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Red Snapper (*Lutjanus campechanus*) larval indices of relative abundance from SEAMAP Fall Plankton Surveys, 1986 to 2016

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Abstract: *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 larvae captured during these surveys were initially reviewed as a potential fishery-independent index to reflect trends in the relative spawning stock size of Red Snapper during the Southeast Data Assessment and Review (SEDAR7) process in 2004. Indices of larval abundance as a proxy for adult spawning stock have been incorporated into the SEDAR7 (2004), SEDAR7 Update (2009), SEDAR31 (2012), SEDAR31 Update (2014) assessments. Three age corrected CPUA indices were generated for the SEDAR52 assessment process. A single index was generated for the western GOM (WGOM). A continuity index was not needed for the WGOM as the index formulation remained unchanged since the prior assessment update. An eastern GOM (EGOM) index based on current methods to account for inconsistent spatial coverage in the eastern GOM, and an eastern GOM continuity (EGOM-Continuity) index based on methods used for the prior assessment update were generated. Trends from the current WGOM, EGOM and EGOM-continuity indices were consistent with indices developed for the previous update assessment.*

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. The SEAMAP Fall Plankton Survey conducted primarily during the month of September is the only Gulfwide plankton survey of U.S. continental shelf and coastal waters during the Red Snapper (*Lutjanus campechanus*) spawning season occurring from late April through October. Occurrence and abundance of larvae captured during these surveys were initially reviewed as a potential fishery-independent index to reflect trends in the relative spawning stock size of Red Snapper during the Southeast Data Assessment and Review (SEDAR7) process in 2004 (Lyczkowski-Shultz *et al.*, 2004 and Hanisko *et al.*, 2004). Indices of larval abundance as a proxy for adult spawning stock have been incorporated into the SEDAR7 (2004), SEDAR7 Update (2009), SEDAR31 (2012), SEDAR31 Update (2014) assessments. There have been several changes to the formulation of the indices over time. Detailed information concerning previous iterations of the indices is documented in Hanisko *et al.* (2004), Hanisko *et al.* (2007) and Pollack *et al.* (2012), the SEDAR 31 – Gulf of Mexico Red Snapper Stock Assessment Report (SEDAR, 2013) and the SEDAR 31 Update Assessment Report (Cass-Calay *et al.,* 2015). A notable divergence from the SEDAR 31 documentation concerns the formulation of the eastern GOM (EGOM) index. Both the SEDAR 31 and SEDAR 31 Updated Assessment Reports indicate that the formulation of the EGOM index was based on a frequency of occurrence (logistic) model and not larval abundance. The EGOM index for the 2012 assessment was indeed a frequency of occurrence only model. However, an age corrected abundance index and not a frequency of occurrence index was submitted and used for SEDAR 31 Update Assessment.

Currently, the time series of data from the Fall Plankton Survey available for analysis extends from 1986 to 2016. This document outlines the development of Red Snapper larval indices for the western and eastern GOM continental shelf based on the same methodology used for the SEDAR 31 Update assessment (continuity) and updated methodology (current) that addresses the inconsistent spatial coverage for several years of the Fall Plankton Survey in the EGOM.

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 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 National Marine Fisheries Service (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.

In order to assure consistent identifications over the SEAMAP time series, all snapper larvae were examined and identified by ichthyoplankton specialists at the SEFSC Mississippi Laboratories using an identification protocol based on descriptions in Drass *et al.* (2000) and Lindeman *et al.* (2005). The level of identification achievable under this protocol depended on the extent of first dorsal fin development, as well as the following morphological traits: presence or absence of melanistic pigment on the throat (sternohyoideus muscle), and on the anterior surface of the visceral mass or gut; and whether preopercular spines or dorsal spines were smooth or serrated. Specimens were identified as Red Snapper only when a minimum of five dorsal spines were present, those spines were smooth, not serrated and melanistic pigmentation on the body and fins matched the description and illustrations of reared and wild caught Red Snapper larvae in Rabalais *et al.* (1980), Collins *et al.* (1980), and Drass *et al.* (2000).

