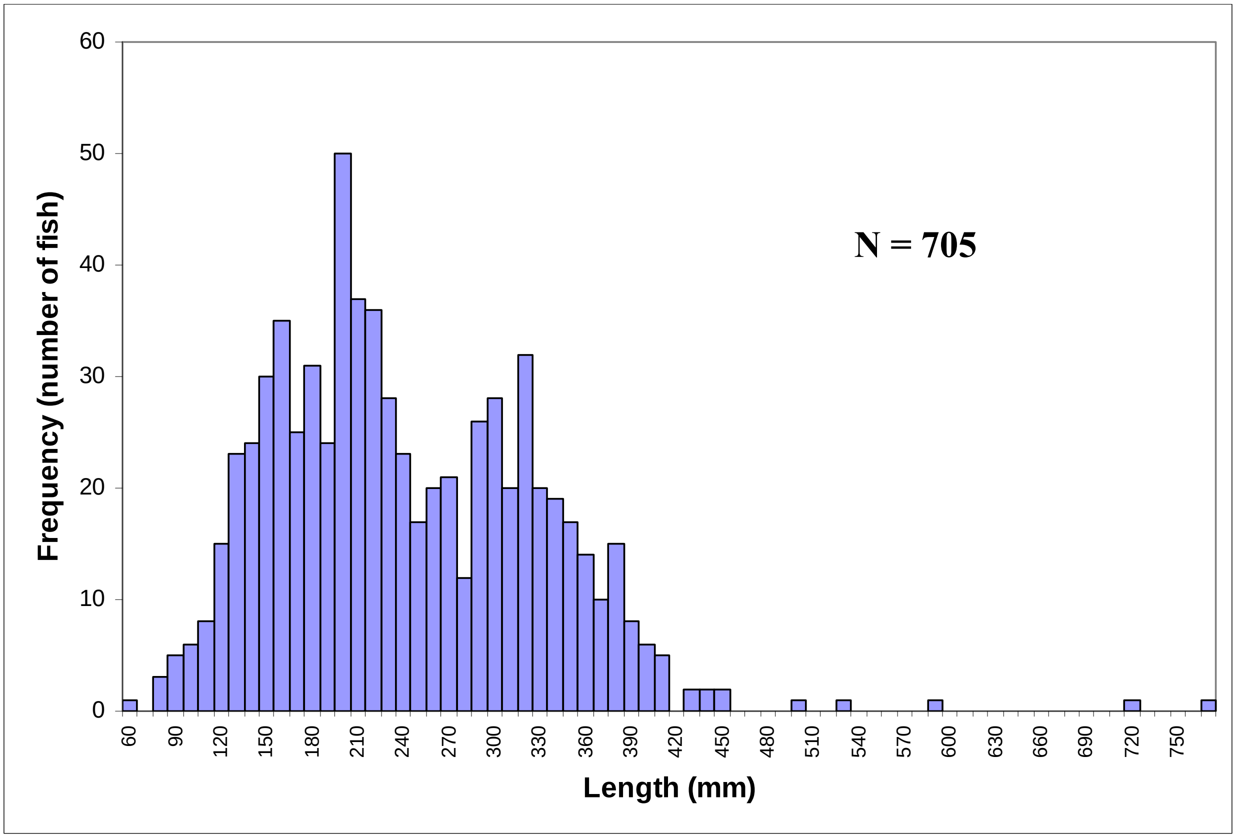

Figure 1. Length frequency histogram of king mackerel collected in this NOAA Fisheries Fall SEAMAP Groundfish Surveys.

Table 2. Type 3 tests of fixed effects for the lognormal submodel

Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*
year	27	5613	118.26	4.38	<.0001	<.0001
DZ	22	5613	47.24	2.15	0.0014	0.0014
ALONG	4	5613	46.07	11.52	<.0001	<.0001

Table 3. Type 3 tests of fixed effects for the lognormal submodel.

Effect	*Num DF*	*Den DF*	*F Value*	*Pr > F*
Year	27	291	0.86	0.6653
Shrimp Statistical Zone	4	291	3.53	0.0079
Depth Zone	22	291	5.00	<.0001

