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King mackerel (*Scomberomorus cavalla*) larval indices of relative abundance from SEAMAP Fall Plankton Surveys, 1986 to 2012

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Abstract: *The occurrence and abundance of 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 the relative spawning stock size of king mackerel since 2000. Indices of relative abundance based on larval catch from SEAMAP summer and fall plankton sampling were first incorporated into the king mackerel Southeast Data, Assessment and Review (SEDAR 5) stock assessment in 2003. These indices were re-formulated using new methods and data solely from SEAMAP Fall Plankton Surveys for the SEDAR 16 stock assessment in 2006. The larval indices presented in this document are an update to the SEDAR 16 indices using the same methodology and the most recent data available from the 1986 to 2012 SEAMAP Fall Plankton Surveys.*

Introduction

The Southeast Area Monitoring and Assessment Program (SEAMAP) has supported the collection and analysis of ichthyoplankton samples from resource surveys in the Gulf of Mexico (GOM) since 1982 with the goal of producing a long-term database on the early life stages of fishes. Occurrence and abundance of king mackerel (*Scomberomorus cavalla*) larvae captured during these surveys have been used to reflect trends in the relative spawning stock size of king mackerel since 2000 (Gledhill and Lyczkowski-Shultz, 2000). However, indices of relative spawning stocks size based on larval occurrence and abundance were not incorporated into the king mackerel stock assessment process until 2003 (SEDAR5 Assessment Reports 1-5, 2003).

The indices developed for the 2003 assessment were based on the occurrence of larvae captured in bongo net samples taken during both the Summer Shrimp/Bottomfish and the Fall Plankton Surveys because together these two long-term resource surveys encompass the king mackerel spawning season (late April to early October) in the Gulf of Mexico. The Indices Working Group at the time questioned whether to include Summer Shrimp/Bottomfish data in the index, as the survey only covers the continental shelf area of the western GOM but ultimately recommended retaining the data. They also raised concerns related to inter-annual geographic differences in sampling due to difficulties posed by weather and/or ship related failures. Final recommendations by the group included the development of procedures to adjust for spatial variability within and among the Summer Shrimp/Bottomfish and Fall Plankton surveys and the standardization of the index with the Delta-lognormal methods for future consideration.

The larval indices were re-formulated using new methodology and data solely from bongo net collections taken during Fall Plankton Surveys for the 2006 (SEDAR16) king mackerel stock assessment (SEDAR, 2006). Prior to the assessment, the spatial distribution of sampling conducted during the Summer/Shrimp Botttomfish and Fall Plankton surveys were examined in detail and the Summer Shrimp/Bottomfish survey was found to have consistently sampled the intended survey area in the western GOM only for 12 years of the 25 year time series (1982-2006). 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. Therefore, data from Summer Shrimp/Bottomfish surveys was not included in the updated 2006 indices. Per the SEDAR5 Indices Working Group recommendations, procedures were developed to account for much of the year to year variability in sampling coverage during the Fall Plankton survey (see current methodology), and the index standardized using the Delta-lognormal method.

The indices presented in this document are an update to the SEDAR16 larval indices of relative abundance from bongo net caught king mackerel larvae using the same methodology and the most recent data available from the 1986 to 2012 SEAMAP Fall Plankton Surveys.

Methodology

SEAMAP Plankton Sample Methodologies

The standard sampling gear and methodology used to collect plankton samples during SEAMAP surveys were similar to those recommended by Kramer et al. (1972), Smith and Richardson (1977) and Posgay and Marak (1980). A 61 cm or 60 cm (inside diameter) bongo net fitted with 0.335 mm mesh netting was 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. Maximum bongo tow depth was 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 was mounted off-center in the mouth of each bongo net to record the volume of water filtered. Water volume filtered during bongo net tows ranged from ~20 to 600 m^3 but was 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 were standardized to account for sampling effort and expressed as number under 10 m^2 sea surface (CPUA, Catch Per Unit Area) 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).

Sample Processing and Identification of King Mackerel Larvae

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 were removed from bongo net samples. Fish eggs were not identified further, whereas, larvae were identified to the lowest possible taxon which in most cases was the family level. Body length (BL) in mm was 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 Joanne Lyczkowski-Shultz of specimens initially identified at ZSIOP from samples taken in 1984-1986 and 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. Larvae identified only to the genus, *Scomberomorus sp.* or the family level, Scombridae between 1995 and 2006, were re-examined at Mississippi Labs. Larvae found among those specimens that could be identified as king mackerel larvae were added to the data set. Few misidentifications were found during re-examination of specimens identified as *Scomberomorus sp.* or Scombridae from 1996 to 2006 and no further re-examination of larvae have been undertaken for samples after 2006. The SEAMAP larval indices presented here include all king mackerel larvae collected and identified from 1986 through 2012.

Standardized SEAMAP Station/Sample Data Set

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 was conducted during the SEAMAP Fall Plankton survey (late summer/early fall (typically in September, annually, 1986 to present)). The area surveyed during Fall Plankton cruises was consistently sampled for 24 of the 27 years since the survey began in 1986 (Appendix Figure 1). The three 'missing' fall plankton survey years were 1998, 2005 and 2008 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.

The intended sample design for SEAMAP surveys calls for 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 14 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, 2006-2007 and 2009-2012 SEAMAP Fall Plankton surveys taken in accordance with the sample design from stations sampled during at least 14 years (~60%) of the time series were used to calculate the king mackerel larval indices and summaries presented in this report.

Index Construction

Delta-lognormal modeling methods were used to estimate relative abundance indices for larval king mackerel (Lo *et al*. 1992). The main advantage of using this method is allowance for the probability of zero catch (Ortiz *et al*. 2000). 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). A single Delta-lognormal abundance index was constructed for larval king mackerel for the GOM.

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

(3) $$I_y = c_y p_y,$$

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

(4) $$\ln(c) = X\beta + \varepsilon$$

and

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

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. Therefore, c_y and p_y were estimated as least-squares means for each year along with their corresponding standard errors, SE(c_y) and SE(p_y), respectively. From these estimates, I_y was calculated, as in equation (1), and its variance calculated as:

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

where:

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

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

The factors Y*ear*, *Region*, *Time of Day* (TOD) 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. Year by factor interactions were only tested for significant factors in the base model. 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 and Discussion

Distribution, Abundance and Size at Capture

A total of 1,907 king mackerel larvae were captured in the 2,551 bongo net samples (index samples only) during 24 SEAMAP Fall Plankton surveys from 1986-2012 (data from the surveys in 1998, 2005 and 2008 is not included). Captured larvae ranged from 1.3 to 38 mm BL with a mean of 3.3 mm (median = 2.9). Ninety-five per cent of larvae in bongo net samples were ≤ 6.0 mm. Larvae were taken in 27.7 % of samples with a mean CPUA of 3.1 larvae per 10 m^2 sea surface (Table 2). Larvae were captured throughout the survey area but occurred 1.7 times more often and at 4 times greater CPUA in the western GOM than in the eastern (Table 2 and Figure 2). Daytime versus nighttime sampling closely reflected the expected ratios of light to dark, with 52.7% samples taken during the day and 47.3% at night. Gear avoidance in bongo nets was apparent between day and night sampling. The mean abundance of king mackerel larvae was 1.7 times greater at night than during the day (Table 3). Larvae were captured over station depths ranging from 9 to 371 m with a mean station depth of 60 m and a median station depth of 48 m.

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(CPUA) = Region + Depth + Year + Time of Day + Year*Region

However, the annual means from the LSMEANS output for the nonzero larval abundance model were not estimable by the procedure for the Year*Region factor. Therefore the final model for the nonzero larval abundance used to generate the Delta-lognormal index is:

LN(CPUA) = Region + Depth + Year + 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 Tables 4 and 5. Both the binomial and log-normal models converged. Diagnostic plots of the final parameterizations indicated acceptable fits of the data to both the binomial (Figure 3) and lognormal (Figures 4 and 5) models. The AIC for the binomial and lognormal submodels were 11861.5 and 1628.4, respectively.

Observed proportion of positive occurrence and nominal CPUA are shown in Figure 6 and summarized in Table 6. The delta-log normal index of larval CPUA is show in Figure 7 and summarized in Table 7. The standardized index is nearly identical to nominal CPUA, and also similar to the observed proportion of positive occurrence. Nominal CPUA, occurrence and the Delta-lognormal index all suggest an increase in larval king mackerel CPUA from 1986 to 1995. Larval CPUA and occurrence after 1995 were relatively constant. A comparison between the SEDAR 38 and SEDAR 16standardized indices show minimal differences in annual estimates with identical trends from 1986 to 2006 (Figure 8).

The SEAMAP Fall Plankton Survey 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 stock assessment (Table 7). The current larval index uses identical methodology as the index submitted for SEDAR16. The only differences are due to corrections of raw data, a correction in the coding that selects which samples meet the sample design criteria of the SEAMAP Fall Plankton Survey, the cutoff point for the minimum number of years of sampling to include, and the addition of the 2007 to 2012 data.

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

Factors	Levels	Description
Year	24	1986-1997, 1999-2004, 2006-2007 and 2009-2012
Region	2	West = Western Gulf of Mexico (>89.25 Degrees W Longitude) East = Eastern Gulf of Mexico (< 89.25 Degrees W Longitude)
Time of Day (TOD)	2	D = Day (Sunrise to Sunset) N = Night (Sunset to Sunrise)
Depth		Water Depth

Table 2. Nominal catch per unit area (CPUA) and proportion positive of larval king mackerel in bongo net samples Gulfwide (GOM) and from the western GOM and the eastern GOM.

Region	N	CPUA	SE CPUA	Proportion Positive	SE Proportion Positive
West	1193	5.1556	0.3082	0.3982	0.0142
East	1358	1.3029	0.1402	0.1708	0.0102
GOM	2551	3.1047	0.1667	0.2771	0.0089

Table 3. Nominal catch per unit area (CPUA) and proportion positive of larval king mackerel in bongo net samples by time of day.

Time of Day	N	CPUA	SE CPUA	Proportion Positive	SE Proportion Positive
Day	1345	2.3459	0.1986	0.2297	0.0115
Night	1206	3.9509	0.2724	0.3300	0.0136

Table 4. Deviance analysis showing the stepwise procedure used to develop the binomial model on proportion of positive occurrence.

Proportion of Positive Occurrence Factors	d.f	Deviance	Deviance/DF	% Reduction in Deviance/d.f	Chi-Square	Pr>Chi Square	Notes
Null Model	2550	3011.39	1.1809				
Region	2549	2845.80	1.1164	5.4619	165.59	<0.0001	
Year	2527	2925.26	1.1576	1.9731	86.13	<0.0001	
Time of Day (TOD)	2549	2979.47	1.1689	1.0162	31.92	<0.0001	
Depth	2549	3008.57	1.1803	0.0508	2.82	0.0931	
Region +							
Year	2526	2762.76	1.0937	2.0333	83.04	<0.0001	
Time of Day (TOD)	2548	2805.95	1.1012	1.3615	39.85	<0.0001	
Depth	2548	2845.75	1.1169	0.0448	0.05	0.8149	
Region + Year +							
Time of Day (TOD)	2525	2720.89	1.0776	1.4721	41.87	<.0001	
Depth	2525	2762.71	1.0941	0.0366	0.05	0.8305	
Region + Year + Time of Day (TOD) +							
Depth	2524	2720.82	1.078	0.0371	0.07	0.7936	
Region + Year + Day/Night +							
Year * Region	2502	2695.35	1.0773	0.0278	25.54	0.3231	
Year*Time of Day (TOD)	2502	2697.66	1.0782	0.0557	23.23	0.4477	

Table 5. Deviance analysis showing the stepwise procedure used to develop the lognormal model on nonzero abundance of king mackerel larvae.