Red Snapper are among six of the twelve snapper species of the subfamily Lutjaninae found in the GOM whose larvae have been described. Despite these descriptions snapper larvae can be distinguished from each other only after dorsal and pelvic spines have begun to develop using a combination of morphological characters (Lindeman et al. 2005). Red Snapper larvae prior to dorsal and pelvic spine formation are generally less than 3.5 mm BL and cannot be confidently identified in field collections because of the lack of established characteristics that permit early stage larvae of the lutjanines to be distinguished from each other. The few specimens identifiable as Red Snapper in SEAMAP collections that were less than 3.5 mm BL resulted from variability in size at developmental stage and/or shrinkage during capture and preservation. The question arises as to the potential for misidentification of Red Snapper larvae in SEAMAP collections since the larvae of all snappers found in the region have not been described. It is unlikely that this caused extensive misidentification of red snapper larvae considering how much larvae of species whose larval development has been described differ from each other and red snapper in pigmentation and body shape (Drass *et al.* 2000). Most of the snappers whose larvae remain undescribed inhabit coral reefs and reef associated ledges as adults, and clear shallow waters or mangrove areas as juveniles (Anderson 2003); biotopes of limited extent in the northern GOM (Parker *et al.* 1983). No adults or juveniles of the six snapper species whose larvae are undescribed were taken during annual summer and fall SEAMAP shrimp/bottomfish (trawl) surveys from 1982 to 2005 (G. Pellegrin, NOAA/SEFSC Mississippi Laboratories, personal communication). Fewer than five individuals per year of these species were ever observed during ten years of NMFS reef fish video surveys of reef and hard bottom habitat from Brownsville, Texas to the Florida Keys (K. Rademacher, NMFS/SEFSC Mississippi Laboratories, personal communication).

Standardized SEAMAP Station/Sample Data Set

The SEAMAP Fall Plankton sampling area covers the northern GOM from the 10 m isobath out to the continental shelf edge within the U.S. EEZ, and originally comprised approximately 132 designated sampling sites i.e. 'SEAMAP' stations. Beginning in 1999 and continuing to the present, samples have been taken at 11 additional SEAMAP stations located off the continental shelf in the western GOM during the survey. 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.

The intended sample design for SEAMAP surveys calls for a single 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. 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.

Spatial coverage of the Fall Plankton Survey from 1986 to 2016 has at times been impacted due to severe weather, vessel breakdowns and/or time constraints (Appendix Figure 1). Sampling for both the western (> 89.25° West Longitude) and eastern (< 89.25° West Longitude) GOM was severely curtailed or cancelled due to tropical storms or vessel breakdowns during the 1998, 2005, 2008 and 2015 surveys. Spatial coverage in the western GOM (WGOM) has been consistent over the time series with the exception of the four years impacted by tropical storms and vessel delays. In the EGOM, spatial coverage has been considerably more variable. Curtailed sampling during the 1988, 1989, 1992, 2002 and 2004 surveys resulted in large portions of the EGOM remaining un-sampled. Much of the spatial variability in the EGOM stems from the typical west to east progression of the survey. Due to this progression, any reduction in survey time often limits sampling effort in the southern (Tampa, FL to Key West, FL) portion of the survey area.

Year to year variability in spatial coverage from Fall Plankton Survey data was addressed by limiting observations to samples taken at SEAMAP stations that were sampled during at least (~66%)of all years for which there was consistent spatial coverage respectively for the western and eastern GOM (Figure 1).   The WGOM index includes all samples taken during at least 17 of the 27 years of available data. Only samples from years (1998, 2005, 2008 and 2015) impacted by tropical storms and vessel breakdowns were excluded. Formulation of the WGOM index remains unchanged from the previous assessment and no continuity index is needed. Samples from 1988, 1989, 2002 and 2004 surveys were previously included in the EGOM index formulation, but have since been determined to lack consistent spatial coverage.   Therefore, the current EGOM indices include samples taken during at least 14 of the 22 years with consistent spatial coverage, and excludes samples from years (1998, 2005, 2008 and 2015) greatly impacted by tropical storms and vessel breakdowns and years (1988, 1989, 2002 and 2004) with lack of spatial coverage. The EGOM continuity index includes samples taken during at least 17 of the 27 years of available data and only excludes samples from years (1998, 2005, 2008 and 2015) greatly impacted by tropical storms and vessel breakdowns.

Aging of Larvae, Mortality Estimates and Age Corrected Abundance

Estimates of total larval catch per unit area (CPUA) of each size class (catch curves) were developed for larval Red Snapper by summing the CPUA of each size class under 10 m^2 of sea surface. Size classes of 0.5 mm were utilized, with the midpoint of each size representing larvae lengths within ± 0.25 mm. Larvae less than 3.75 mm and greater than 9.25 mm in length were excluded from analysis due to identification uncertainty of smaller larvae and gear avoidance of larger rarely caught larvae. All primary B-Number samples with the exception of samples collected during years (1998, 2005, 2008 and 2015) greatly impacted by tropical storms and vessel breakdowns were used to estimate mortality.

Red Snapper larvae collected during SEAMAP collections are not aged as part of standard protocol. However, Jones (2013) has examined the age and growth of Red Snapper larvae (n=103) obtained from samples collected during the SEAMAP Summer Shrimp/Bottomfish trawl survey in 2008 and the Fall Plankton surveys in 2006, 2007, and 2008. The study established the following length-at-age relationship for Red Snapper larvae:

$$(1) \qquad l = 1.9302e^{0.0705t}$$

where *l* was length in mm and *t* is age in days. The *r*-squared value for this relationship was 0.8744.

