King mackerel (*Scomberomorus cavalla*) larval indices of relative abundance from SEAMAP Fall plankton surveys, 1986 to 2006

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Abstract

The occurrence and abundance king mackerel larvae captured during Southeast Area Monitoring and Assessment Program (SEAMAP) resource surveys in the Gulf of Mexico (GOM) have been used to reflect trends in relative spawning stock size of king mackerel since 1996. In the 2003 assessment the SEAMAP larval index (occurrence) was calculated from catches in bongo net samples taken during both the Summer Shrimp/Bottom fish Survey and the Fall Plankton Survey because together these two long-term resource surveys encompass the king mackerel spawning season in the Gulf of Mexico, summer months to early fall. The larval indices presented in this document are based solely on data from SEAMAP Fall Plankton surveys which began in 1986. This survey is the only Gulfwide survey of U.S. continental shelf and coastal waters during the king mackerel spawning season. Although the Summer Shrimp/Bottom fish Survey which began in 1982 represents a longer time series than the fall survey only the area west of 88° W longitude is sampled and, therefore, the summer survey only provides data from a portion of the presumable range of mackerel spawning in the GOM. Data from the summer survey (especially early in the time series) contain biases principally due to inconsistent coverage of the survey area; whereas sampling during the Fall Plankton survey (a dedicated plankton survey) has been consistent in time and space over the SEAMAP time series.

Methods and Materials:

<u>SEAMAP Plankton Sample Methodologies:</u>
The standard sampling gear and methodology used to collect plankton samples during SEAMAP surveys are similar to those recommended by Kramer et al. (1972), Smith and Richardson (1977) and Posgay and Marak (1980). A 61 cm (outside diameter) bongo net fitted with 0.335 mm mesh netting is fished in an oblique tow path from a maximum depth of 200 m or to 2-5 m off the bottom at station depths less than 200 m. A single or double, 2x1 m pipe frame neuston net fitted with 0.950 mm mesh netting is the other primary (standard) gear employed and it is towed at the surface with the frame half-submerged for 10 minutes.

Maximum bongo tow depth is calculated using the amount of wire paid out and the wire angle at the ‘targeted’ maximum tow depth or measured directly using an electronic depth sensor mounted on the tow cable. A mechanical flowmeter is mounted off-center in the mouth of each bongo net to record the volume of water filtered. Water volume filtered during bongo net tows ranges from ~20 to 600 m^3 but is typically 30 to 40 m^3 at the shallowest stations and 300 to 400 m^3 at the deepest stations.

Catches of larvae in bongo net samples are standardized to account for sampling effort and expressed as number under 10 m^2 sea surface by dividing the number of larvae by volume filtered and then multiplying the resultant by the product of 10 and maximum depth of tow. This procedure results in a less biased estimate of abundance than number per unit of volume filtered alone and permits direct comparison of abundance estimates across samples taken over a wide range of water column depths (Smith and Richardson 1977). Standardized catches of larvae taken in neuston samples are expressed as number per 10 min tow.

Initial processing of most SEAMAP plankton samples has been carried out at the Sea Fisheries Institute, Plankton Sorting and Identification Center (ZSIOP), in Szczecin, Poland, under a Joint Studies Agreement with NMFS. Fish eggs and larvae are removed from bongo net samples, and fish larvae only from neuston net samples. Fish eggs are not identified further, whereas, larvae are identified to the lowest possible taxon which in most cases is the family level. Body length (BL) in mm is measured and recorded.

The larvae of king mackerel are well described; and are identifiable at the smallest sizes (~2 mm) typically found in plankton samples. Few misidentifications of mackerel larvae (< 5%) were found during re-examination by JL-S of specimens initially identified at ZSIOP from samples taken in 1984-1986, 1988-1995 prior to the first use of a SEAMAP larval index for king mackerel. Based on these earlier results no further re-examination of larvae identified as king mackerel at ZSIOP have been undertaken but all larvae identified only to the genus, *Scomberomorus sp.* or the family level, Scombridae, are re-examined at Mississippi Labs. Larvae found among those specimens that could be identified as king mackerel larvae were added to the data set. The SEAMAP larval indices presented here include king mackerel larvae collected from1986 through 2006.

<u>Standardized SEAMAP Station/Sample Data Set</u>

The overall SEAMAP plankton sampling area covers the northern GOM from the 10 m isobath out to the U.S. EEZ, and comprises approximately 300 designated sampling sites i.e. ‘SEAMAP’ stations. Most stations are located at 30-nautical mile or 0.5^o (~56 km) intervals in a fixed, systematic, 2-dimensional (latitude-longitude) grid of transects across the GOM. Some SEAMAP stations are located at < 56 km intervals especially along the continental shelf edge, while others have been moved to avoid obstructions, navigational hazards or shallow water.

Plankton sampling during the spawning season of king mackerel is conducted during two SEAMAP surveys: Summer Shrimp/Bottom fish trawl survey (June and July, annually, 1982 to present); and Fall Plankton survey late summer/early fall (typically in September, annually, 1986 to present). The summer trawl survey encompasses only the coastal and continental shelf waters from south Texas to Mobile Bay while the fall plankton survey covers coastal and continental shelf waters from south Texas to south Florida, i.e. presumably spanning the full spatial extent of mackerel spawning in the northern GOM.

Data from the Summer Shrimp/Bottom fish survey spans 25 years from 1982 to 2006. However, only for 12 years of that time series was the shrimp/bottom fish survey area consistently sampled. The area surveyed during Fall Plankton cruises was consistently sampled for 19 of the 21 years since the survey began in 1986. The two 'missing' fall plankton survey years were 1998 and 2005 when the surveys were cancelled or severely curtailed due to tropical storms. Beginning in 1999 and continuing to the present samples have been taken at 11 SEAMAP stations located off the continental shelf in the western GOM during the Fall Plankton survey. These stations were added to the survey in order to more effectively encompass the spawning area of king mackerel. Plots of larval king mackerel occurrence indicated that larvae were found in abundance at the most offshore stations of the original Fall Plankton survey area.