Nonzero Larval Abundance Factors	d.f	Deviance	Deviance/DF	% Reduction in Deviance/d.f	Chi-Square	Pr> Chi Square	Notes
Null Model	706	464.93	0.6585				
Region	705	436.95	0.6198	5.8770	43.88	<0.0001	
Depth	705	446.81	0.6338	3.7509	28.11	<0.0001	
Year	683	434.65	0.6364	3.3561	47.62	0.0019	
Time of Day (TOD)	705	460.46	0.6531	0.8200	6.83	0.009	
Region +							
Depth	704	413.90	0.5879	5.1468	38.32	<0.0001	
Year	682	402.57	0.5903	4.7596	57.95	<0.0001	
Time of Day (TOD)	704	431.26	0.6126	1.1617	9.28	0.0023	
Region + Depth +							
Year	681	379.69	0.5576	5.1539	60.99	<0.0001	
Time of Day (TOD)	703	409.64	0.5827	0.8845	7.31	0.0068	
Region + Depth + Year +							
Time of Day (TOD)	680	373.86	0.5498	1.3989	10.95	0.0009	
Region + Year + Depth + Time of Day +							
Year*Region	658	352.45	0.5356	2.5828	41.69	0.0068	See Results
Year*Depth	657	364.34	0.5546	0.8730	18.22	0.7453	
Year*Time of Day (TOD)	657	358.41	0.5455	0.7821	29.82	0.1545	
Region + Year + Depth + Time of Day + Year*Region +							
Year*Time of Day (TOD)	635	335.46	0.5283	1.3630	34.92	0.0530	
Year*Depth	635	341.73	0.5382	0.4854	21.83	0.5304	

Table 6. Annual sample size, nominal catch per unit area (CPUA) and proportion of positive occurrence of larval king mackerel for 1986 to 2012 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 CPUA	Scaled Nominal CPUA	CV Nominal CPUA	Proportion Positive	Scaled Proportion Positive	CV Proportion Positive
1986	108	0.3337	0.1097	0.4094	0.0648	0.2355	0.3672
1987	118	0.9542	0.3138	0.2292	0.1610	0.5851	0.2110
1988	66	1.5010	0.4936	0.3748	0.1515	0.5506	0.2935
1989	68	2.1210	0.6974	0.2837	0.2353	0.8551	0.2202
1990	70	1.8805	0.6184	0.2831	0.2429	0.8825	0.2126
1991	74	2.1061	0.6925	0.2959	0.2432	0.8839	0.2064
1992	101	2.0013	0.6581	0.1863	0.3267	1.1874	0.1435
1993	105	4.0154	1.3204	0.1932	0.3810	1.3844	0.1250
1994	122	2.9967	0.9854	0.1981	0.2951	1.0723	0.1405
1995	119	6.3564	2.0902	0.1842	0.3613	1.3131	0.1224
1996	117	2.5347	0.8335	0.2774	0.2308	0.8386	0.1695
1997	118	4.2558	1.3995	0.1914	0.3475	1.2627	0.1267
1998							
1999	117	2.7040	0.8892	0.2381	0.3162	1.1492	0.1365
2000	114	2.7403	0.9011	0.2115	0.2281	0.8288	0.1731
2001	112	4.2803	1.4075	0.2249	0.3571	1.2979	0.1273
2002	93	4.6680	1.5350	0.2140	0.3978	1.4458	0.1283
2003	120	3.0195	0.9929	0.2071	0.3083	1.1205	0.1373
2004	95	5.2461	1.7251	0.3182	0.4105	1.4919	0.1236
2005							
2006	111	3.3899	1.1147	0.2181	0.2613	0.9494	0.1603
2007	123	3.8405	1.2629	0.2127	0.3008	1.0932	0.1380
2008							
2009	122	1.9532	0.6423	0.1892	0.2623	0.9532	0.1525
2010	120	3.0622	1.0070	0.2482	0.2417	0.8782	0.1624
2011	121	4.2209	1.3880	0.3213	0.2397	0.8710	0.1626
2012	117	2.8034	0.9219	0.2424	0.2393	0.8697	0.1655

Table 7. Indices of larval king mackerel Gulf of Mexico abundance developed using the delta-lognormal model for 1986-2012. The nominal frequency of occurrence, the number of samples (*N*), the DL Index (number under 10 m^2 sea surface), the 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.

SurveyYear	*NominalFrequency*	*N*	*LoIndex*	*ScaledLoIndex*	*CV*	*LCL*	*UCL*
1986	0.06481	108	0.31505	0.11459	0.53011	0.04235	0.31002
1987	0.16102	118	1.03439	0.37622	0.31789	0.20228	0.69975
1988	0.15152	66	1.62125	0.58967	0.43265	0.25752	1.35022
1989	0.23529	68	2.20192	0.80088	0.33368	0.41817	1.53384
1990	0.24286	70	1.80422	0.65623	0.32701	0.34689	1.24140
1991	0.24324	74	1.93558	0.70400	0.31449	0.38091	1.30114
1992	0.32673	101	1.72619	0.62785	0.23335	0.39614	0.99508
1993	0.38095	105	3.35846	1.22153	0.20501	0.81408	1.83291
1994	0.29508	122	2.78428	1.01269	0.22049	0.65498	1.56575
1995	0.36134	119	5.34024	1.94234	0.19556	1.31841	2.86153
1996	0.23077	117	2.03849	0.74144	0.26106	0.44366	1.23908
1997	0.34746	118	3.55260	1.29214	0.20186	0.86642	1.92705
1998							
1999	0.31624	117	2.52511	0.91842	0.21593	0.59927	1.40755
2000	0.22807	114	2.50818	0.91227	0.26906	0.53764	1.54793
2001	0.35714	112	4.22606	1.53709	0.20126	1.03185	2.28971
2002	0.39785	93	3.89616	1.41710	0.21194	0.93182	2.15511
2003	0.30833	120	2.89699	1.05369	0.21658	0.68666	1.61689
2004	0.41053	95	3.97838	1.44701	0.20778	0.95918	2.18292
2005							
2006	0.26126	111	3.17495	1.15478	0.24997	0.70577	1.88947
2007	0.30081	123	3.85725	1.40295	0.21593	0.91542	2.15012
2008							
2009	0.26230	122	2.26181	0.82266	0.23689	0.51554	1.31274
2010	0.24167	120	3.11501	1.13298	0.24988	0.69257	1.85347
2011	0.23967	121	3.48081	1.26603	0.24916	0.77496	2.06828
2012	0.23932	117	2.35198	0.85545	0.25651	0.51634	1.41729

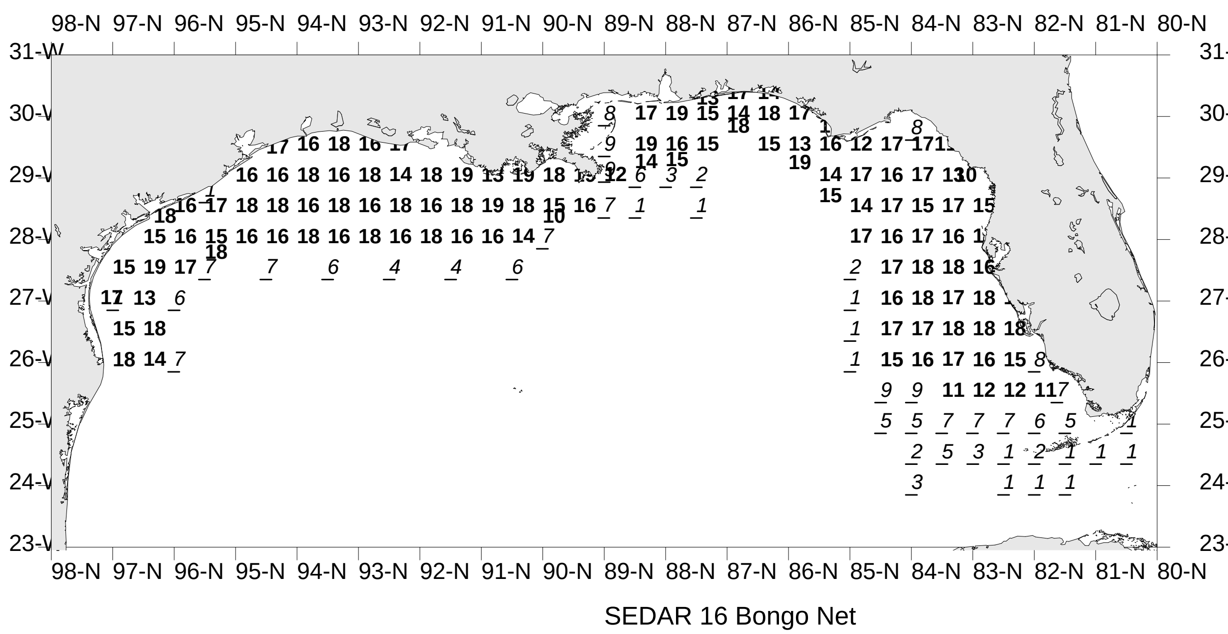


Figure 1. SEDAR 38 (upper) number of bongo net index samples at each SEAMAP B-number location from 1986-1997, 1999-2004, 2006-2007 and 2009-2012 collected during the SEAMAP Fall Plankton Survey. Bold numbers represent locations that were sampled at least 14 times (~60%) during the survey, and were included in analysis while those underlined and in italics were not included in the analysis. SEDAR 16 (lower) bongo net index samples from 1986-1997, 1999-2004 and 2006 for comparison.

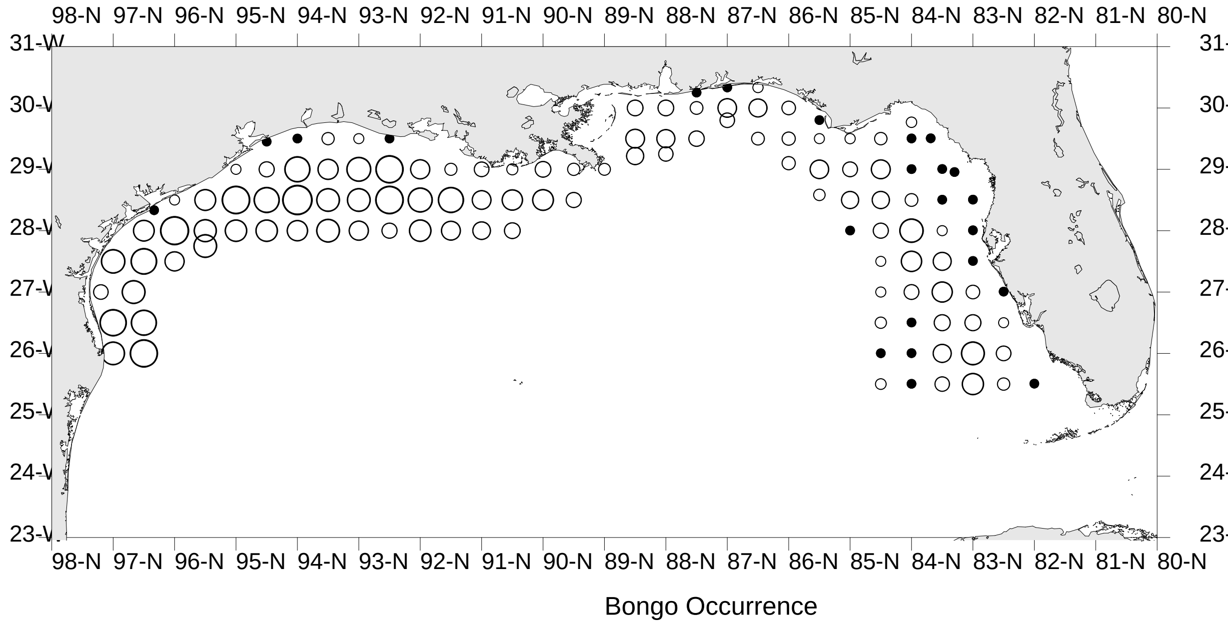


Figure 2. Proportion of positive occurrence (upper) and mean number under 10 m^2 sea surface (lower) of king mackerel larvae captured in bongo net samples during the index years of the SEAMAP Fall Plankton survey. ● = zero catch; ○ = from > 0 to 1 proportion of positive occurrence or ○ = from > 0 to 15 larvae m^2 sea surface. Symbol size is scaled proportionally over the range of positive values.

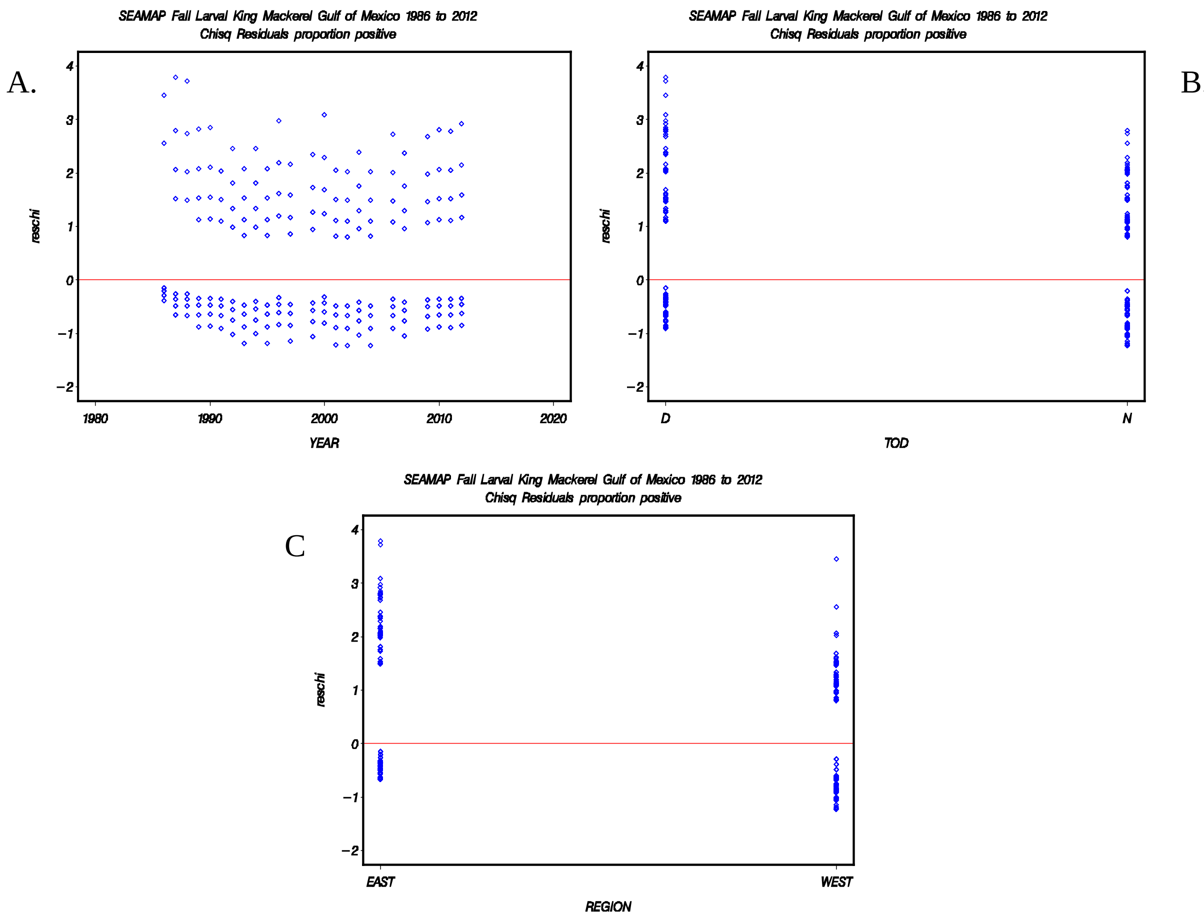


Figure 3. Diagnostic plots for binomial component of the larval king mackerel SEAMAP Fall Plankton Survey Gulf of Mexico index: **A.** the Chi-Square residuals by year, **B.** the Chi-Square residuals by time of day (TOD) and **C.** the Chi-Square residuals by region.