Size classes were converted to age classes using the length-at-age relationship established by Jones (2013) to assign an age to the mid-points of each 0.5 mm size class. The summed abundance of each age/size class was then corrected to account for exponential growth by dividing the summed abundance of each size class by their respective duration of the size class in days (Houde, 1977). Duration was calculated by subtracting the age of the lower boundary of length of a size class from the age of the upper boundary of length of the size class. An estimate of larval Red Snapper mortality was then estimated from the descending limb of the catch curve. Subsequently, the instantaneous mortality rate (Z=0.1810) was estimated as the slope of a non-linear least squares function relating the duration-corrected larval abundance and age (Figure 2, Ricker, 1975).

Individual larvae in each sample were then back calculated to the number of larvae at 10.5 days of age by assigning age based on their length and adjusting for daily mortality. The total number of 10.5 day old larvae was then summed and standardized to the total number of larvae per 10 m^2 of sea surface for each sample.

Index Construction

Delta-lognormal modeling methods were used to estimate relative abundance indices for Red Snapper (Pennington, 1983; Bradu and Mundlak, 1970). 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 (*cf.* Lo *et al*. 1992). Overall, three age corrected CPUA indices were generated for the western and eastern GOM. Only a single index was generated for the WGOM. A continuity index was not needed for the WGOM, as the formulation of the index remained unchanged since the prior assessment update. An EGOM index based on current methods, and an EGOM continuity (EGOM-Continuity) index based on methods used for the prior assessment update were generated.

The delta-lognormal index of relative abundance (I_y) was 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, 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:

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

and

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

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 using the delta method approximation

(4) $$V(I_y) \approx V(c_y)p_y^2 + c_y^2 V(p_y).$$

A covariance term is not included in the variance estimator since there is no correlation between the estimator of the proportion positive and the mean CPUE given presence. The two estimators are derived independently and have been shown to not covary for a given year (Christman, unpublished).

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 $\alpha = 0.05$. The year effect is integral to the calculation of annual estimates and is forced into the standardization procedure regardless of significance when at least one other factor is significant. 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 in addition to AIC. The factors Y*ear*, *Subregion*, *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).

Results and Discussion

The WGOM index of larval Red Snapper age corrected CPUA is presented in Table 2 and Figure 3. The backward selection procedure retained year and TOD in the binomial submodel, and year, TOD and subregion in the lognormal submodel (Table 5). The AIC for the binomial and lognormal submodels were 6355.8 and 666.4, respectively. The diagnostic plots for the lognormal submodels are show in Figure 4, and indicated the distribution of the residuals is approximately normal.

The EGOM index of larval Red Snapper age corrected CPUA is presented in Table 3 and Figure 5. The backward selection procedure retained year, TOD and subregion in the binomial submodel, and year, TOD, subregion and depth in the lognormal submodel (Table 5). The AIC for the binomial and lognormal submodels were 7173.5 and 197.3, respectively. The diagnostic plots for the lognormal submodels are show in Figure 4, and indicated the distribution of the residuals is approximately normal.

The EGOM-continuity index of larval Red Snapper age corrected CPUA is presented in Table 4 and Figure 6. The backward selection procedure retained year, TOD and subregion in the binomial submodel, and year, subregion and depth in the lognormal submodel (Table 5). The AIC for the binomial and lognormal submodels were 7949.5 and 203.5, respectively. The diagnostic plots for the lognormal submodels are show in Figure 4, and indicated the distribution of the residuals is approximately normal.

The WGOM index exhibits an increasing trend over the entire time series. The trend is relatively gradual until 2014, but shows a sharp increase in CPUA for the 2016 terminal year. CPUA in the terminal year is two times greater than the 2011 to 2014 average. The EGOM also shows an increasing trend, but is subject to a high degree of uncertainty. CPUA in the EGOM is six times greater and frequency of occurrence nearly three times greater after 2004. The EGOM and EGOM-continuity indices show nearly identical patterns with the exception of the additional years dropped from the EGOM due to inconsistent spatial coverage. Trends from the current WGOM, EGOM and EGOM-continuity indices were consistent with indices developed for the previous update assessment. The WGOM (Table 2) and

EGOM (Table 3) relative indices of abundance are the suggested time series to be considered for inclusion in the assessment models.

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Table 1. Factors considered for inclusion into the binomial and lognormal sub-models of the Delta-lognormal approach for the western (top), eastern (middle) and eastern continuity (bottom) indices.