The intended sample design for SEAMAP surveys calls for a single neuston and/or bongo sample to be taken at each site (SEAMAP station) in the systematic grid. However, over the years additional samples have been taken using SEAMAP gear and collection methods at locations other than designated SEAMAP stations. Some locations were also sampled more than once during a survey year. This year to year variability in spatial coverage during SEAMAP resource surveys was addressed by limiting observations to samples taken at SEAMAP stations that were sampled during at least 10 years of the survey time series (Figure 1). In instances where more than one sample was taken at a SEAMAP station, the sample closest to the central position of the systematic grid location was selected for inclusion in the data set. When SEAMAP stations were sampled by more than one vessel during the survey, priority was given to samples taken by the NMFS (and not the state) vessel. Only samples from the 1986-1997, 1999-2004 and 2006 SEAMAP Fall Plankton surveys taken in accordance with the sample design from stations sampled during at least ten years of the time series were used to calculate the king mackerel larval indices and summaries presented in this report.

<u>Standardized Index of Relative Abundance</u>

A standardized relative index of king mackerel larval abundance was estimated utilizing a delta-lognormal approach, as described by Lo et al. (1992). The approach combines two separate generalized linear models; a binomial model which describes variability in the proportion of positive occurrence (PPO) of larvae (i.e., presence/absence) and a lognormal model which describes variability in only the nonzero larval abundance (ABUNDANCE) data. The factors Y*ear*, *Region*, *Time of Day* and *Depth* were examined as possible influences on the proportion of positive occurrence and abundance of nonzero larval abundance (Table 1). Models to examine these influence of these factors were fitted with the SAS GENMOD Procedure (SAS Institute, 2002) using a forward stepwise approach. An initial null model was run with no factors. Factors were then entered into the model one at a time and then ranked by the largest to smallest reduction in deviance per degree of freedom. The factor with the greatest percent reduction in deviance per degree of freedom was then added into the base model if: (1) it's inclusion reduced the model deviance by at least 1% with respect to the less complex model and (2) the factor was significant at least at the 5% level based on the results of a Chi-Square statistic of a Type III likelihood ratio test. This model then became the base model and the process repeated until no factors or interactions met the criteria for inclusion. The final delta-lognormal model was fit using a SAS macro GLIMMIX and the SAS Procedure PROC MIXED (SAS Institute Inc. 2002). Factors in the final models were fitted as fixed effects except two-way interaction terms containing *Year* which were modeled as random effects.

Results:

Distribution, Abundance and Size at Capture
A total of 1,502 king mackerel larvae were captured in 1,940 bongo net samples ('index' samples) and 1,606 larvae were taken in 2,088 neuston net samples during 19, SEAMAP Fall Plankton surveys over the period 1986-2006 (no surveys in 1998 and 2005). Larvae captured in bongo nets ranged from 1.3 to 14.1 mm BL with a mean of 3.2 mm (median = 2.8); size range in neuston samples ranged from 2.0 to 30 mm BL with a mean of 4.8 mm (median = 4.6). Ninety-five per cent of larvae in bongo samples were ≤ 6.0 mm and in neuston samples ≤ 7.2 mm.

Larvae were captured over station depths ranging from 9 to 730 m with a mean station depth = 62 m and a median station depth = 46 m. King mackerel larvae were captured throughout the Fall Plankton survey area but were consistently more abundant west of the Mississippi River (Figures 2 and 3). Bongo and neuston abundances were 5 times greater and occurrence 2 times greater in the western Gulf of Mexico than in the eastern. The only observations we have on occurrence and abundance of king mackerel larvae in the Atlantic Ocean off the Florida east coast came during the first SEAMAP Fall Plankton survey in 1986 when two NOAA vessels conducted the survey. Most captures of king mackerel larvae were made off Georgia where station abundances were comparable to those in the GOM (Figure 4).

King mackerel larvae were taken in 28.6 % of fall survey bongo samples but only 16.4 % of neuston samples. Gear avoidance of both the bongo and neuston nets was apparent. Mean abundance of king mackerel larvae was two times greater in nighttime (4.14) than in daytime (2.12) bongo samples. This difference was even greater among neuston samples in which mean abundance was 2 orders of magnitude greater in nighttime samples (1.53) than in daytime samples (0.04). Over 97 % of all king mackerel larvae captured with the neuston net were taken in nighttime samples. Due to the extreme avoidance of king mackerel larvae during daytime neuston tows we limited our development of annual indices of kink mackerel larvae occurrence and abundance solely to bongo net samples.

Standardized Index of Abundance
The stepwise parameterization of the binomial model on the proportion of positive occurrence (PPO), and the lognormal model on nonzero larval abundance resulted in the respective final models:

PPO = Region + Year + Time of Day

LN(larval abundance) = Region + Year + Depth + Time of Day

Details of the stepwise parameterization and the percent reduction in the deviance/degrees of freedom of the binomial and lognormal models are outlined in Table 2. Diagnostic plots of the final parameterizations indicated acceptable fits of the data to both the binomial (Figure 5) and lognormal (Figure 6) models.

Observed proportion of positive occurrence and nominal abundance are shown in Figure 7 and summarized in Table 3. The delta-log normal index of larval abundance is show in Figure 8 and summarized in Table 4. The standardized index is nearly identical to nominal abundance, and also similar to the observed proportion of positive occurrence (Figure 7). All three indices suggest an increase in larval king mackerel abundance from 1986 to 1995. Larval abundance and occurrence after 1995 were relatively constant.

Discussion:

The 2003 assessment for king mackerel incorporated a SEAMAP larval index based on the observed proportion of positive occurrence of larvae in bongo net samples taken during the Summer Shrimp/ Shrimp Bottomfish survey and the Fall Plankton survey. The indices Working Group at the time question whether or not to include the Summer Shrimp/Groundfish data in the index as the survey only covers the shelf area of the western Gulf of Mexico. The Working Group was also concerned with the variability in the annual spatial coverage of the Summer/Shrimp Bottomfish and Fall Plankton surveys, particularly with under-sampling off northwest and southwest Florida and central Texas.