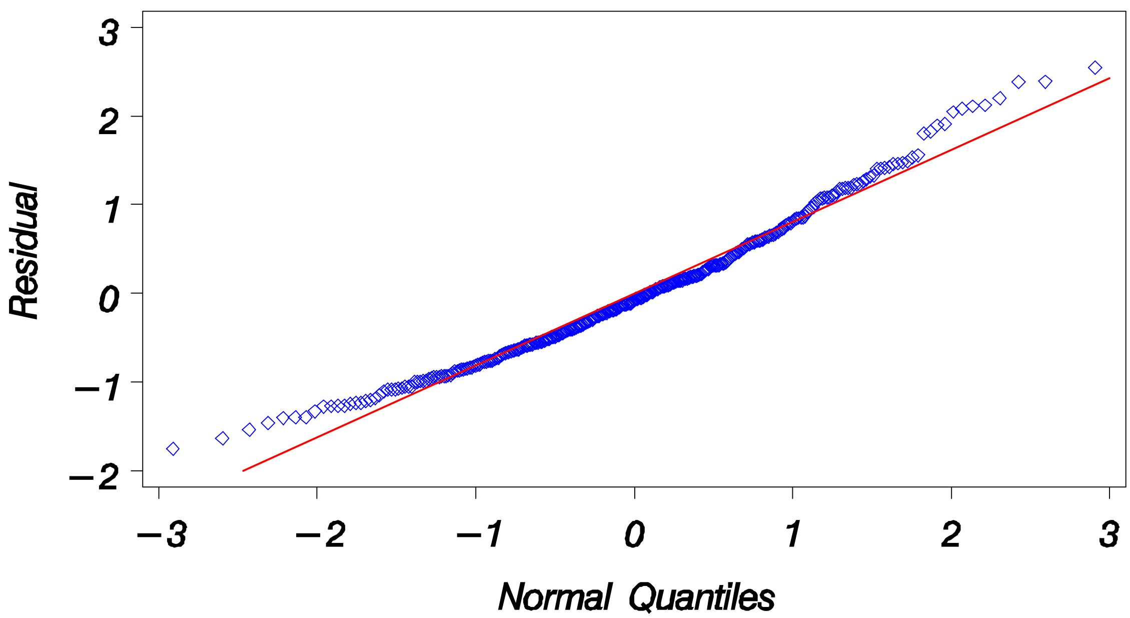

Figure 2. QQ plot of residuals of the lognormal submodel.