Western Gulf of Mexico

Factors	Levels	Description
Year	*26*	*1986-1987, 1989-1997,1999-2004,2006-2007,2009-2014 and 2015*
Subregion	*2*	*TX = Texas (>93.80 Degrees W Longitude)* *LA = Louisiana (> 89.17 and <= 93.80 Degrees W Longitude)*
Time of Day (TOD)	*2*	*D = Day (Sunrise to Sunset)* *N = Night (Sunset to Sunrise)*
Depth		*Water Depth*

Eastern Gulf of Mexico

Factors	Levels	Description
Year	*19*	*1986-1987, 1991, 1994-1995, 1997, 1999-2001, 2003, 2006-2007 and 2009-2014 and 2016*
Subregion	*2*	*MS/LA = Mississippi and Alabama (> 87.25 and <= 89.17)* *FL = Florida (<= 87.25)*
Time of Day (TOD)	*2*	*D = Day (Sunrise to Sunset)* *N = Night (Sunset to Sunrise)*
Depth		*Water Depth*

Easter Gulf of Mexico Continuity

Factors	Levels	Description
Year	*22*	*1986-1988,1991, 1994-1995, 1997 1999-2004, 2006-2007 and 2009-2014 and 2016*
Subregion	*2*	*MS/LA = Mississippi and Alabama (> 87.25 and <= 89.17)* *FL = Florida (<= 87.25)*
Time of Day (TOD)	*2*	*D = Day (Sunrise to Sunset)* *N = Night (Sunset to Sunrise)*
Depth		*Water Depth*

Table 2. SEAMAP Fall Plankton Survey indices of western Gulf of Mexico (WGOM) larval Red Snapper age corrected abundance developed using the delta-lognormal (DL) model. The nominal frequency of occurrence (NominalFrequency), number of samples (*N*), the DL Index (LoIndex) expresses as number of 10.5 day old larvae under 10 m of sea surface, the DL index scaled to a mean of one (ScaledLoIndex) 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. Years with zero nominal frequency represent true zero abundance for years with consistent spatial coverage. These years are not included in the delta-lognormal model.

SurveyYear	*NominalFrequency*	*N*	*LoIndex*	*ScaledLoIndex*	*CV*	*LCL*	*UCL*
1986	0.08163	49	1.1539	0.32139	0.62588	0.10178	1.01488
1987	0.07273	55	1.9077	0.53135	0.62757	0.16782	1.68232
1988	0.00000	28					
1989	0.14286	28	2.2513	0.62706	0.61340	0.20251	1.94164
1990	0.19355	31	1.9094	0.53182	0.49932	0.20700	1.36638
1991	0.09677	31	0.5362	0.14935	0.71478	0.04132	0.53977
1992	0.12727	55	0.9912	0.27610	0.47272	0.11246	0.67786
1993	0.12727	55	1.0542	0.29362	0.47173	0.11980	0.71966
1994	0.07273	55	0.7310	0.20361	0.62685	0.06438	0.64393
1995	0.23636	55	3.0244	0.84239	0.33472	0.43900	1.61645
1996	0.16364	55	2.0508	0.57122	0.41037	0.25950	1.25739
1997	0.25926	54	3.3643	0.93707	0.31997	0.50188	1.74962
1998							
1999	0.14545	55	1.6258	0.45283	0.43722	0.19618	1.04524
2000	0.27273	55	4.7608	1.32603	0.31354	0.71875	2.44641
2001	0.14894	47	3.3782	0.94094	0.46769	0.38659	2.29021
2002	0.22222	54	2.5917	0.72189	0.34700	0.36778	1.41692
2003	0.29630	54	4.7487	1.32268	0.29631	0.74042	2.36282
2004	0.22222	54	2.8989	0.80743	0.35324	0.40668	1.60307
2005							
2006	0.23077	52	4.4777	1.24718	0.35124	0.63049	2.46709
2007	0.29091	55	4.3397	1.20876	0.29447	0.67900	2.15185
2008							
2009	0.30909	55	5.1918	1.44609	0.28651	0.82457	2.53609
2010	0.15094	53	2.1064	0.58669	0.43726	0.25415	1.35433
2011	0.25532	47	7.0892	1.97458	0.34585	1.00814	3.86751
2012	0.30909	55	8.0520	2.24275	0.28708	1.27747	3.93741
2013	0.29630	54	4.1905	1.16718	0.29496	0.65504	2.07975
2014	0.26923	52	6.1986	1.72652	0.31728	0.92933	3.20755
2015							
2016	0.34545	55	12.7219	3.54346	0.26444	2.10674	5.95997

Table 3. SEAMAP Fall Plankton Survey indices of eastern Gulf of Mexico (EGOM) larval Red Snapper age corrected abundance developed using the delta-lognormal (DL) model. The nominal frequency of occurrence (NominalFrequency), number of samples (*N*), the DL Index (LoIndex) expresses as number of 10.5 day old larvae under 10 m of sea surface, the DL index scaled to a mean of one (ScaledLoIndex) 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. Years with zero nominal frequency represent true zero abundance for years with consistent spatial coverage. These years are not included in the delta-lognormal model.