Since the last king mackerel SEDAR, the spatial distribution of sampling during the Summer/Shrimp Botttomfish and Fall Plankton surveys has been examined in detail. We have developed methodology to account for much of the year to year variability in sampling coverage during the Fall Plankton survey (see above). However, the Summer Shrimp/Bottom fish survey was found to have consistently sampled the intended survey area in the western Gulf of Mexico only for 12 of the 25 year time series. Lack of coverage was primarily due to the fact that prior to 2002 plankton sampling was considered a secondary objective and often curtailed in order to meet the primary objectives of the trawling portion of the survey. We are continuing to pursue ways to incorporate data from the Summer/Shrimp Bottomfish survey into our analysis, but for now recommend indices of larval king mackerel abundance based solely on samples collected during the Fall Plankton survey.

Per our recommendation, the indices presented here are based solely on samples taken during the Fall Plankton surveys. Furthermore the indices use only samples taken in accordance with the sample design and from stations sampled during at least ten years of the time series. This accounted for much of the annual variance in survey coverage. In contrast, the larval indices included in the previous king mackerel stock assessment used a single sample from all stations collected during each year of the Summer/Shrimp Bottomfish and Fall Plankton surveys. The current indices have also been constructed using the delta-lognormal approach which incorporates information on both the proportion of positive occurrence and nonzero abundance of larvae. Whereas, the larval index used for the last stock assessment was based solely on the observed proportion of positive occurrence.

The delta-lognormal index of larval king mackerel abundance presented in this working paper is our current recommendation for consideration as a fishery-independent tuning index for the current king mackerel stock assessment (Table 4). The index of observed proportion of positive occurrence presented in this working paper represents an index closest in methodology to that of the index of larval occurrence incorporated into to last assessment (Table 3).

References:

Kramer, D., M.J. Kalin, E.G. Stevens, J.R. Thrailkill, and J.R. Zweifel. 1972. Collecting and processing data on fish eggs and larvae in the California Current region. NOAA Technical Report NMFS Circular 370. 38 p.

Lo, N. C. H., L.D. Jacobson, and J.L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat. Sci. 49: 2515-1526.

Posgay, J.A. and R.R. Marak. 1980. The MARMAP bongo zooplankton samplers. Journal of Northwest Atlantic Fishery Science 1: 9-99.

Smith, P.E. and S. L. Richardson, eds. 1977. Standard techniques for pelagic fish egg and larva surveys. FAO Fisheries Technical Paper 175. 100 p.

Table 1. Factors considered for inclusion into the binomial and lognormal sub-models of the delta-lognormal approach.

Factors	Levels	Description
Year	19	1986-1997, 1999-2004 and 2006
Region	2	1 = Western Gulf of Mexico (>89.25 Degrees W Longitude) 2 = Eastern Gulf of Mexico (< 89.25 Degrees W Longitude)
Time of Day	2	1 = Day (Sunrise to Sunset) 2 = Night (Sunset to Sunrise)
Depth		Water Depth

Table 2. Deviance analysis showing the stepwise procedure used to develop the binomial model on proportion of positive occurrence and the lognormal nonzero abundance of king mackerel larvae.

Proportion of Positive Occurrence

Factors	d.f	Deviance	Deviance/DF	% Reduction in Deviance/d.f	Chi-Square	Pr>Chi Square
Null Model	1939	2322.5937	1.1978			
Region	1938	2173.8493	1.1217	6.35	148.74	<0.0001
Year	1921	2239.4553	1.1658	2.67	83.14	<0.0001
Time of Day	1938	2288.9065	1.1811	1.39	33.69	<0.0001
Depth	1938	2321.4227	1.1978	0.00	1.17	0.2792
Region +						
Year	1920	2091.4356	1.0893	2.89	148.02	<0.0001
Day/Night	1937	2130.3029	1.0998	1.95	43.55	<0.0001
Region + Year +						
Day/Night	1919	2045.3453	1.0658	2.16	46.09	<.0001
Region + Year + Day/Night +						
Year * Region	1901	2032.4716	1.0692	0.32	12.87	0.7990
Year*Day/Night	1901	2027.7116	1.0667	0.08	17.63	0.4800

Nonzero Larval Abundance

Factors	d.f	Deviance	Deviance/DF	% Reduction in Deviance/d.f	Chi-Square	Pr> Chi Square
Null Model	554	365.1894	0.6592			
Region	553	332.3531	0.601	8.83	52.29	<0.0001
Year	536	339.4026	0.6332	3.94	40.64	0.0017
Depth	553	350.2045	0.6333	3.93	23.25	<0.0001
Time of Day	553	360.3697	0.6517	1.14	7.37	0.0066
Region +						
Year	535	302.0766	0.5646	6.06	53.01	<0.0001
Depth	552	315.0916	0.5708	5.02	29.6	<0.0001
Time of Day	552	324.8039	0.5884	2.10	12.75	0.0004
Region + Year +						
Depth	534	287.3486	0.5381	4.69	27.74	<0.0001
Time of Day	534	293.5744	0.5498	2.62	15.84	<0.0001
Region + Year + Depth +						
Time of Day	533	280.116	0.5256	2.32	14.05	<0.0002
Region + Year + Depth + Time of Day +						
Year*Time of Day	515	268.4731	0.5213	0.82	23.66	0.1665
Year*Region	516	269.2304	0.5218	0.72	22.1	0.1810
Year*Depth	515	269.7268	0.5237	0.36	21.07	0.2756

Table 3. Annual sample size, nominal abundance and proportion of positive occurrence with associated percent coefficient of variation (CV, standard error/mean). Scaled abundance and proportion positive are scaled by dividing the annual values by the mean of all years.