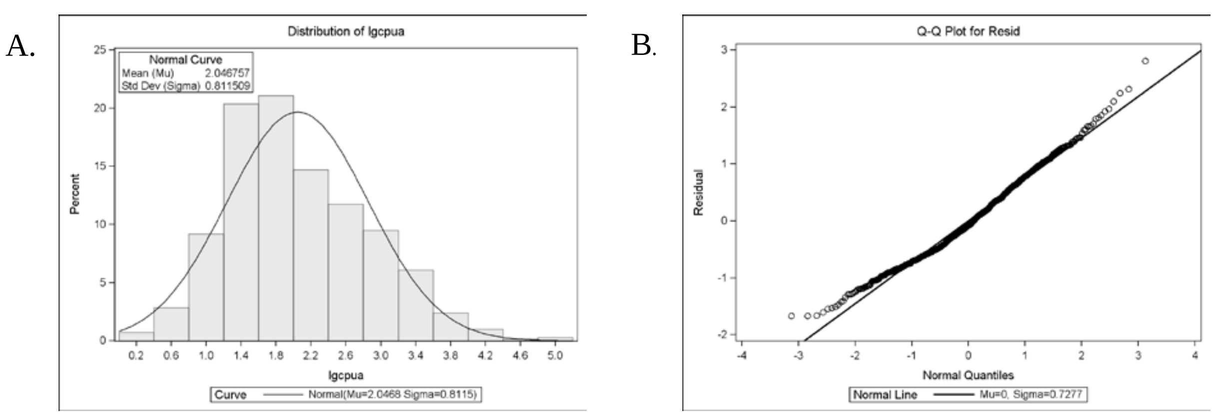


Figure 4. Diagnostic plots for lognormal component of the larval king mackerel SEAMAP Fall Plankton Survey Gulf of Mexico model: **A.** the frequency distribution of log(CPUA) on positive stations and **B.** the cumulative normalized residuals (QQ plot).

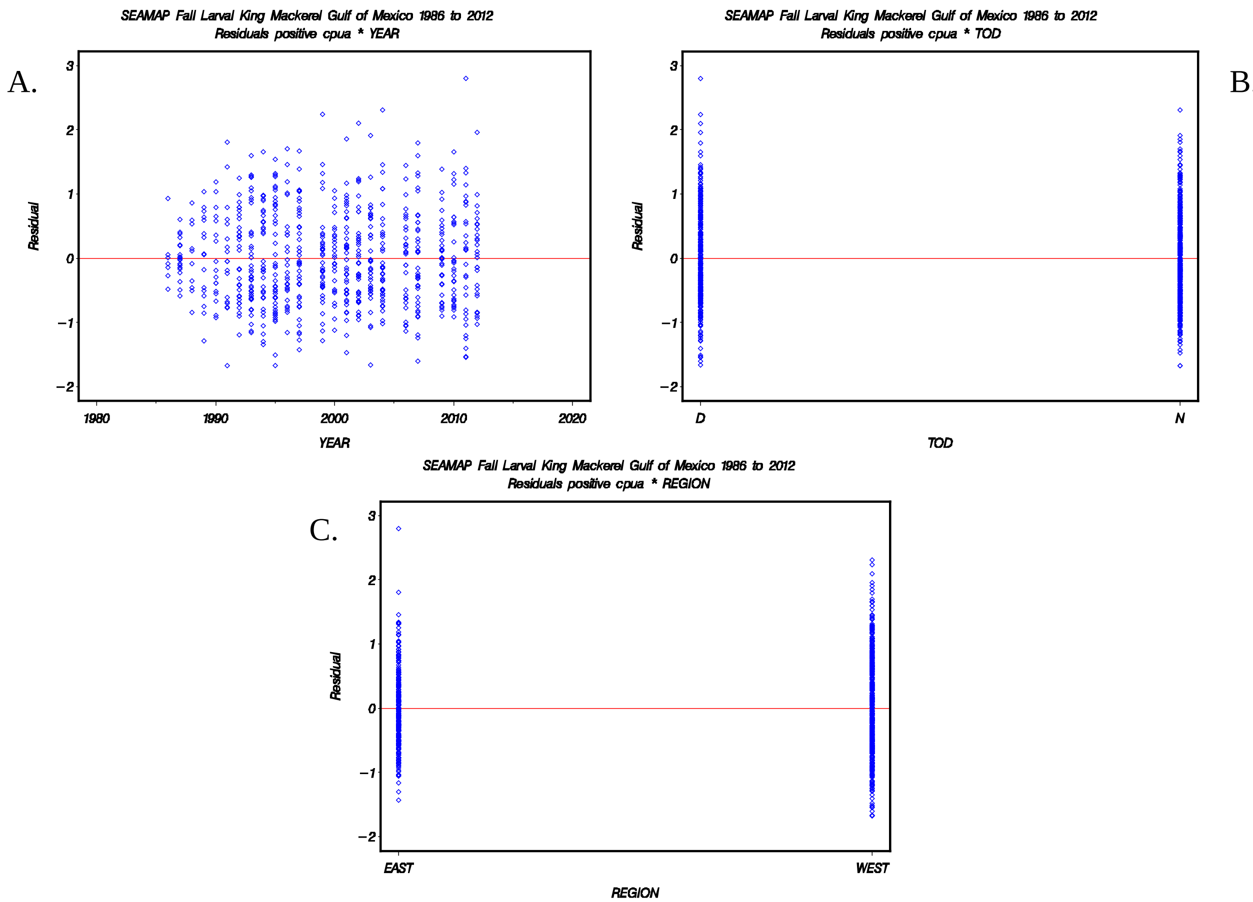


Figure 5. Diagnostic plots for lognormal component of the larval king mackerel SEAMAP Fall Plankton Survey Gulf of Mexico model: **A.** residuals by year, **B.** residuals by time of day (TOD) and **C.** residuals by region.

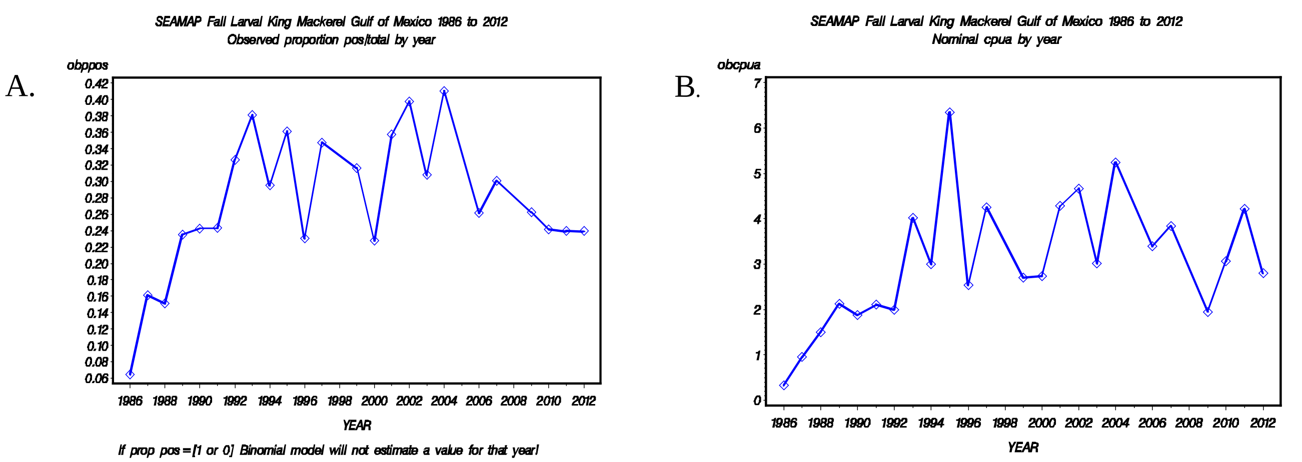


Figure 6. Annual trends for larval king mackerel captured during the SEAMAP Fall Plankton Survey from 1986 to 2012 in **A.** proportion of positive stations and **B.** nominal CPUA.

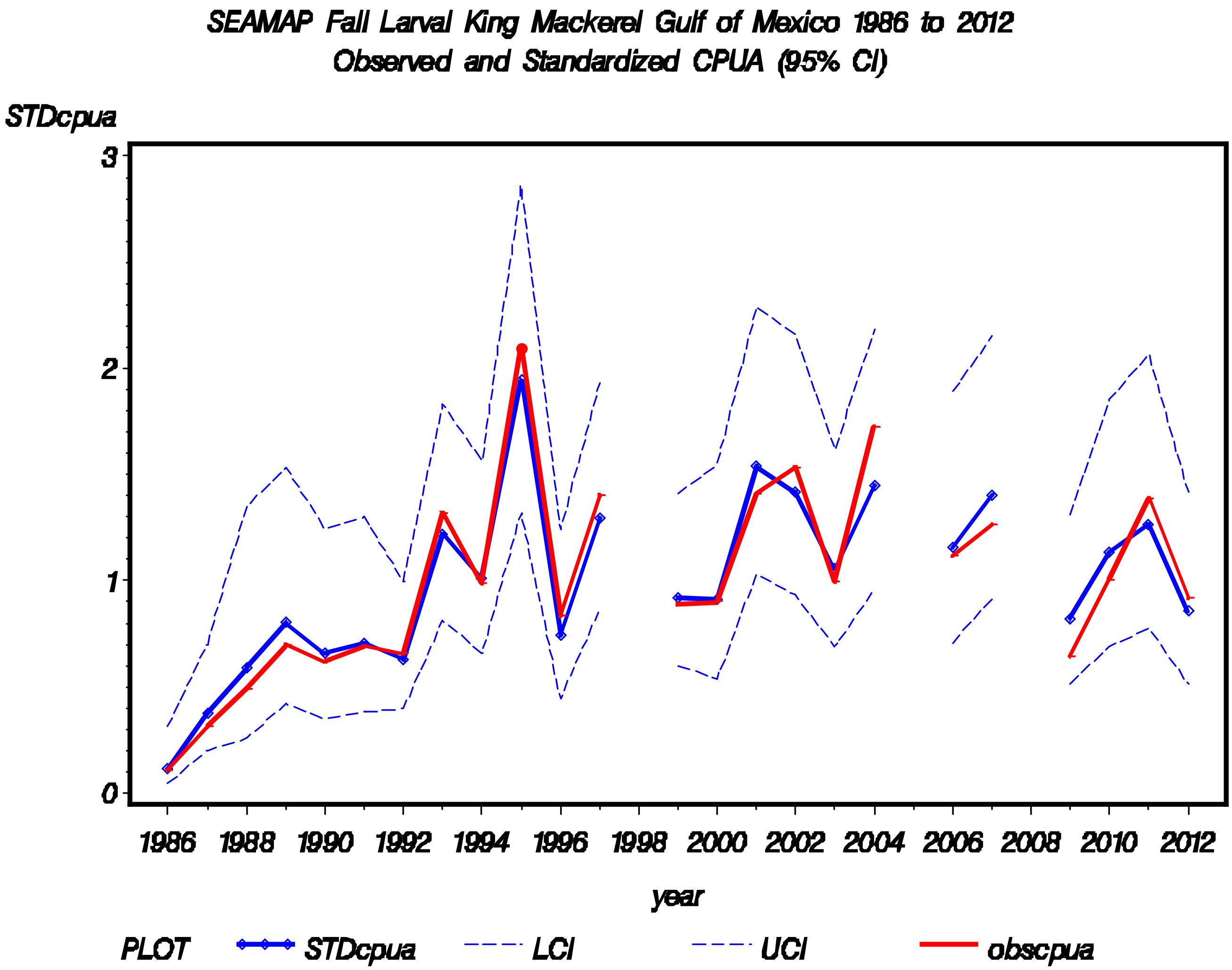
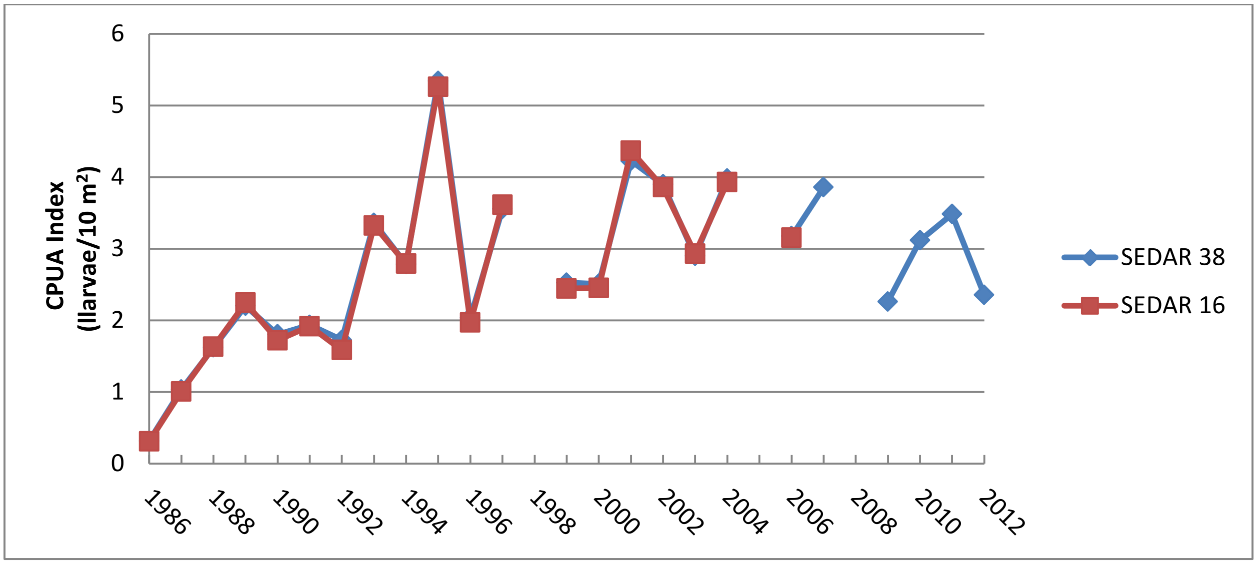
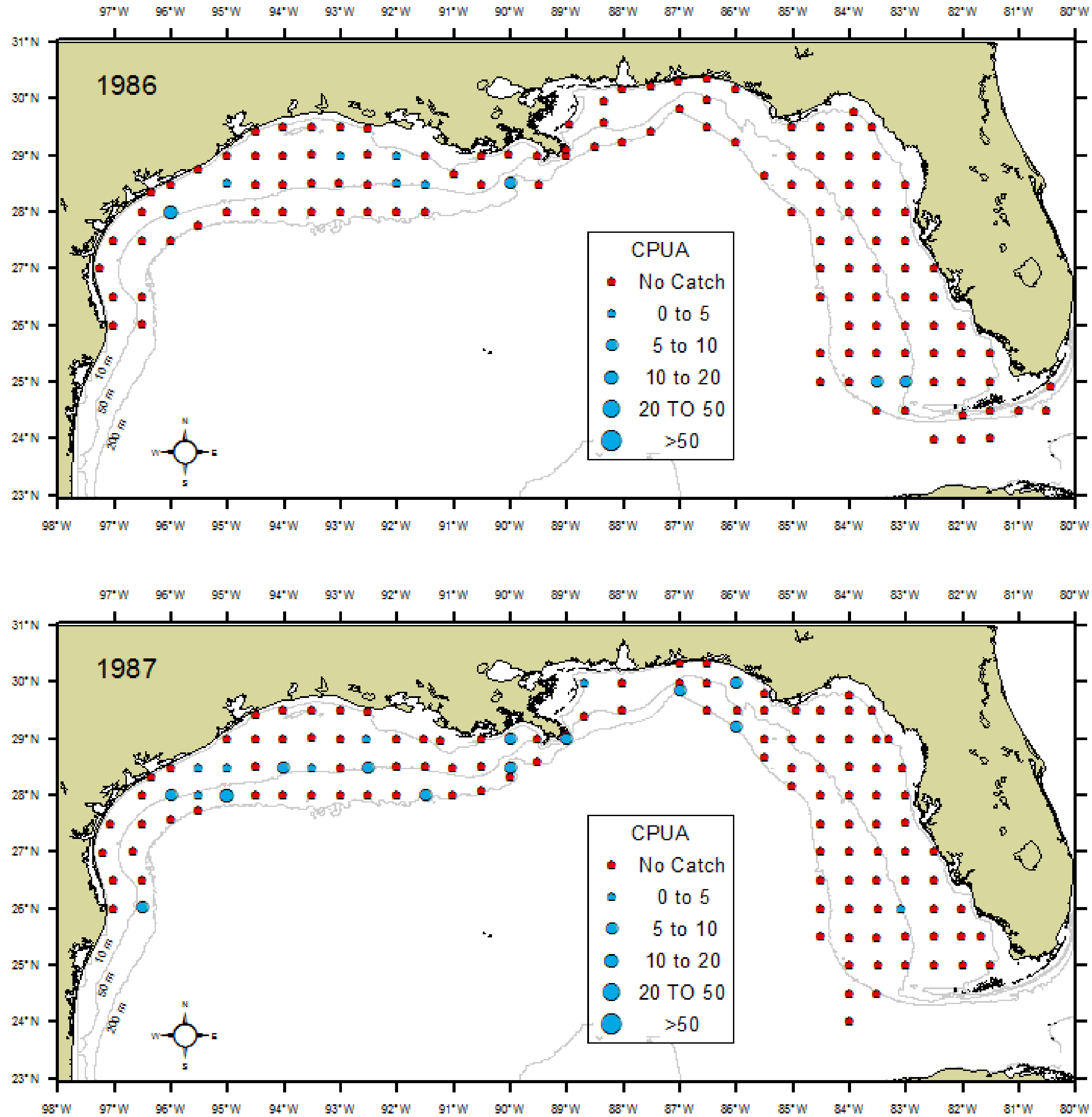