SurveyYear	*NominalFrequency*	*N*	*LoIndex*	*ScaledLoIndex*	*CV*	*LCL*	*UCL*
1986	0.01695	59	0.15666	0.10212	1.20543	0.01536	0.67907
1987	0.03175	63	0.52001	0.33898	0.86927	0.07560	1.51989
1988							
1989							
1990	0.00000	39					
1991	0.04651	43	0.41715	0.27193	0.85685	0.06166	1.19933
1992							
1993	0.00000	50					
1994	0.01493	67	0.03716	0.02422	1.20749	0.00363	0.16141
1995	0.03125	64	0.15188	0.09901	0.87068	0.02204	0.44476
1996	0.00000	62					
1997	0.03125	64	0.20756	0.13530	0.86806	0.03023	0.60568
1998							
1999	0.04839	62	0.63112	0.41142	0.71646	0.11355	1.49062
2000	0.06780	59	1.53673	1.00177	0.62493	0.31771	3.15862
2001	0.04615	65	0.32978	0.21498	0.70745	0.06013	0.76859
2002							
2003	0.06061	66	0.58465	0.38113	0.62152	0.12152	1.19530
2004							
2005							
2006	0.05085	59	1.42500	0.92893	0.71224	0.25799	3.34474
2007	0.08824	68	1.40523	0.91605	0.50706	0.35191	2.38453
2008							
2009	0.08955	67	2.18622	1.42517	0.50033	0.55376	3.66786
2010	0.13433	67	5.62041	3.66386	0.39377	1.71461	7.82913
2011	0.14706	68	4.27605	2.78749	0.38265	1.33086	5.83840
2012	0.11290	62	1.94972	1.27099	0.45797	0.53105	3.04195
2013	0.08955	67	1.68339	1.09738	0.49518	0.43013	2.79968
2014	0.09375	64	3.32760	2.16921	0.50641	0.83424	5.64042
2015							
2016	0.14706	68	2.69994	1.76005	0.37310	0.85498	3.62323

Table 4. SEAMAP Fall Plankton Survey indices of eastern Gulf of Mexico continuity (EGOM-Continuity) larval Red Snapper age corrected abundance developed using the delta-lognormal (DL) model. The nominal frequency of occurrence (NominalFrequency), number of samples (*N*), the DL Index (LoIndex) expresses as number of 10.5 day old larvae under 10 m of sea surface, the DL index scaled to a mean of one (ScaledLoIndex) 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. Years with zero nominal frequency represent true zero abundance for years with consistent spatial coverage. These years are not included in the delta-lognormal model.

SurveyYear	*NominalFrequency*	*N*	*LoIndex*	*ScaledLoIndex*	*CV*	*LCL*	*UCL*
1986	0.01695	59	0.18795	0.13890	1.22226	0.02053	0.93983
1987	0.03175	63	0.38220	0.28246	0.87653	0.06240	1.27861
1988	0.02632	38	0.20702	0.15299	1.22212	0.02262	1.03500
1989	0.00000	40					
1990	0.00000	39					
1991	0.04651	43	0.41072	0.30354	0.87107	0.06754	1.36420
1992	0.00000	46					
1993	0.00000	50					
1994	0.01493	67	0.04639	0.03428	1.22412	0.00506	0.23241
1995	0.03125	64	0.18347	0.13559	0.88126	0.02977	0.61762
1996	0.00000	62					
1997	0.03125	64	0.25821	0.19083	0.87795	0.04208	0.86543
1998							
1999	0.04839	62	0.60608	0.44792	0.72885	0.12141	1.65255
2000	0.06780	59	1.58165	1.16890	0.63433	0.36532	3.74006
2001	0.04615	65	0.30919	0.22851	0.71968	0.06277	0.83182
2002	0.05128	39	0.76145	0.56274	0.87827	0.12403	2.55320
2003	0.06061	66	0.62730	0.46360	0.63145	0.14554	1.47672
2004	0.02439	41	0.47457	0.35073	1.22648	0.05161	2.38331
2005							
2006	0.05085	59	1.32526	0.97942	0.72328	0.26764	3.58423
2007	0.08824	68	1.54591	1.14249	0.51428	0.43360	3.01035
2008							
2009	0.08955	67	2.29336	1.69488	0.50812	0.64995	4.41978
2010	0.13433	67	5.44163	4.02159	0.40191	1.85477	8.71979
2011	0.14706	68	4.33651	3.20486	0.38903	1.51262	6.79026
2012	0.11290	62	2.07052	1.53020	0.46495	0.63166	3.70688
2013	0.08955	67	1.52914	1.13010	0.50260	0.43742	2.91964
2014	0.09375	64	2.74292	2.02713	0.50905	0.77614	5.29448
2015							
2016	0.14706	68	2.44688	1.80834	0.37872	0.86954	3.76071

Table 5. Summary of the final delta-lognormal models from the backward selection procedure for the western Gulf of Mexico, eastern Gulf of Mexico and eastern Gulf of Mexico continuity Red Snapper indices of abundance.