Year	N	Nominal Abundace	Scaled Abundance	CV Nominal Abundance	Proportion Positive	Scaled Proportion Positive	CV Proportion Positive
1986	105	0.3467	0.1148	0.4080	0.0667	0.2361	0.3669
1987	116	0.9706	0.3214	0.2289	0.1638	0.5801	0.2107
1988	64	1.5452	0.5117	0.3748	0.1563	0.5534	0.2928
1989	67	2.2288	0.7381	0.2740	0.2537	0.8987	0.2111
1990	78	1.7377	0.5754	0.2774	0.2308	0.8173	0.2081
1991	73	2.1349	0.7070	0.2956	0.2466	0.8733	0.2060
1992	109	1.8544	0.6141	0.1882	0.3028	1.0723	0.1460
1993	112	3.8823	1.2856	0.1884	0.3839	1.3598	0.1202
1994	120	2.9787	0.9864	0.2025	0.2833	1.0035	0.1458
1995	116	6.5693	2.1754	0.1820	0.3793	1.3434	0.1193
1996	117	2.5347	0.8394	0.2774	0.2308	0.8173	0.1695
1997	116	4.3718	1.4477	0.1889	0.3621	1.2824	0.1238
1998							
1999	112	2.5028	0.8288	0.2473	0.3125	1.1068	0.1408
2000	113	2.7645	0.9155	0.2113	0.2301	0.8149	0.1728
2001	109	4.3981	1.4564	0.2243	0.3670	1.2997	0.1264
2002	93	4.6680	1.5458	0.2140	0.3978	1.4091	0.1283
2003	117	3.1237	1.0344	0.2058	0.3162	1.1200	0.1365
2004	94	5.2995	1.7549	0.3182	0.4149	1.4695	0.1231
2005							
2006	109	3.4644	1.1472	0.2171	0.2661	0.9423	0.1598

Table 4. Annual sample size, observed proportion of positive occurrence, delta-lognormal (D-L) abundance with associated coefficient of variation (CV, standard error/mean) and scaled delta-lognormal abundance with upper and lower 95% confidence limits. Scaled values are scaled by dividing by the mean of D-L abundance.

Year	N	Proportion Positive	D-L Abundance	CV on D-LN Abundance	Scaled D-L Abundance	D-L Scaled Lower 95% Confidence Limit	Scaled Upper 95% Confidence Limint
1986	105	0.0667	0.3084	0.5341	0.1160	0.0426	0.3160
1987	116	0.1638	1.0068	0.3219	0.3788	0.2022	0.7097
1988	64	0.1563	1.6293	0.4365	0.6130	0.2659	1.4132
1989	67	0.2537	2.2461	0.3255	0.8450	0.4479	1.5942
1990	78	0.2308	1.7224	0.3211	0.6480	0.3464	1.2124
1991	73	0.2466	1.9169	0.3181	0.7212	0.3876	1.3418
1992	109	0.3028	1.5842	0.2372	0.5960	0.3733	0.9516
1993	112	0.3839	3.3238	0.1987	1.2505	0.8436	1.8535
1994	120	0.2833	2.7909	0.2310	1.0500	0.6655	1.6566
1995	116	0.3793	5.2595	0.1947	1.9787	1.3453	2.9104
1996	117	0.2308	1.9689	0.2647	0.7407	0.4401	1.2466
1997	116	0.3621	3.6140	0.2007	1.3597	0.9138	2.0231
1999	112	0.3125	2.4449	0.2249	0.9198	0.5899	1.4344
2000	113	0.2301	2.4505	0.2730	0.9219	0.5393	1.5762
2001	109	0.3670	4.3656	0.2026	1.6424	1.0997	2.4530
2002	93	0.3979	3.8572	0.2143	1.4511	0.9498	2.2172
2003	117	0.3162	2.9310	0.2190	1.1027	0.7153	1.6999
2004	94	0.4149	3.9285	0.2108	1.4780	0.9740	2.2427
2006	109	0.2661	3.1536	0.2533	1.1865	0.7206	1.9536

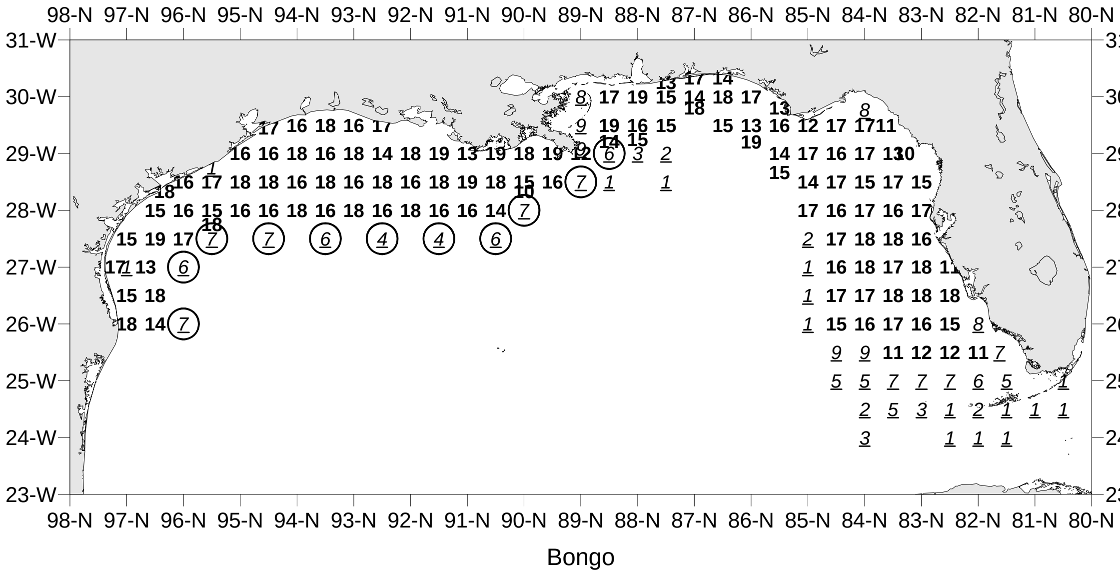
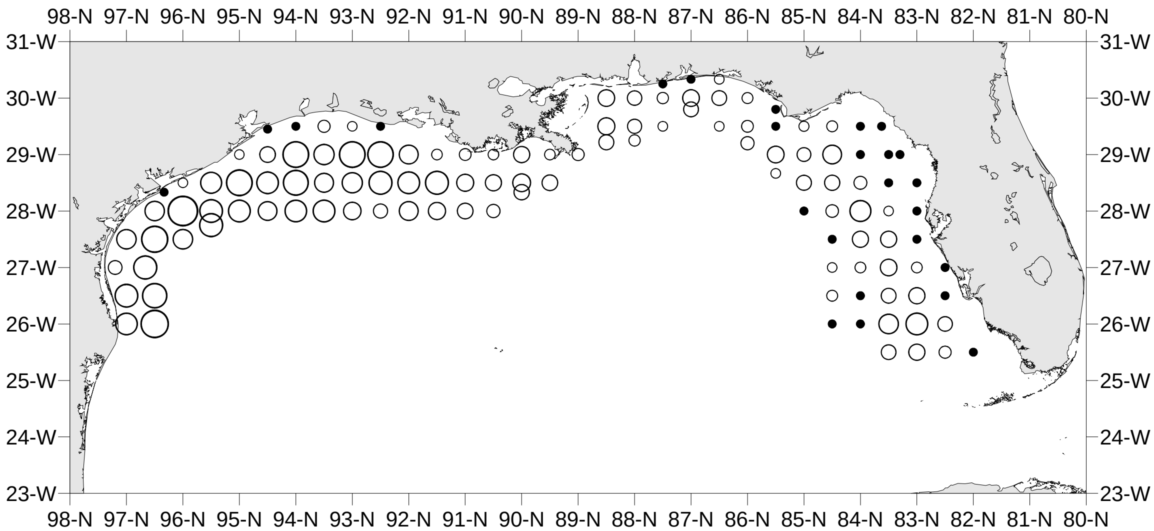