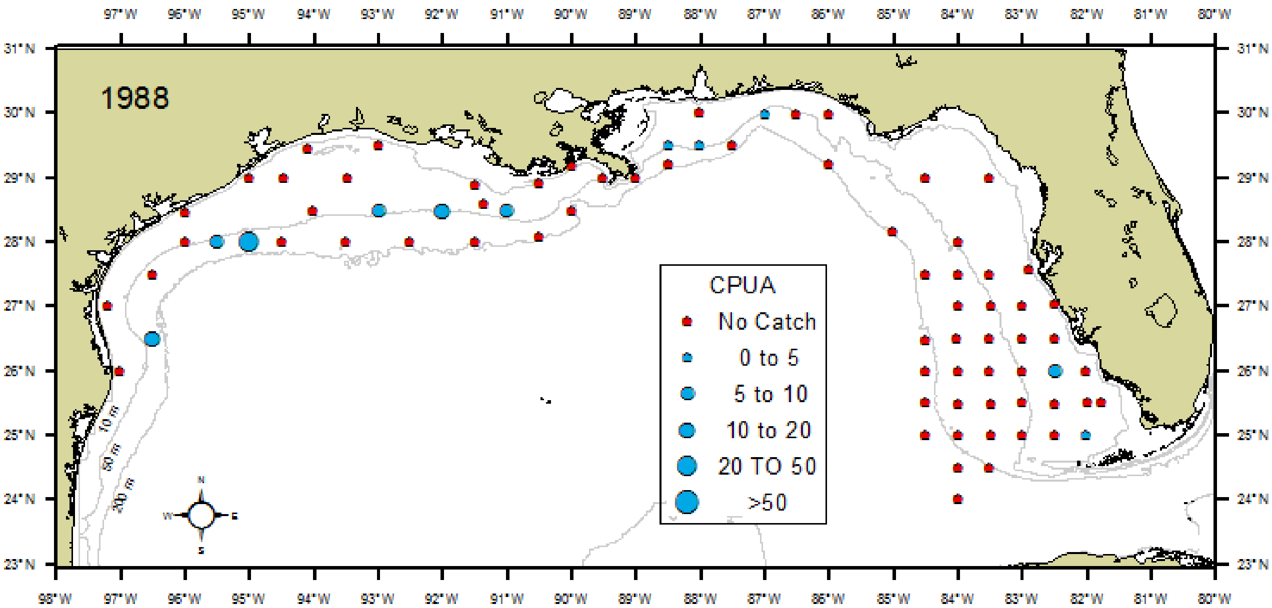
Figure 7. Annual index of abundance for Gulf of Mexico larval king mackerel captured during SEAMAP Fall Plankton Surveys from 1986 – 2012.

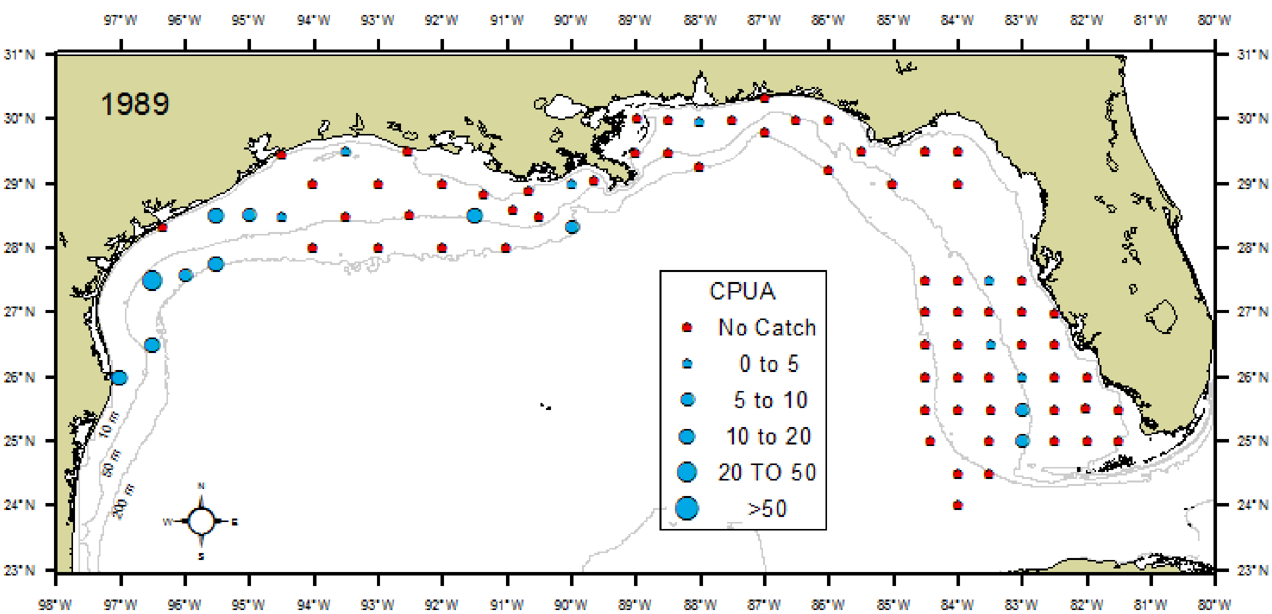
Figure 8. Comparison of the SEDAR 38 and SEDAR 16 annual indices of catch per unit effort (CPUA) of Gulf of Mexico larval king mackerel captured during SEAMAP Fall Plankton Surveys from 1986 – 2012.

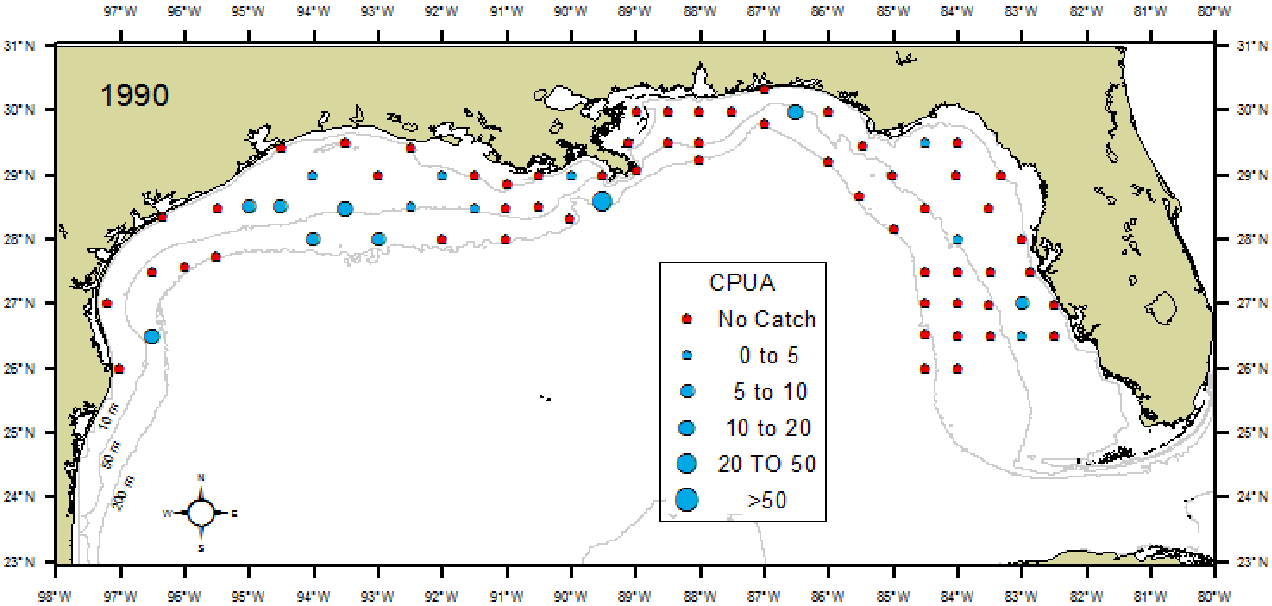


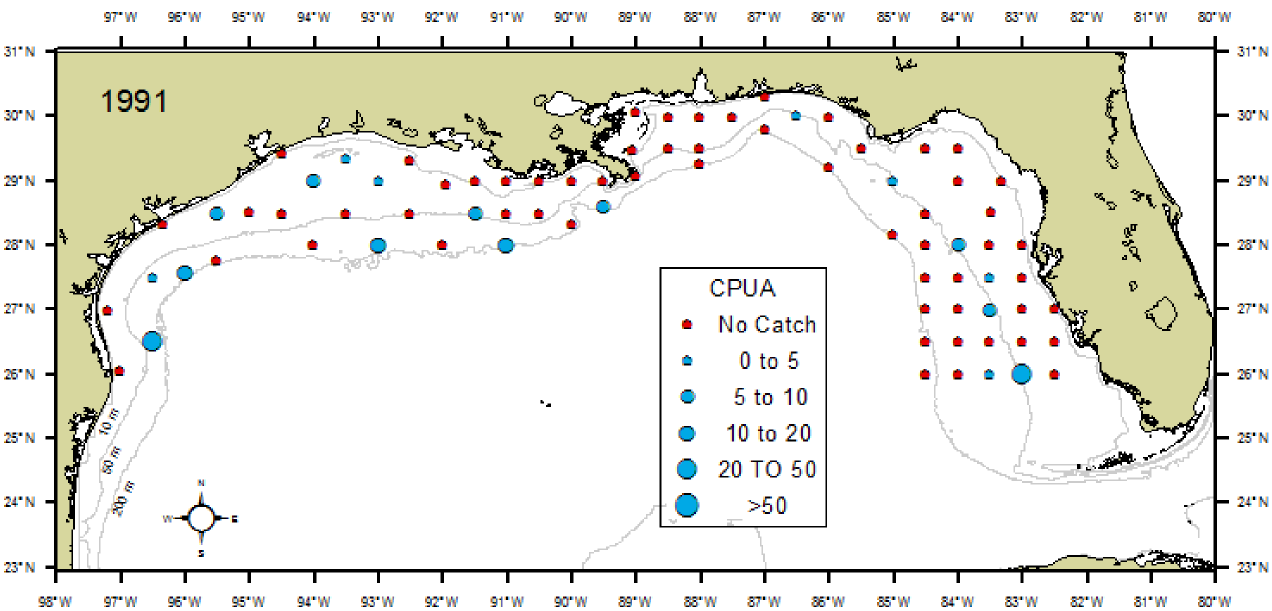
Appendix Figure 1. Annual survey effort and catch per unit area (CPUA) of larval king mackerel from the SEAMAP Fall Plankton Survey conducted from 1986-2012. CPUA is expressed as the number of larvae under 10 m^2.