Western Gulf of Mexico

	Binomial Submodel Type 3 Tests(AIC=6355.8)						*Lognormal Submodel Type 3 Tests (AIC=666.4)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
YEAR	25	1293	50.96	2.04	0.0016	0.0019	25	248	2.34	0.0005
TOD	1	1293	41.58	41.58	<.0001	<.0001	1	248	31.1	<.0001
SUBREGION				Dropped			1	248	12.69	0.0004
DEPTH				Dropped					Dropped	

Eastern Gulf of Mexico

	Binomial Submodel Type 3 Tests(AIC=7173.5)						*Lognormal Submodel Type 3 Tests (AIC=197.3)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
YEAR	18	1181	30.25	1.68	0.0351	0.0368	18	65	1.93	0.0288
TOD	1	1181	5.49	5.49	0.0191	0.0193	1	65	4.54	0.037
SUBREGION	1	1181	60.60	60.60	<.0001	<.0001	1	65	16.16	0.0002
DEPTH				Dropped			1	65	7.06	0.0099

Eastern Gulf of Mexico Continuity

	Binomial Submodel Type 3 Tests(AIC=7949.5)						*Lognormal Submodel Type 3 Tests (AIC=203.5)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
YEAR	21	1296	33.56	1.6	0.0403	0.0422	18	333	2.6	0.0004
TOD	1	1296	5.89	5.89	0.0152	0.0154			Dropped	
SUBREGION	1	1296	53.99	53.99	<.0001	<.0001	1	67	13.73	0.0004
DEPTH				Dropped			1	67	9.79	0.0026