Figure 1. SEAMAP plankton stations denoted by the number of years in which samples were taken at that location during SEAMAP Fall Plankton surveys. Bold numbers represent stations where samples were taken in at least 10 years of the time series (1986-2006) and were retained in the analysis. Underlined, italicized and circled numbers represent stations where samples were taken in fewer than 10 years of the time series and were not retained in the analysis. Circled stations are those stations added to the Fall Plankton survey in 1999.

(A)



(B)

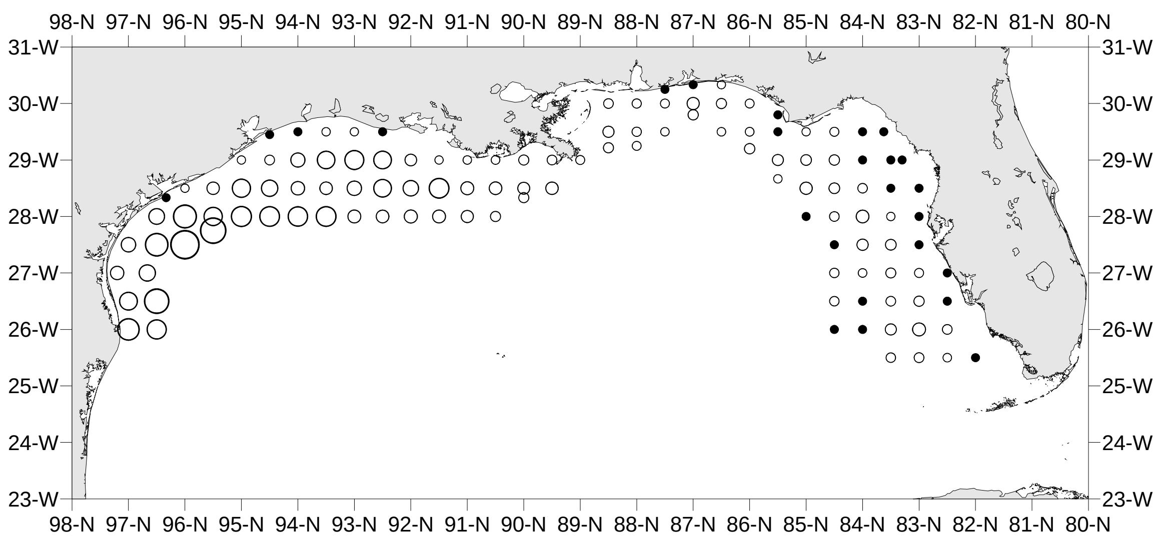
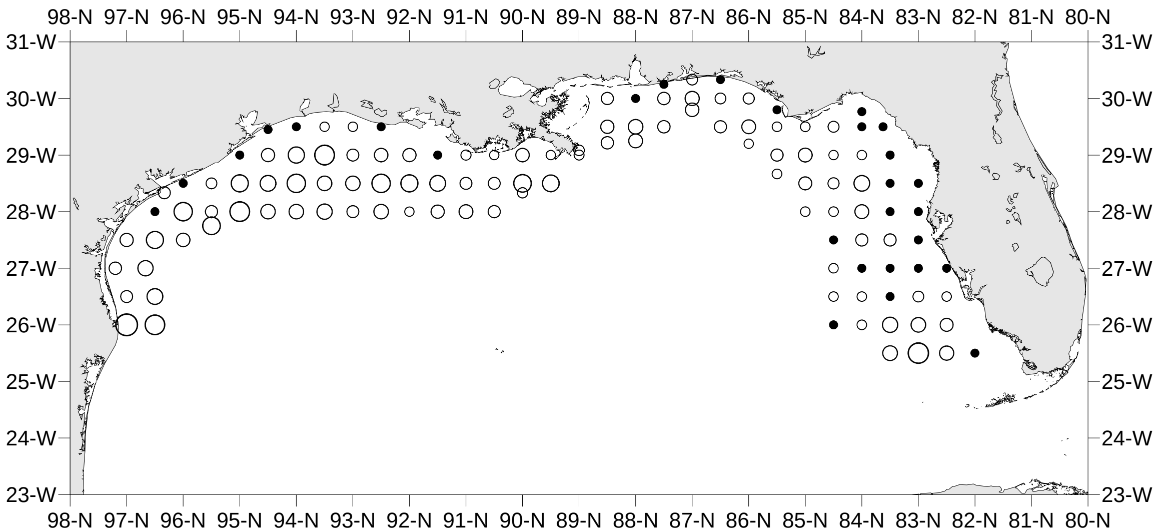