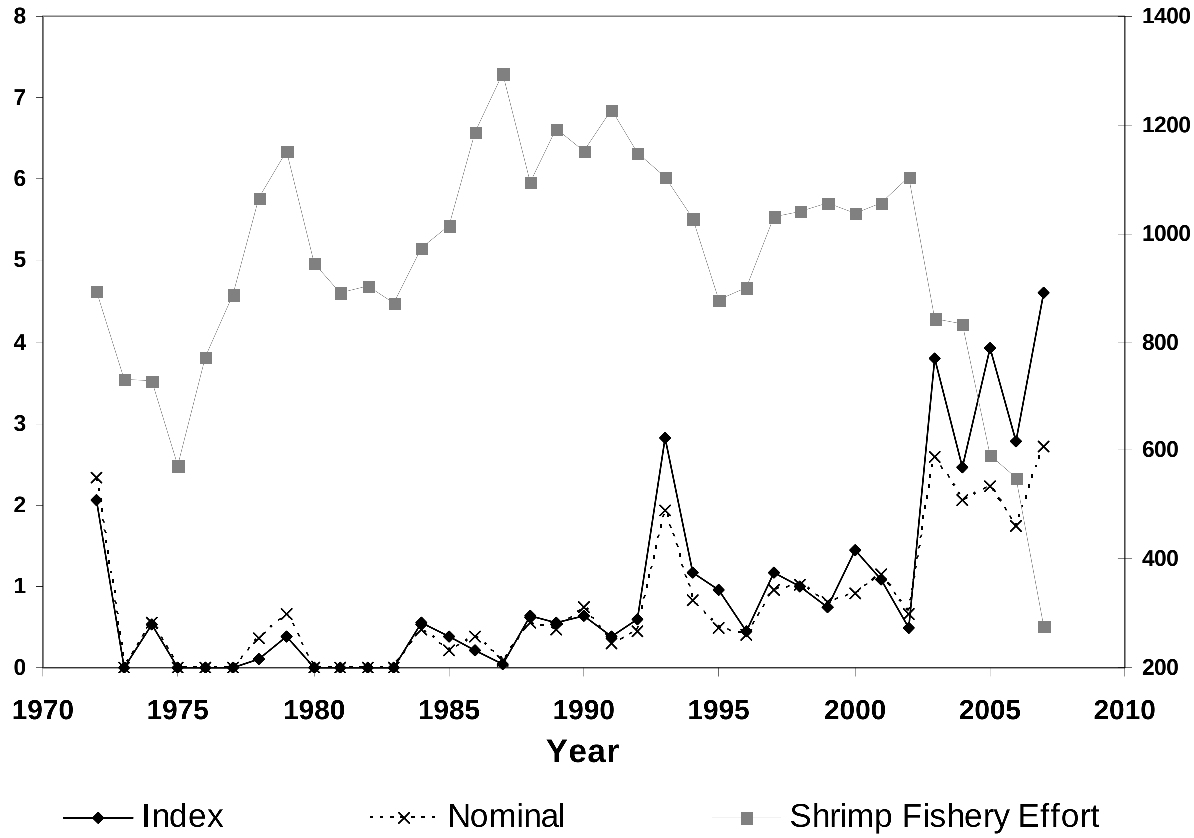

Figure 3. Index of relative abundance of age-0 king mackerel collected in NOAA Fisheries groundfish trawls in the Gulf of Mexico. The left vertical axis represents relative CPUE units. Both the index values and the nominal values are scaled to mean of one across the time series. The right vertical axis represents shrimp fishery effort in the western Gulf of Mexico (in units of vessel-weeks).

Table 4. Indices of age-0 king mackerel developed using the delta-lognormal model. The nominal frequency of occurrence, the number of samples (*N*), the DL Index (number per trawl-hour), the nominal and DL indices scaled to a mean of one for the time series, the coefficient of variation on the mean (CV), and lower and upper confidence limits (LCL and UCL) for the scaled index are listed.

Survey Year	*Frequency*	*N*	*DL Index*	*Scaled Nominal*	*Scaled Index*	*CV*	*LCL*	*UCL*
1972	0.05882	153	0.51138	2.04984	2.33079	0.53360	0.85651	6.34271
1973	0.00000	173	0.00000	0.00000	0.00000			
1974	0.02013	149	0.12113	0.52622	0.55211	0.89993	0.11831	2.57653
1975	0.00000	280	0.00000	0.00000	0.00000			
1976	0.00000	189	0.00000	0.00000	0.00000			
1977	0.00000	155	0.00000	0.00000	0.00000			
1978	0.01042	192	0.08061	0.11176	0.36738	1.09309	0.06237	2.16389
1979	0.01974	152	0.14262	0.38009	0.65004	0.90146	0.13902	3.03955
1980	0.00000	144	0.00000	0.00000	0.00000			
1981	0.00000	176	0.00000	0.00000	0.00000			
1982	0.00000	160	0.00000	0.00000	0.00000			
1983	0.00000	146	0.00000	0.00000	0.00000			
1984	0.02041	147	0.10054	0.56145	0.45823	0.91081	0.09683	2.16858
1985	0.01316	304	0.04544	0.38009	0.20709	0.82317	0.04914	0.87282
1986	0.00870	230	0.08524	0.21530	0.38851	1.07970	0.06696	2.25397
1987	0.00662	151	0.01754	0.05289	0.07994	1.48197	0.00926	0.69033
1988	0.04167	216	0.12226	0.63347	0.55722	0.52739	0.20689	1.50078
1989	0.02273	220	0.10128	0.55564	0.46160	0.70179	0.13020	1.63655
1990	0.06579	228	0.16194	0.63828	0.73811	0.40856	0.33640	1.61954
1991	0.03636	220	0.06287	0.38850	0.28654	0.56468	0.10005	0.82061
1992	0.03756	213	0.09586	0.59638	0.43691	0.55882	0.15402	1.23934
1993	0.10860	221	0.42425	2.82185	1.93365	0.32524	1.02552	3.64594
1994	0.05164	213	0.18261	1.16267	0.83231	0.47974	0.33494	2.06824
1995	0.03077	195	0.10772	0.95327	0.49097	0.64096	0.15188	1.58720
1996	0.04433	203	0.08734	0.45589	0.39810	0.53149	0.14680	1.07955
1997	0.07330	191	0.20862	1.17715	0.95087	0.42539	0.42061	2.14961
1998	0.07692	195	0.22361	1.00072	1.01917	0.41264	0.46113	2.25254
1999	0.07296	233	0.17701	0.74370	0.80678	0.39550	0.37638	1.72933
2000	0.05140	214	0.20181	1.43366	0.91982	0.48032	0.36979	2.28795
2001	0.07692	234	0.25238	1.08059	1.15028	0.37599	0.55585	2.38042
2002	0.04455	202	0.14431	0.49166	0.65773	0.53554	0.24092	1.79564
2003	0.13656	227	0.56636	3.79686	2.58137	0.28905	1.46489	4.54877
2004	0.15882	170	0.44986	2.46795	2.05038	0.30763	1.12370	3.74129
2005	0.13274	226	0.49087	3.92691	2.23731	0.29209	1.26239	3.96513
2006	0.09794	194	0.38066	2.78775	1.73497	0.36872	0.84953	3.54329
2007	0.18391	174	0.59717	4.60945	2.72182	0.28421	1.55876	4.75269