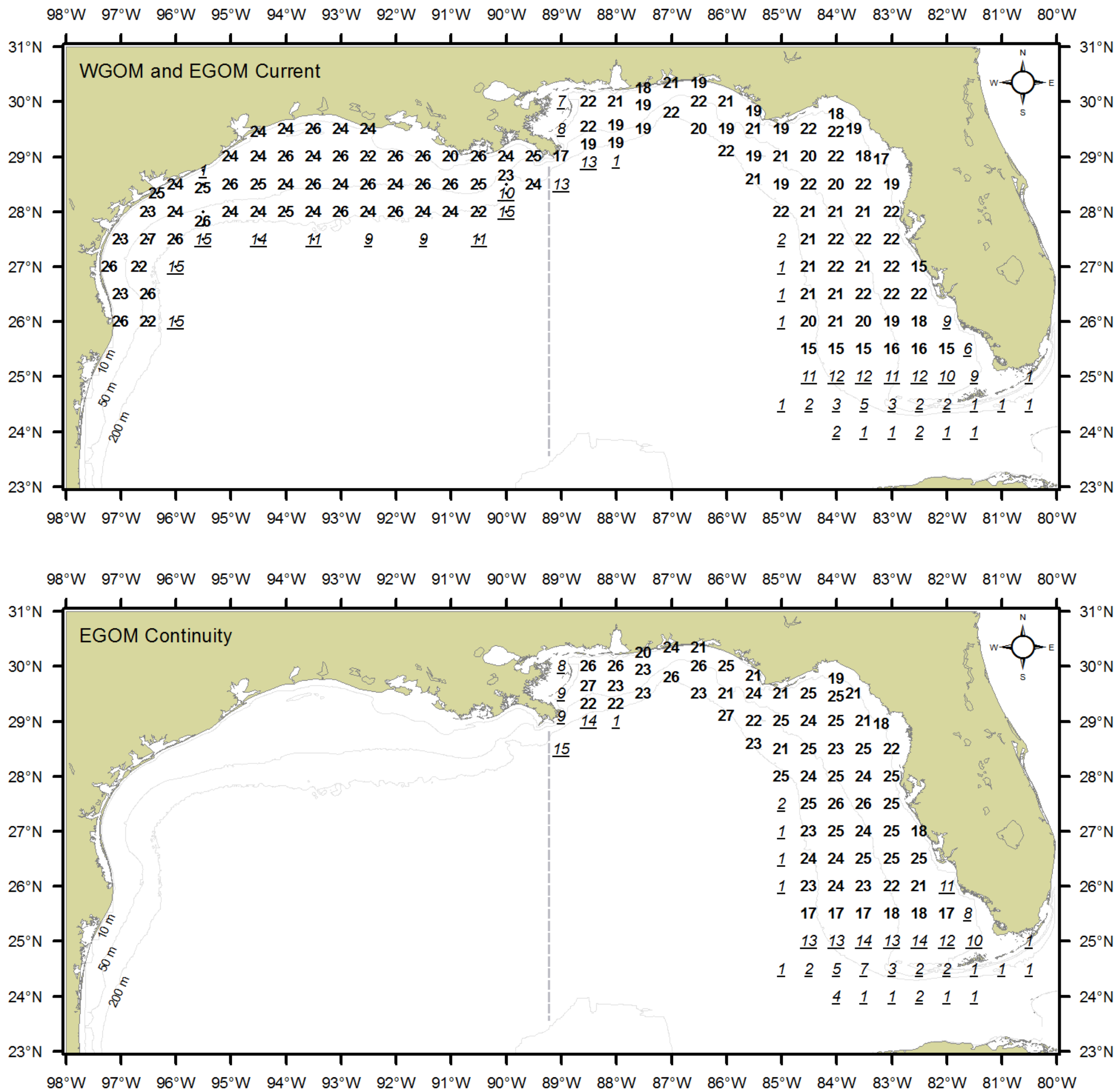


Figure 1. Number of primary bongo net samples taken at each SEAMAP B-Number locations from SEAMAP Fall Plankton Surveys 1986 to 2016 with consistent spatial coverage respective to the western Gulf of Mexico (WGOM), eastern Gulf of Mexico (EGOM) and EGOM-Continuity indices. Only locations with primary samples equal to or exceeding 17 were included in the WGOM (top) and EGOM-Continuity (bottom)indices, and locations with primary samples equal to or exceeding 14 were included in the EGOM (top) index. Bold numbers represent locations of primary samples included in the index and those underlined and in italics represent locations of primary samples excluded from the index. Hashed line indicates western and eastern GOM split at 89.25° longitude.

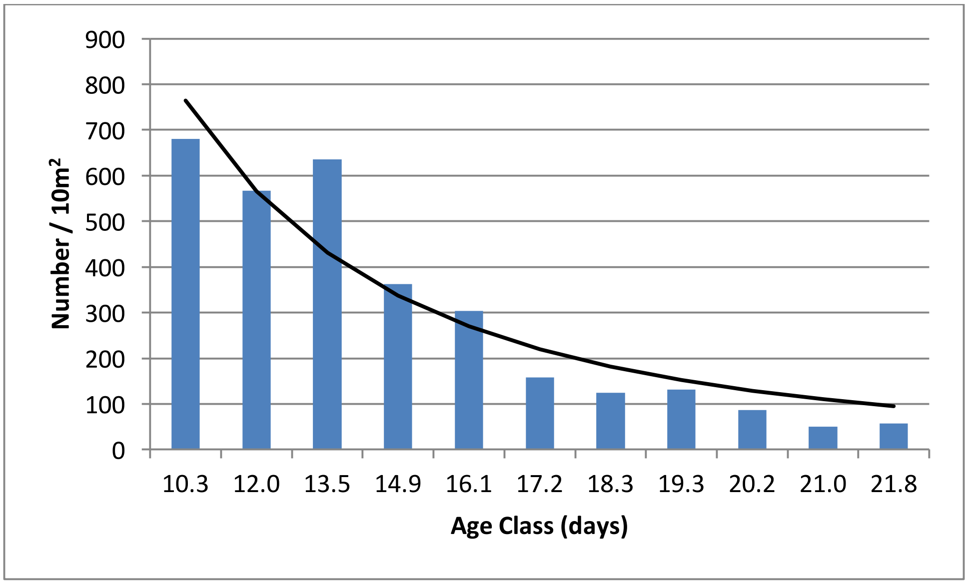


Figure 2. Age distribution (age at size class midpoint) of larval Red Snapper catch and the resulting daily loss rate curve (Z = -0.1801).