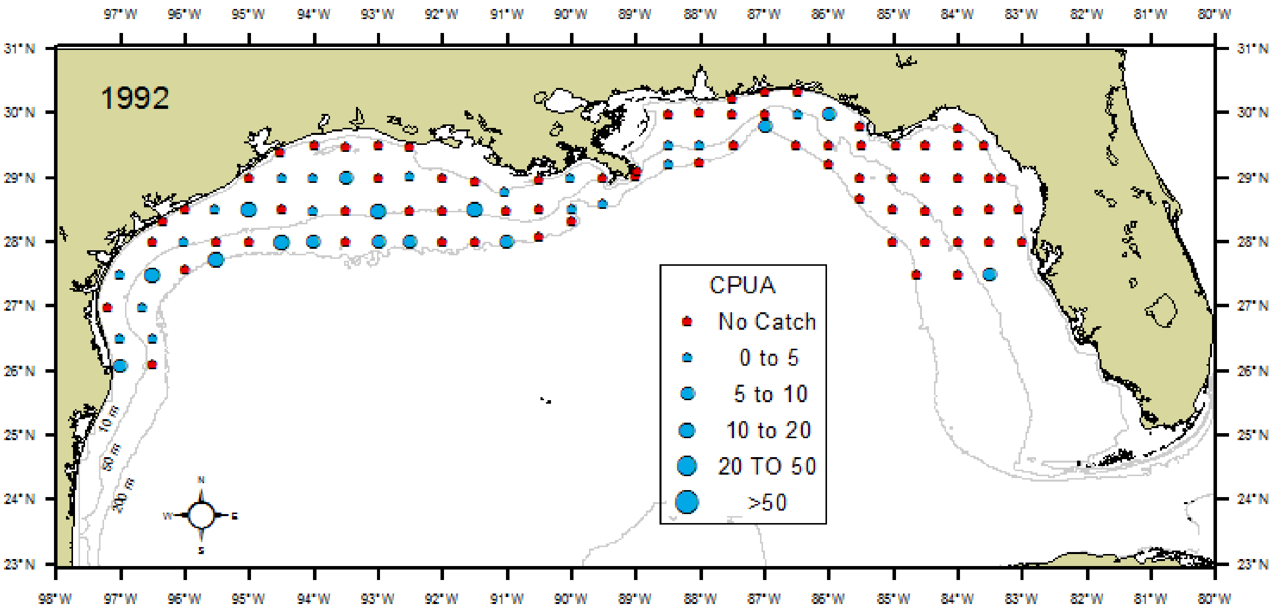


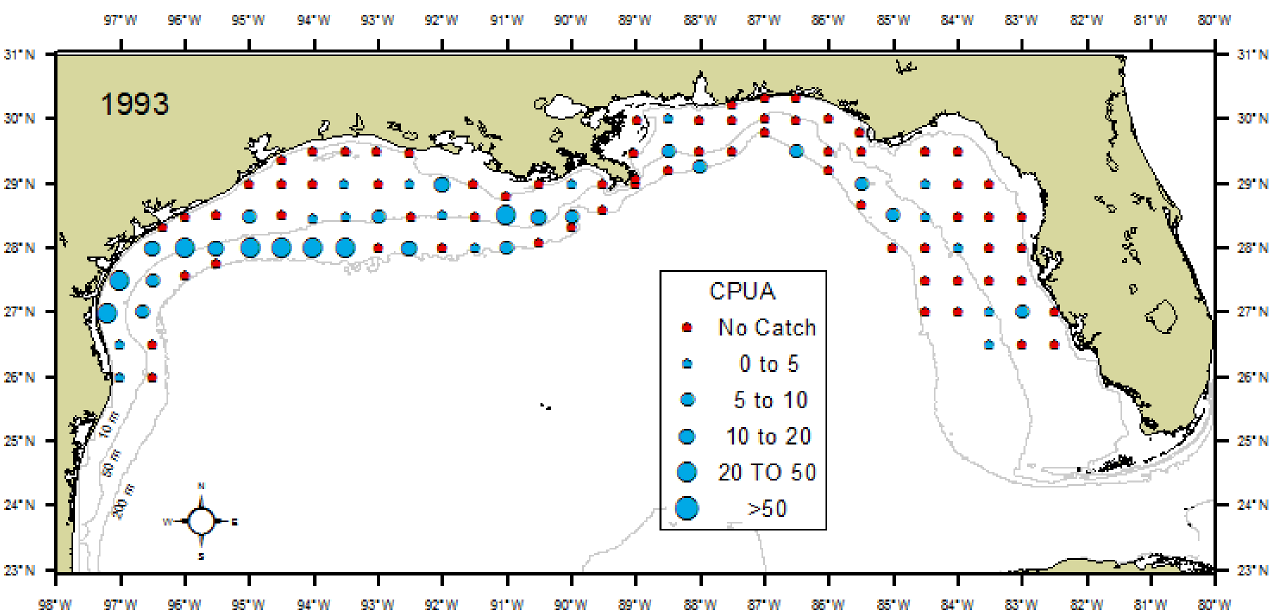

1988
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50

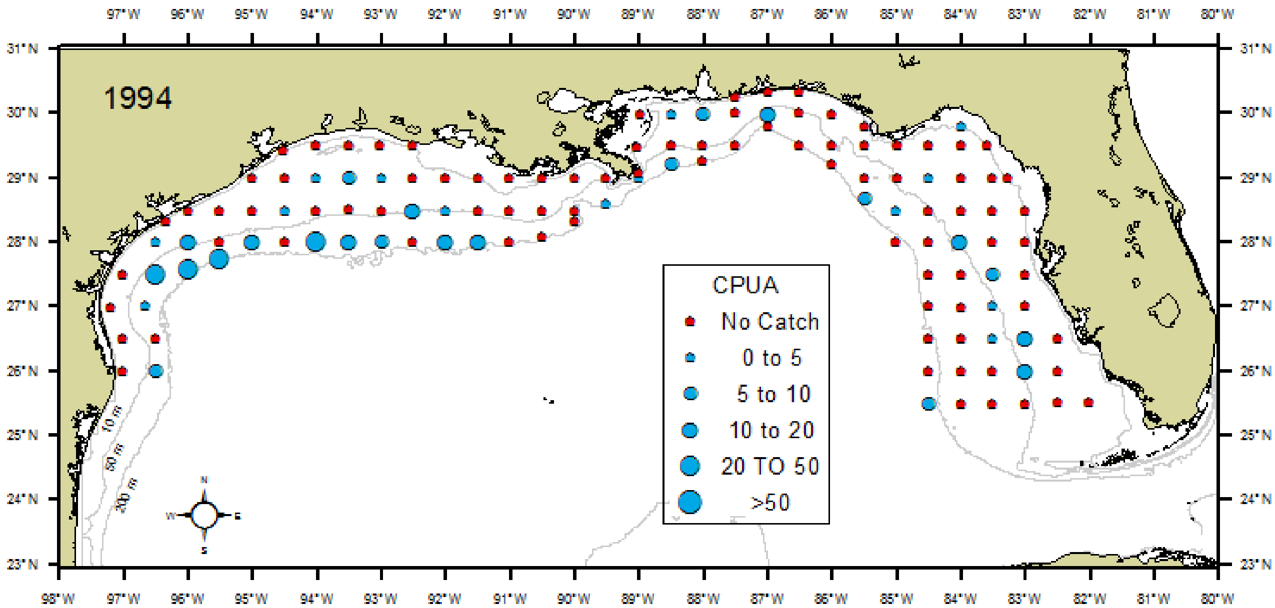

1989
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50

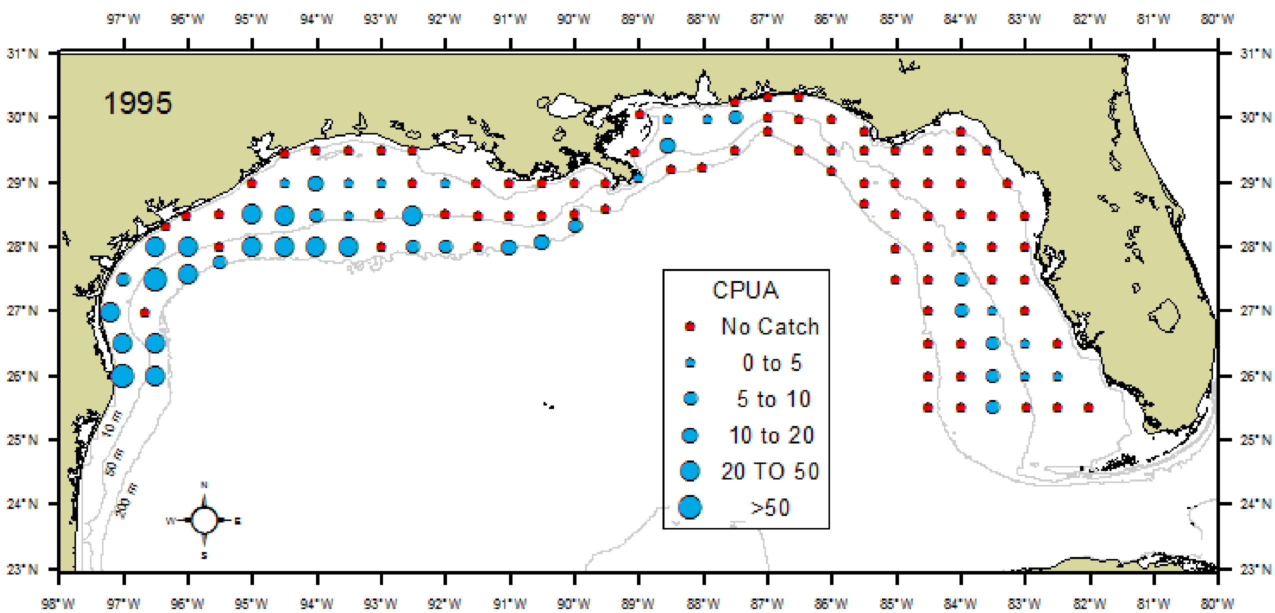

1990
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50
10 m
50 m
200 m

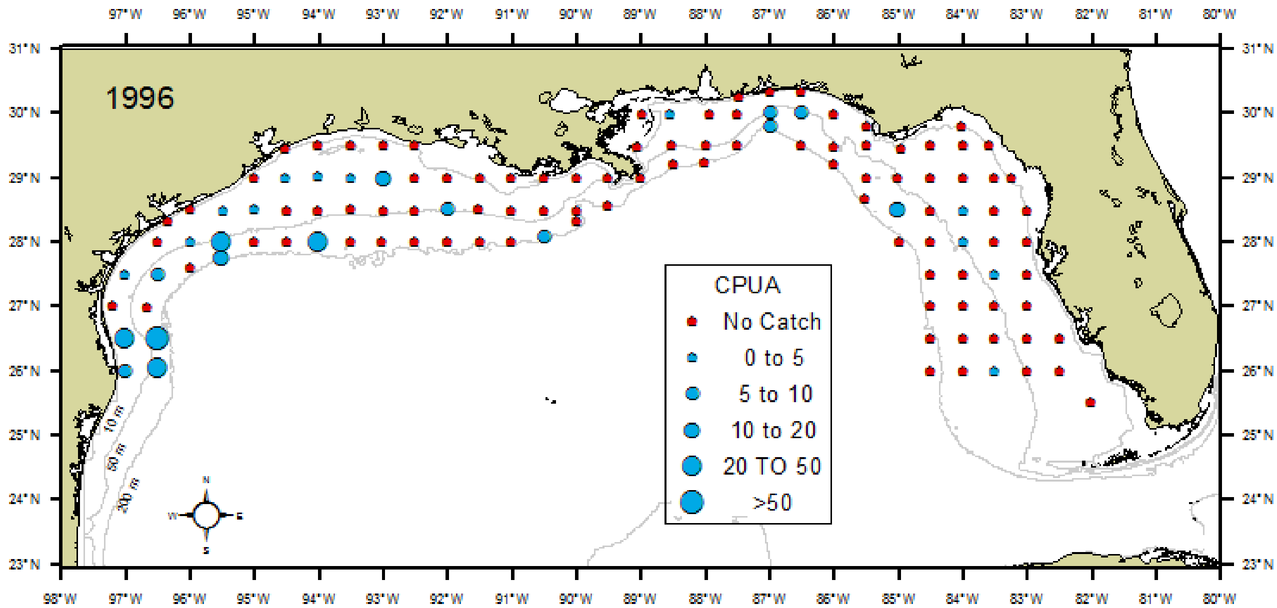

1991
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50
10 m
50 m
200 m

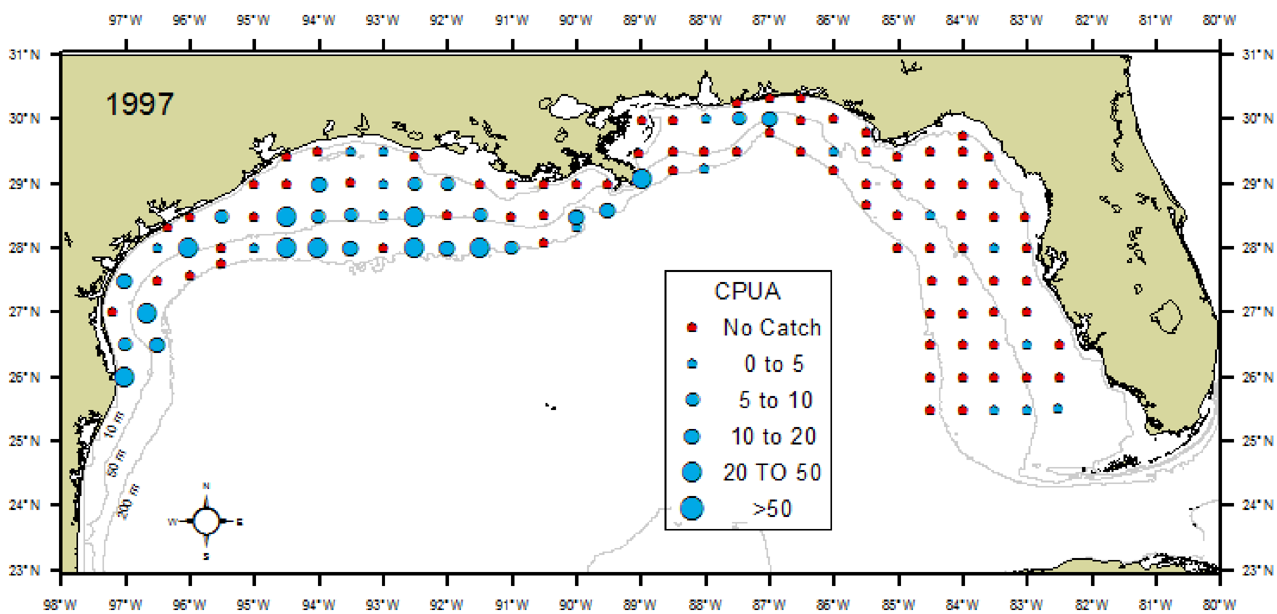

1992
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50
10 m
50 m
200 m

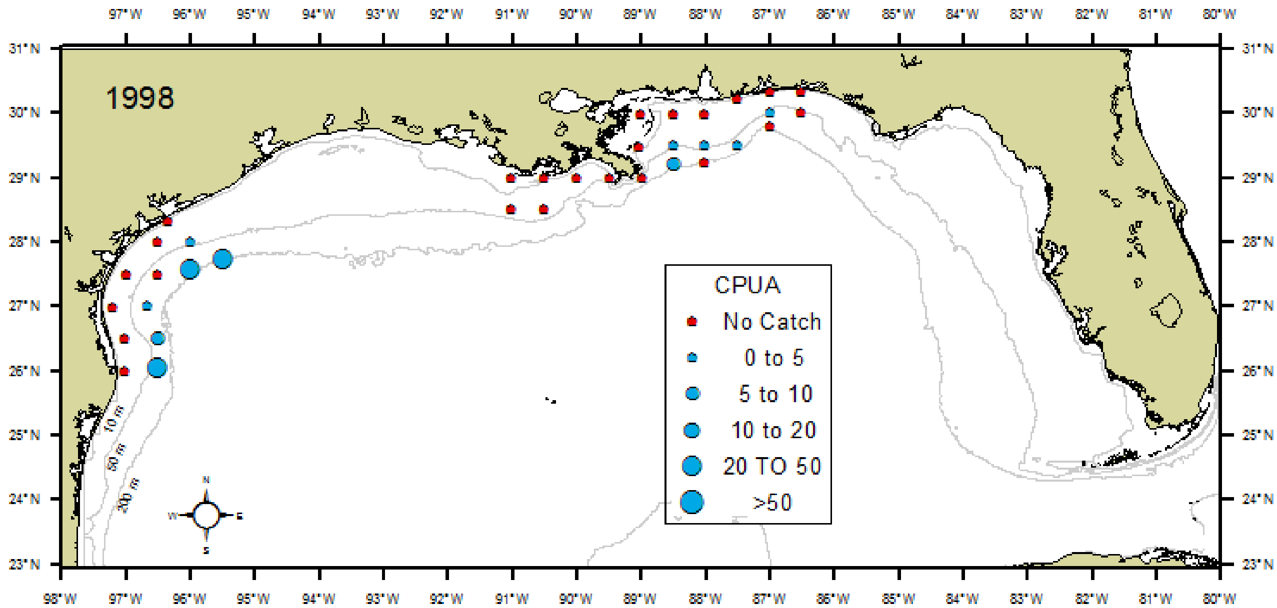

1993
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50
10 m
50 m
200 m

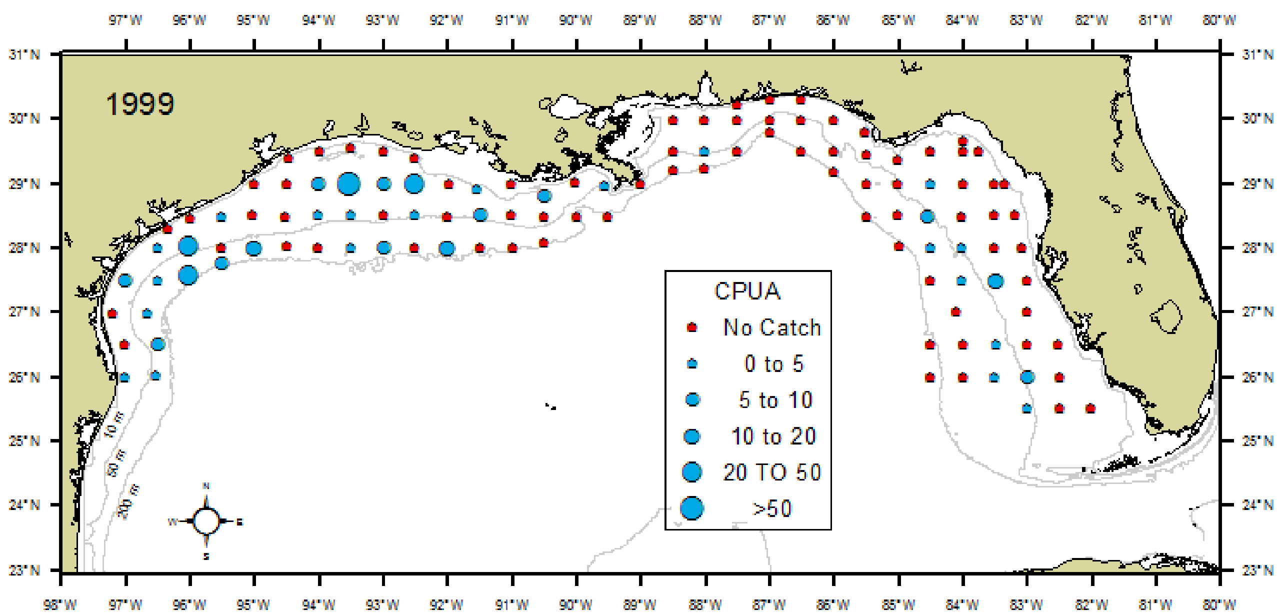

1994