Figure 2. Proportion of positive occurrence (A) and mean number under 10 m^2 sea surface (B) of king mackerel larvae captured in bongo net samples during the 'index years' of the SEAMAP Fall Plankton survey. ● = zero catch; ○ = from > 0 to 1 proportion of positive occurrence or ○ = from > 0 to 20 larvae m^2 sea surface. Symbol size is scaled proportionally over the range of positive values.

(A)



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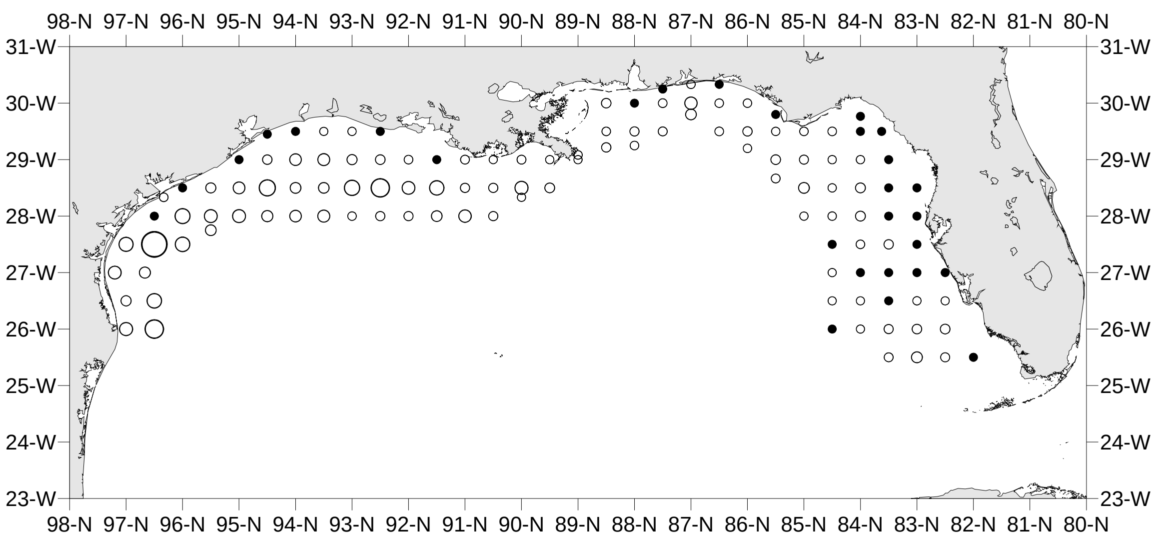
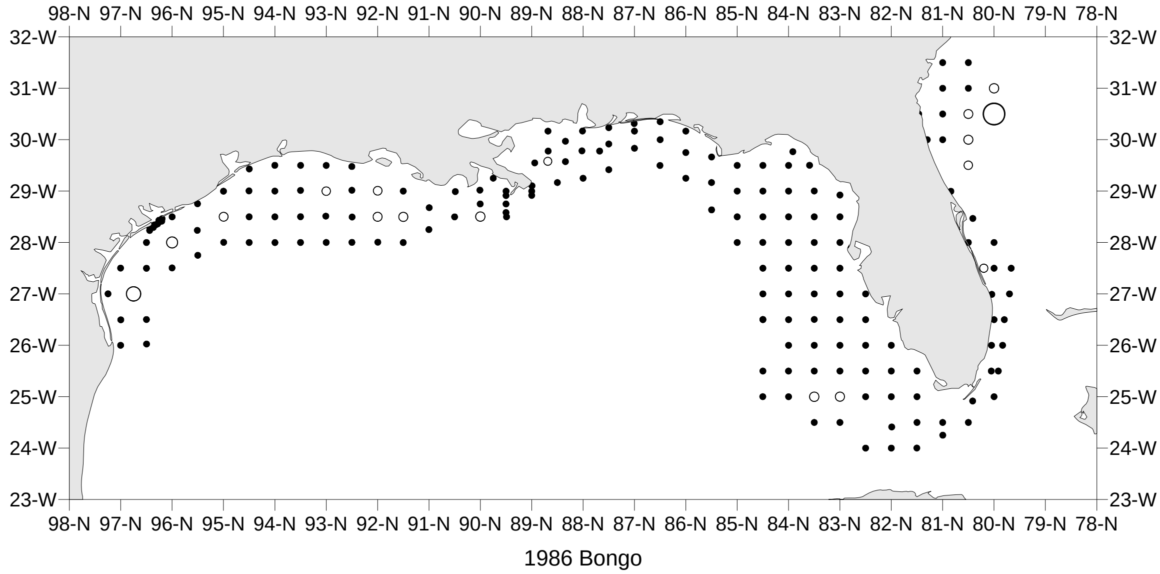


Figure 3. Proportion of positive occurrence (A) and mean number under 10 m^2 sea surface (B) of king mackerel larvae captured in neuston net samples during the 'index years' of the SEAMAP Fall Plankton survey. ● = zero catch; ○ = from > 0 to 1 proportion of positive occurrence or ○ = from > 0 to 10 larvae per 10 minute tow. Symbol size is scaled proportionally over the range of positive values.

(A)



(B)

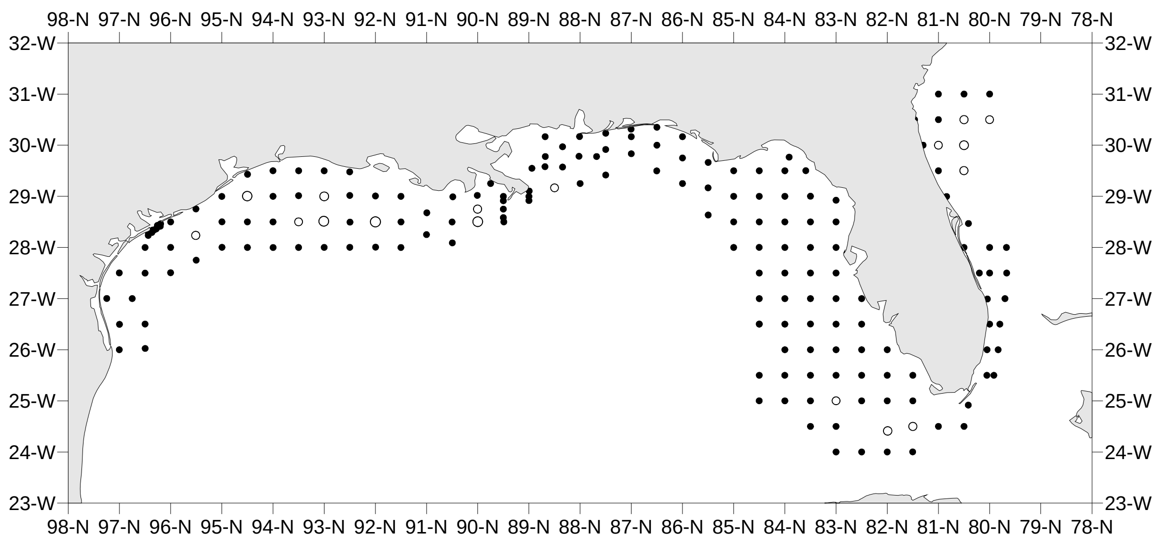


Figure 4. Station abundances of king mackerel larvae captured in (A) bongo net (number under 10 m^2 sea surface) and (B) neuston net (number per 10 min tow) samples during the 1986 SEAMAP Fall Plankton survey; Oregon II cruise 161, 2-12 Sep; and Chapman cruise 865, 13-22 Sep. ● = zero catch; ○ = from > 0 to 43 for bongo catches; from >0 to 8 for neuston catches. Symbol size is scaled proportionally over the range of positive values.

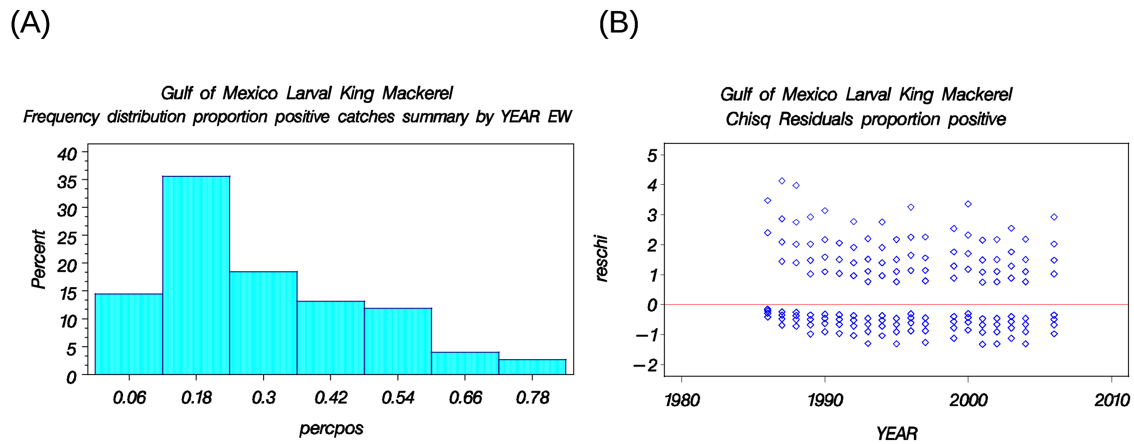


Figure 5. Diagnostic plots of the binomial component of the Gulf of Mexico king mackerel larval index: (A) the frequency distribution of the proportion of positive occurrence and (B) the Chi-Square residuals by year.