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50
10 m
50 m
200 m

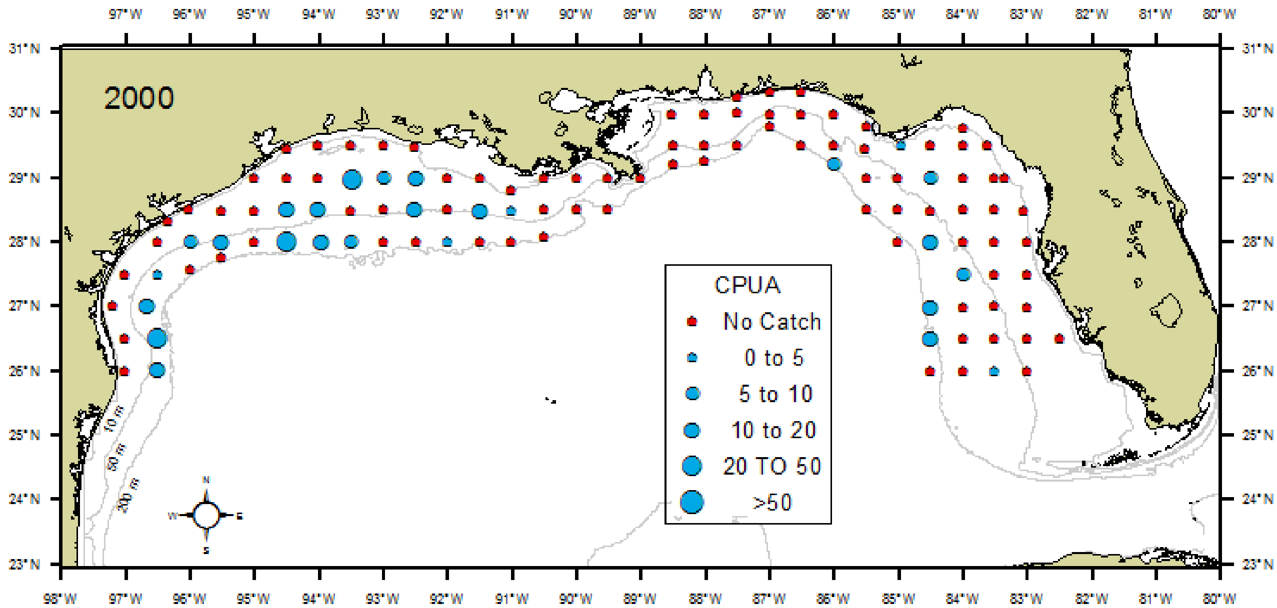

1995
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50
10 m
50 m
200 m

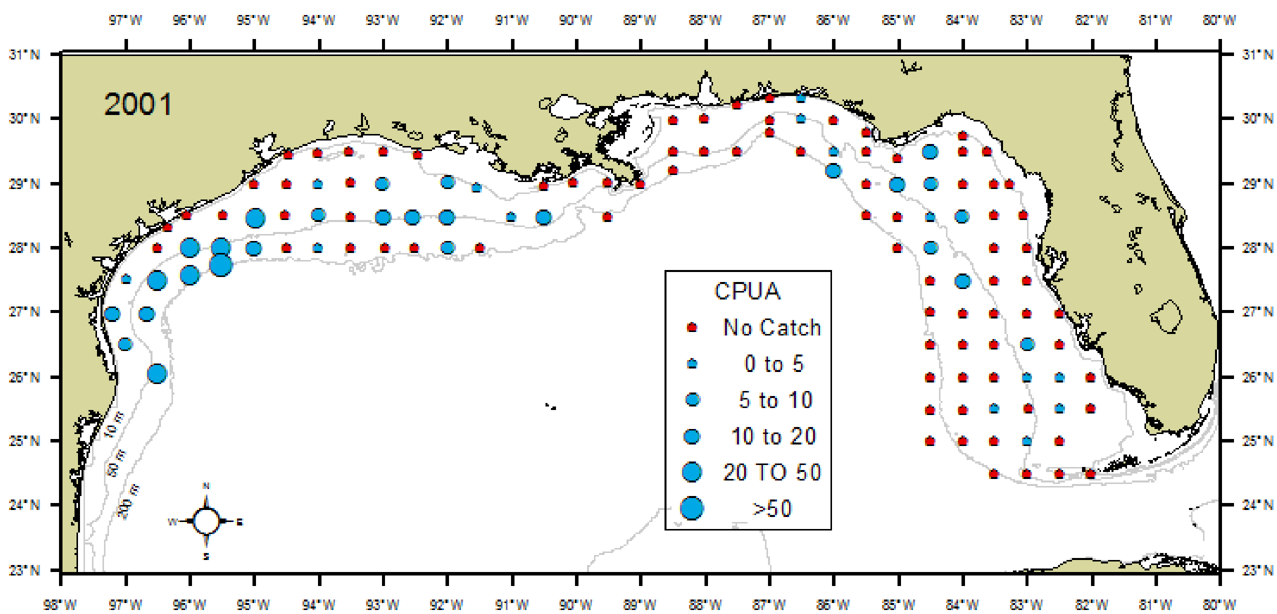

1996
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50

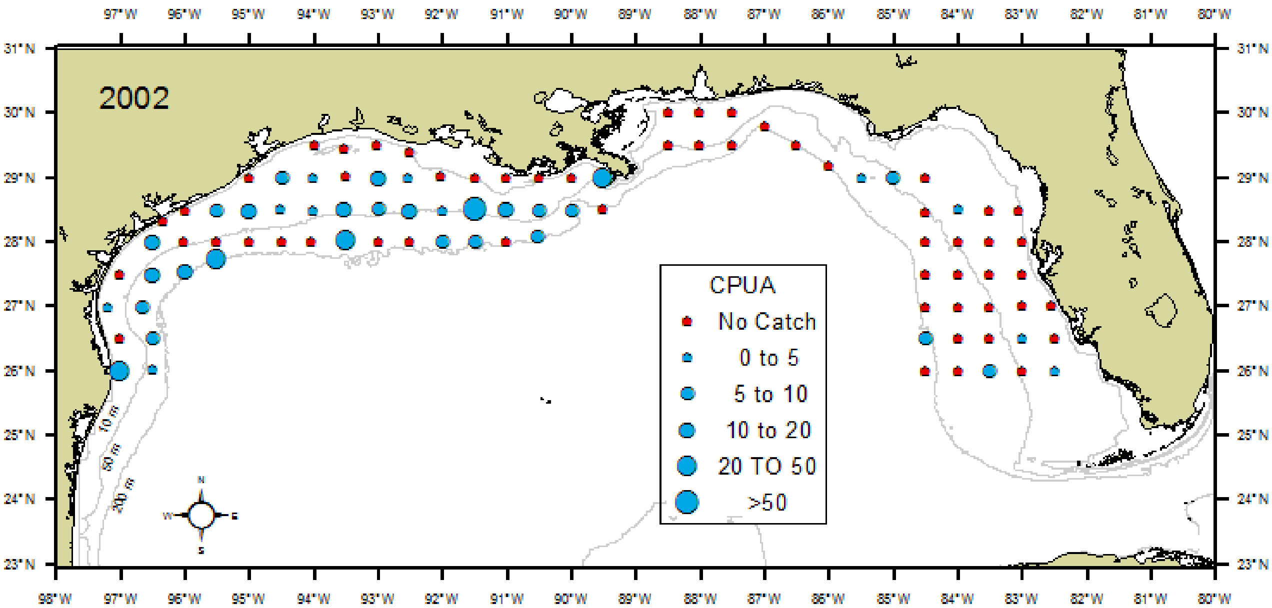

1997
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50

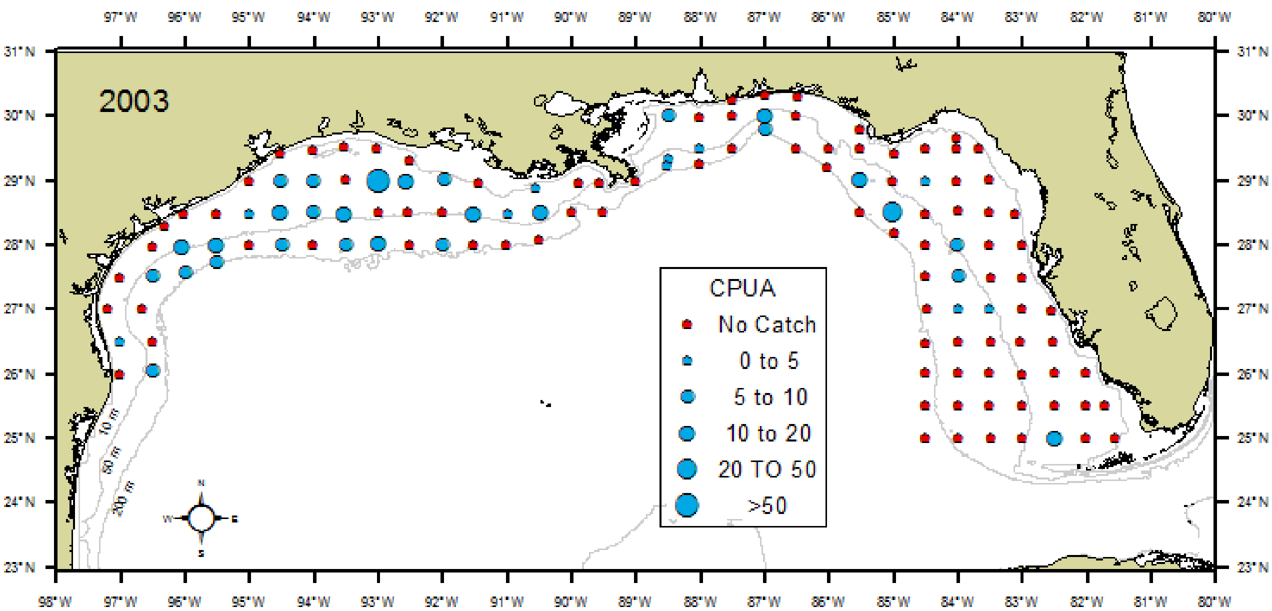

1998
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50
10 m
50 m
200 m

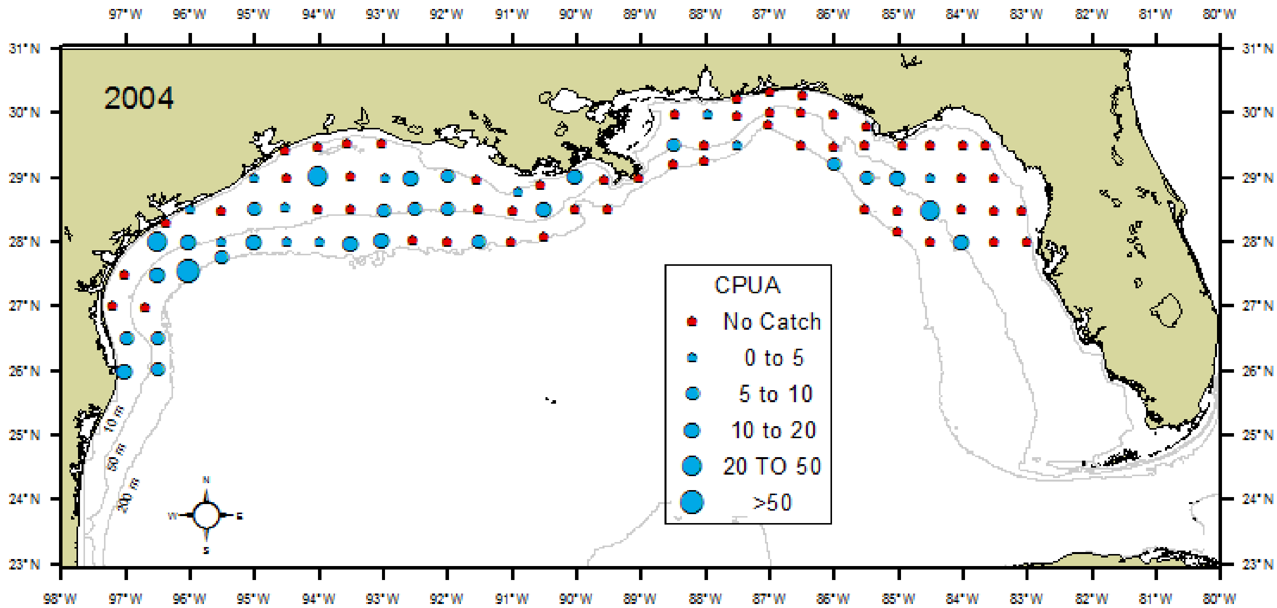

1999
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50
10 m
50 m
200 m


2000
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50
10 m
50 m
200 m
N
S
E
W


2001
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50
10 m
50 m
200 m
N
S
E
W


2002