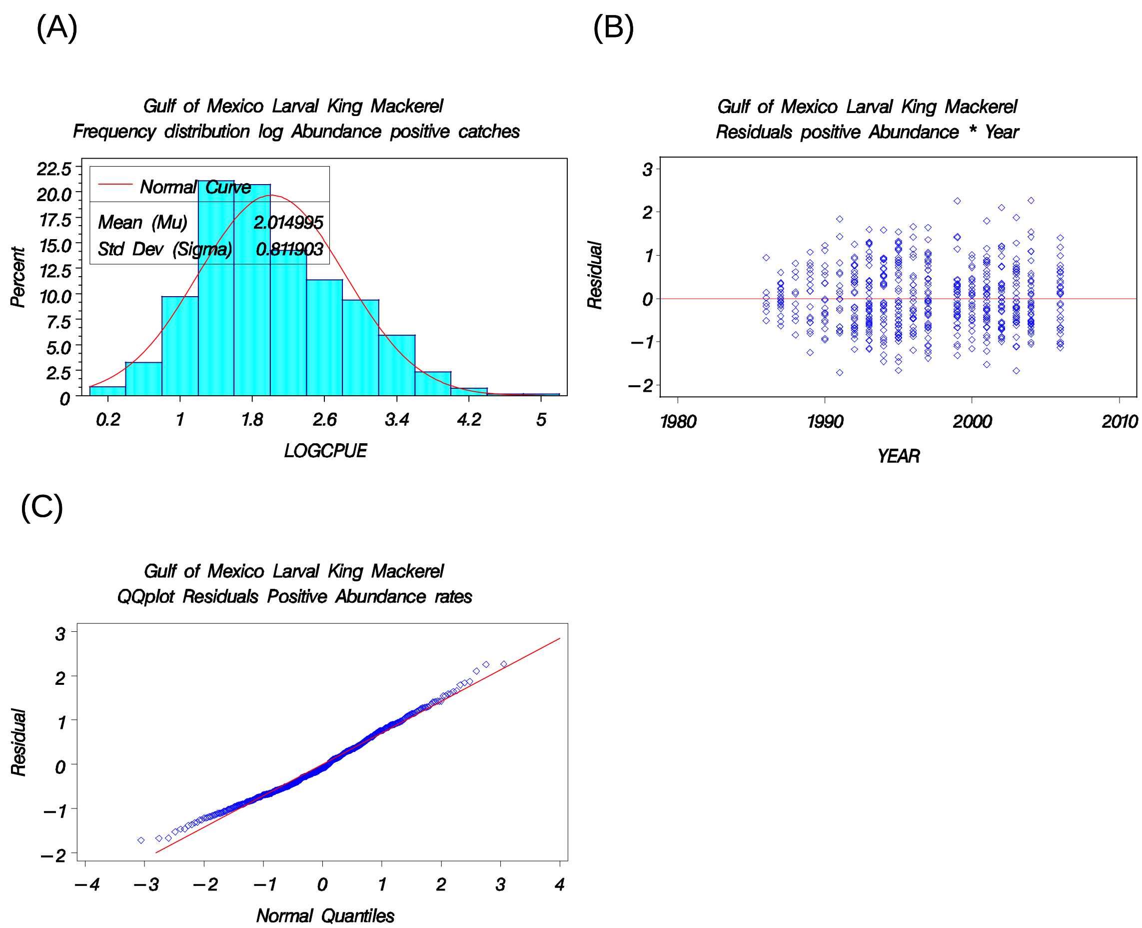


Figure 6. Diagnostic plots for the lognormal sub-model of Gulf of Mexico larval king mackerel index: (A) the frequency distribution of nonzero log(abundance) , (B) the residuals by year and (C) the cumulative normalized residuals from the lognormal model on nonzero abundance. Red lines in each plot indicate the expected normal distribution.

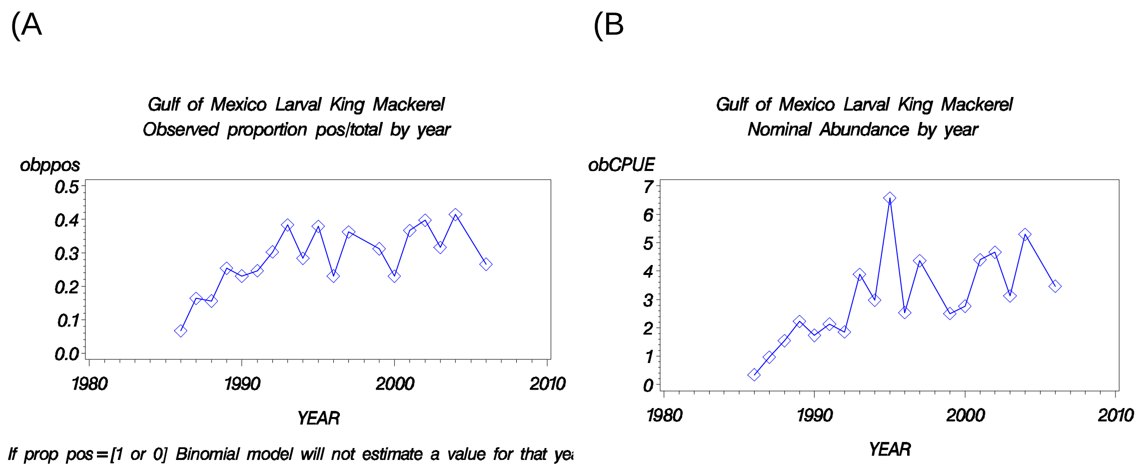


Figure 7. (A) Annual observed proportion of positive occurrence and, (B) annual nominal abundance of Gulf of Mexico king mackerel larvae.

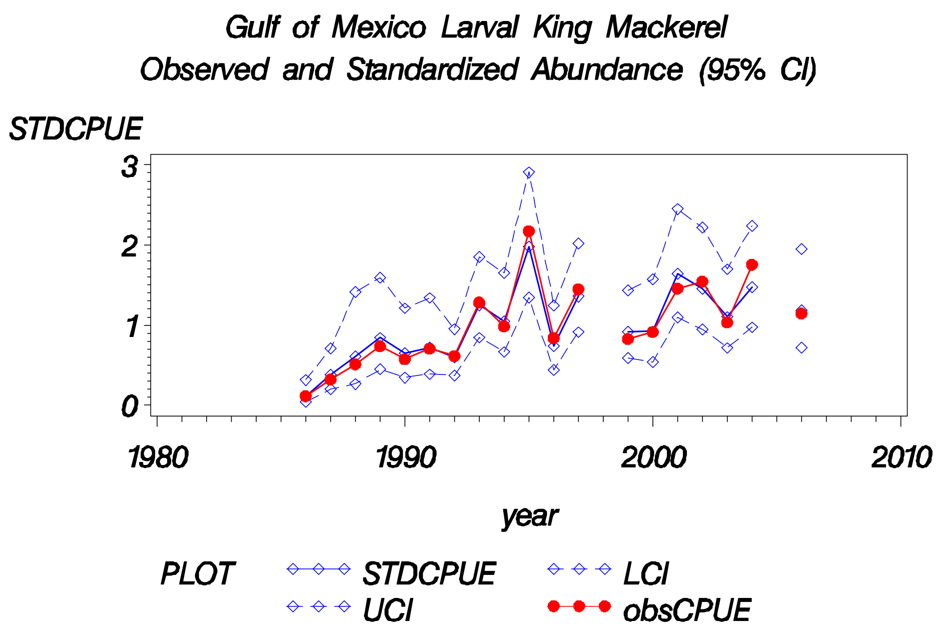


Figure 8. Delta-lognormal index (solid blue line open symbols) with 95% confidence intervals (dashed lines), and nominal abundance (solid red line) of Gulf of Mexico king mackerel larvae.