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50
10 m
50 m
200 m
N
S
W
E


2003
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50
10 m
50 m
200 m
N
S
W
E


2004
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50
10 m
50 m
200 m
N
S
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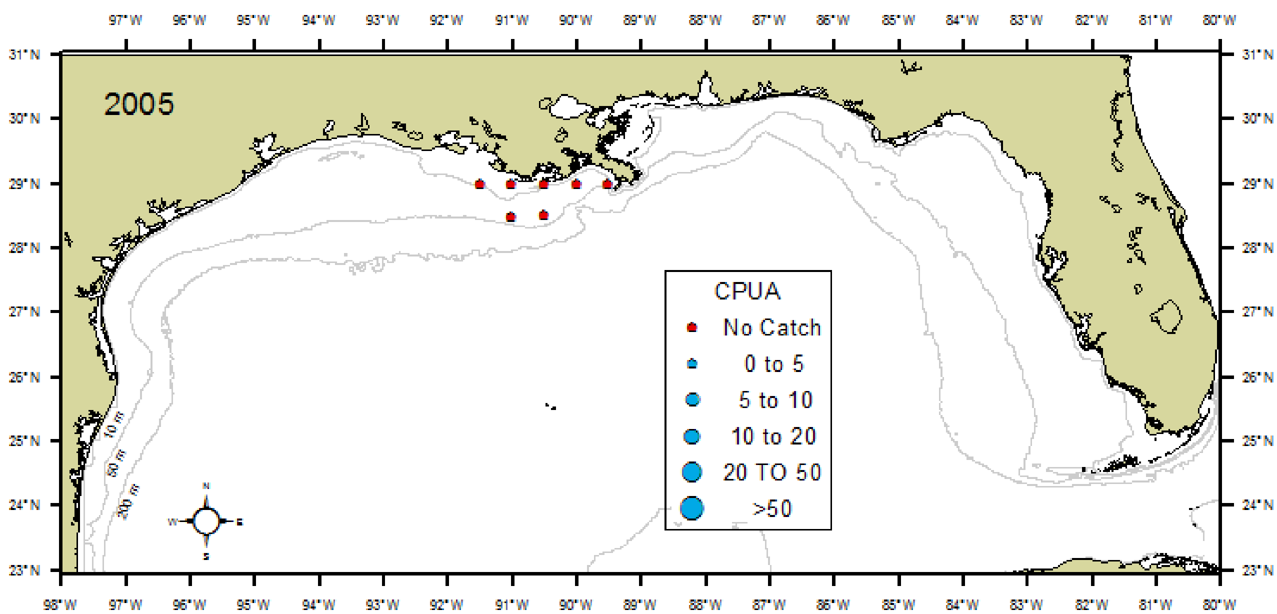
W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CPUA
No Catch
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5 to 10
10 to 20
20 TO 50
>50
10 m
50 m
200 m
N
S
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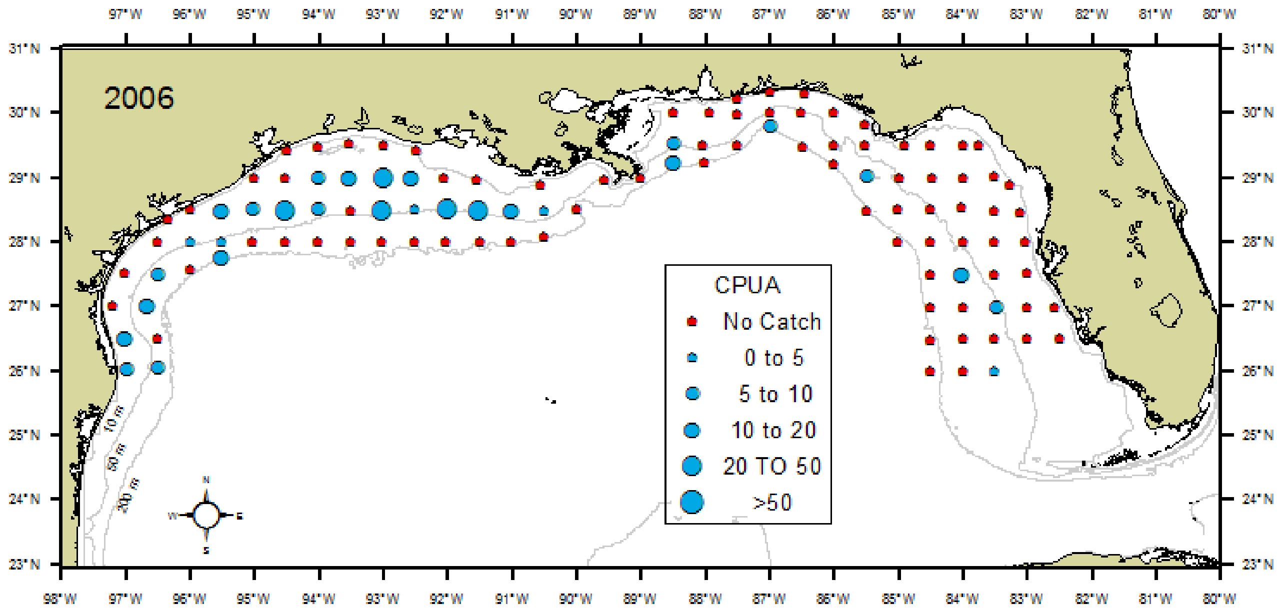
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No Catch
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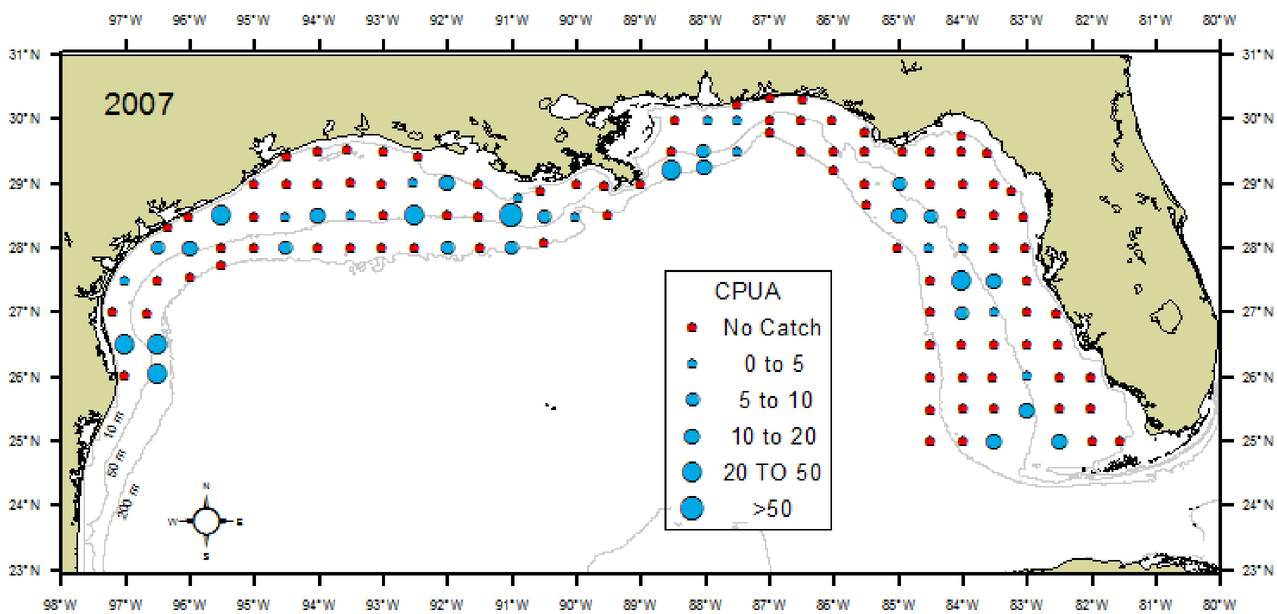
20 TO 50
>50
10 m
50 m
200 m
N
W
E
S


2007
CPUA
No Catch
0 to 5
5 to 10
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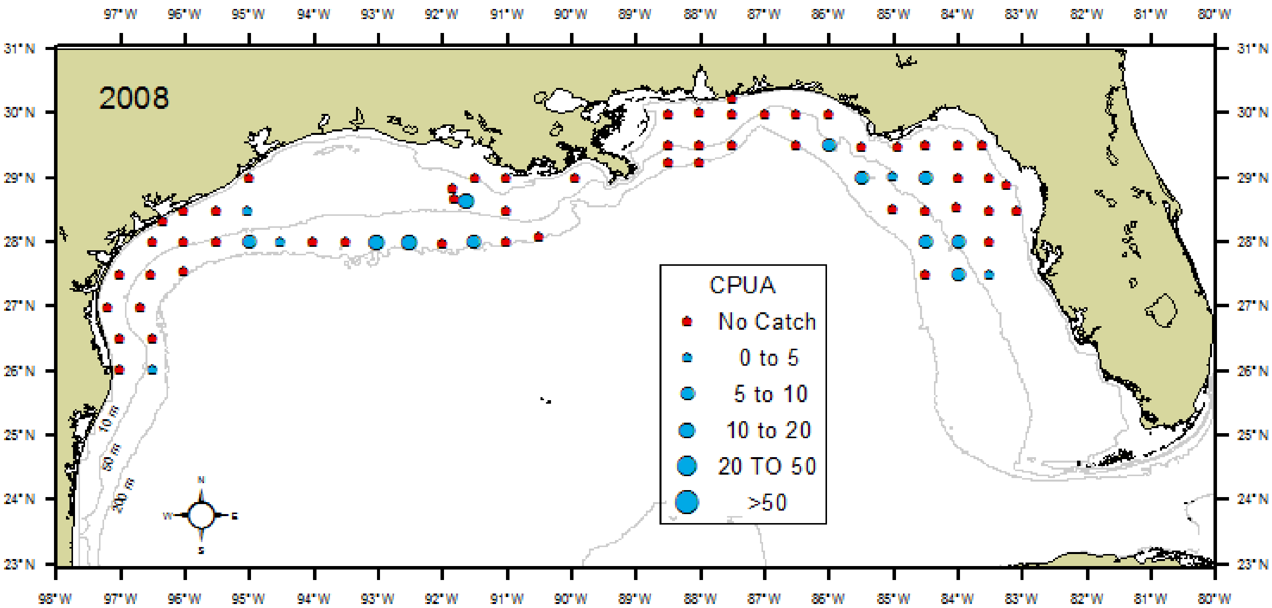
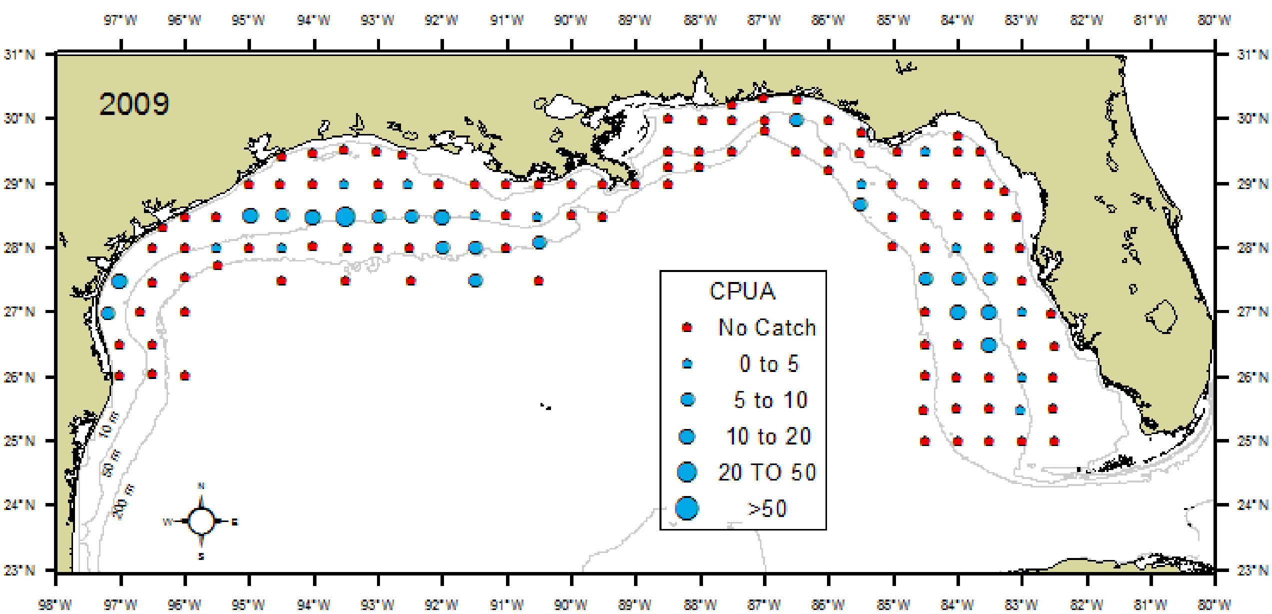
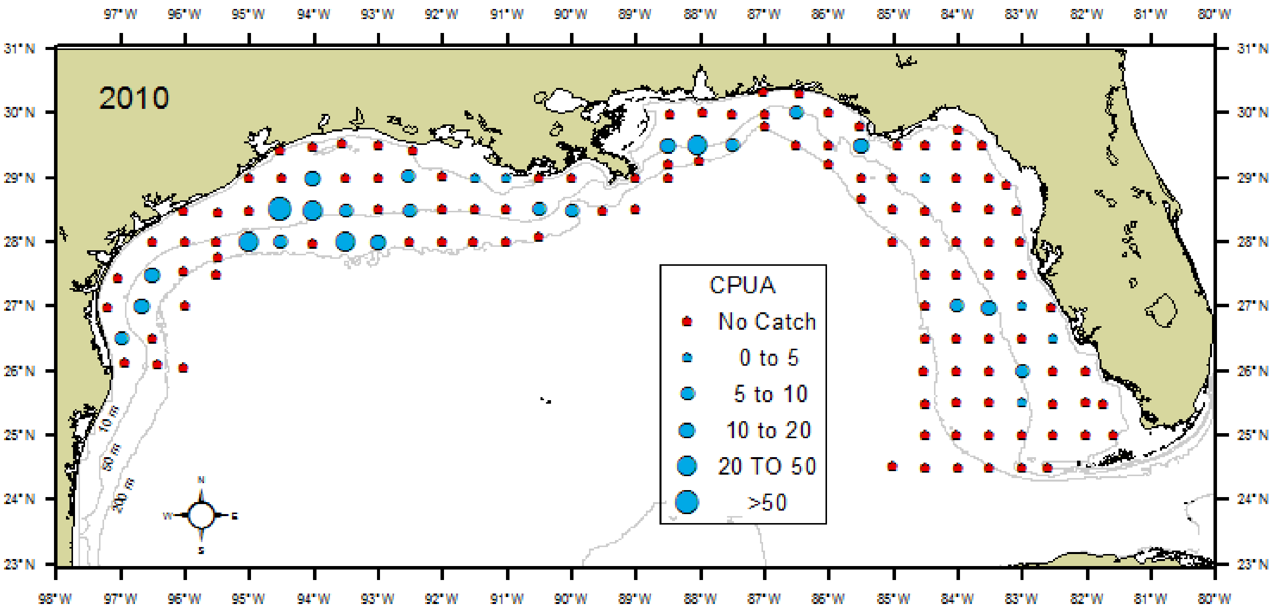
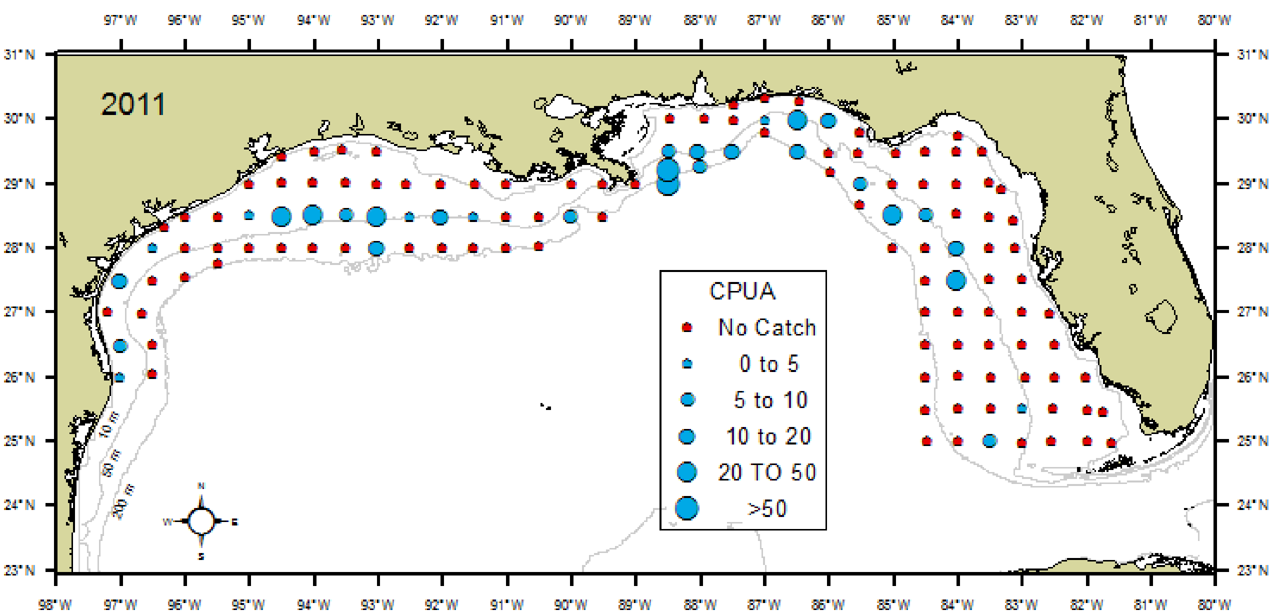
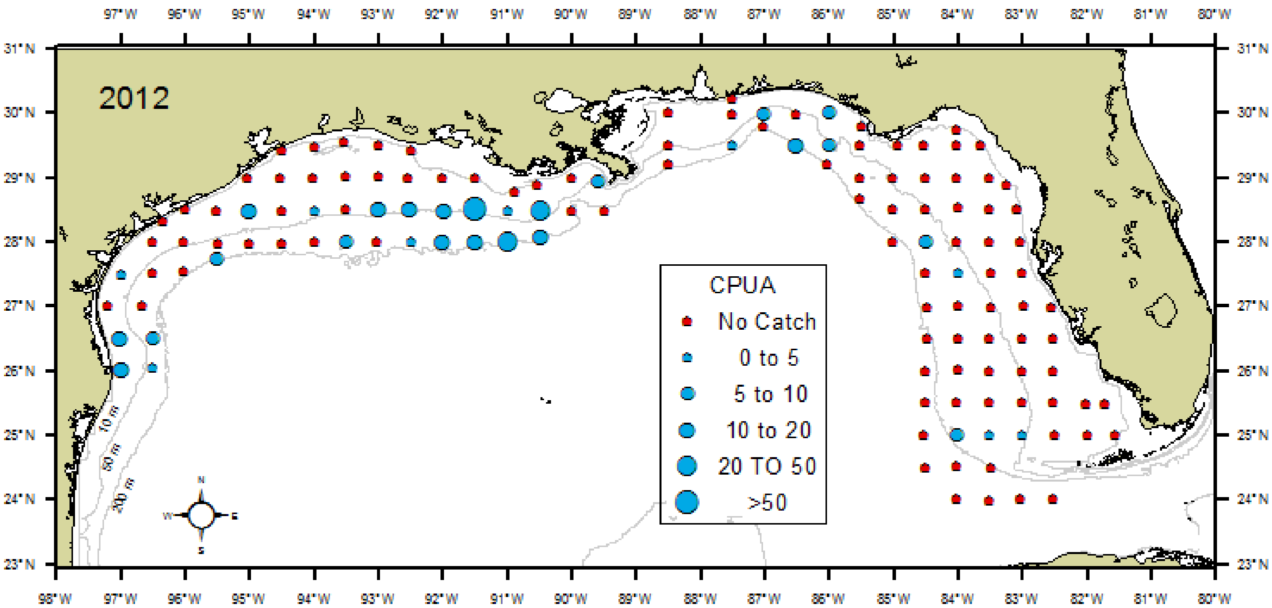
20 TO 50
>50
10 m
50 m
200 m
N
W
E
S


2008
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50


2009
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50


2010
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50


2011
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50


2012
CPUA
No Catch
0 to 5
5 to 10
10 to 20
20 TO 50
>50
10 m
50 m
200 m
N
S
W
E
98°W
97°W
96°W
95°W
94°W
93°W
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91°W
90°W
89°W
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23°N