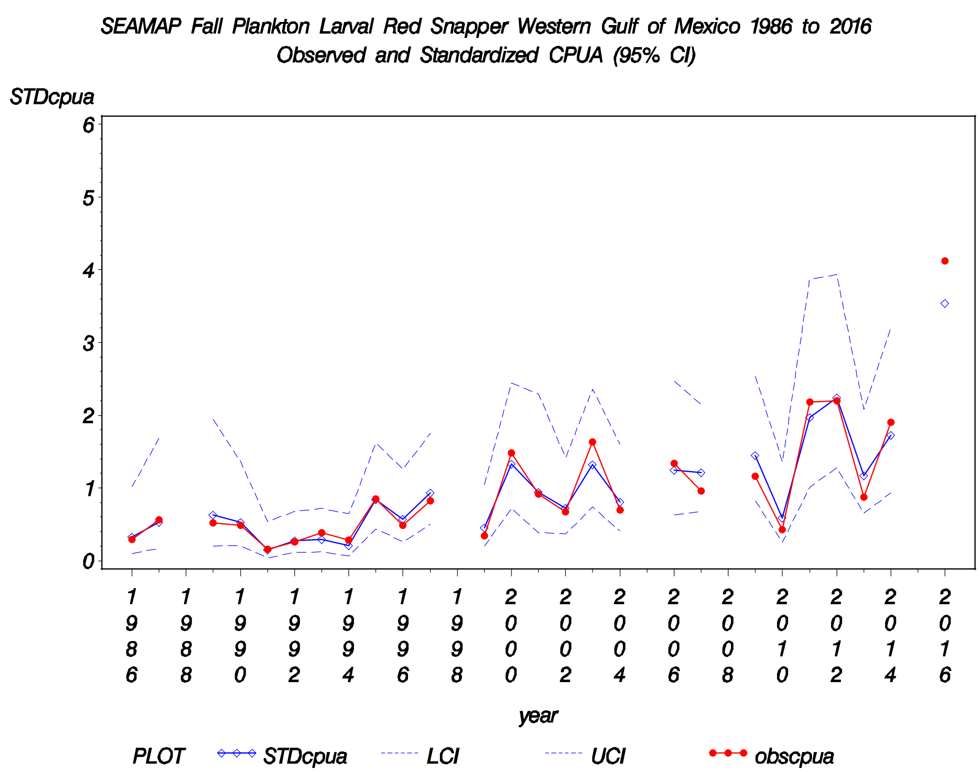
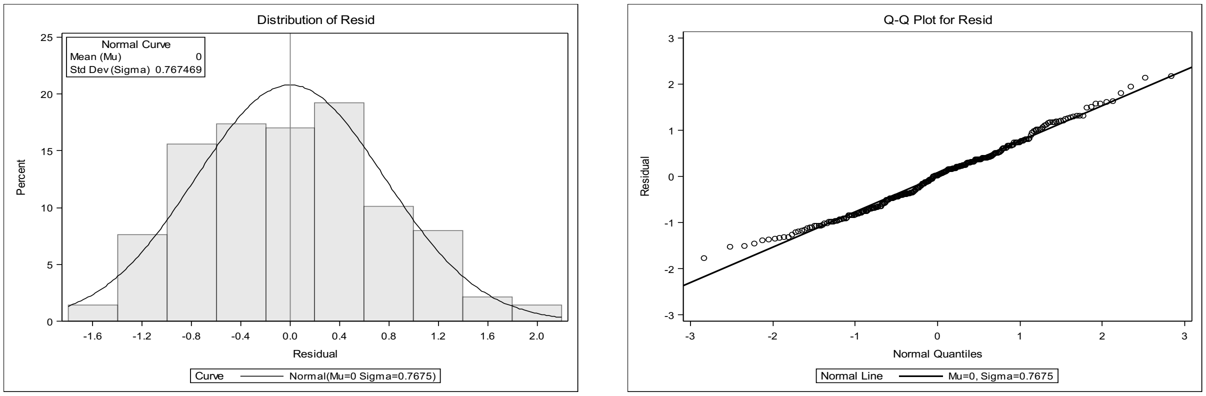
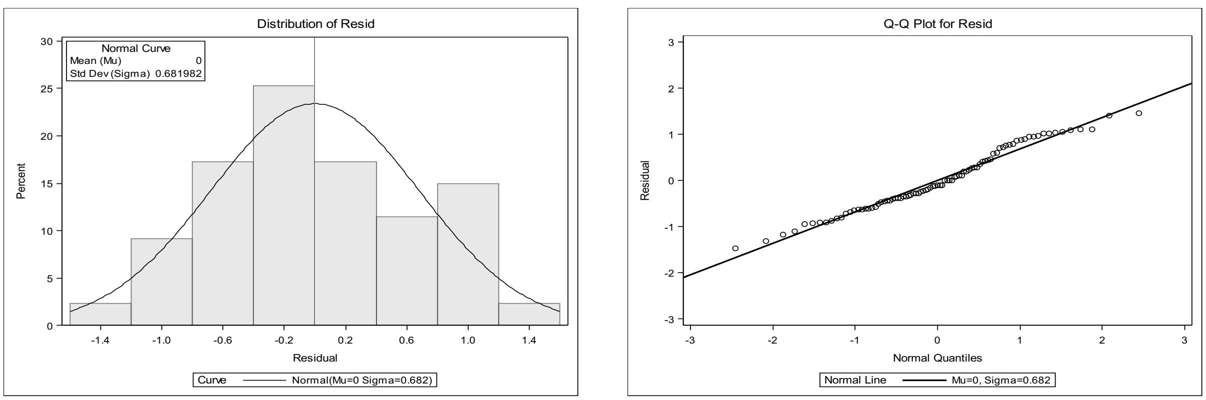


Figure 3. Annual index of larval Red Snapper age corrected abundance from SEAMAP Fall Plankton Surveys from 1986 to 2016 for the western Gulf of Mexico.

WGOM



EGOM



EGOM Continuity

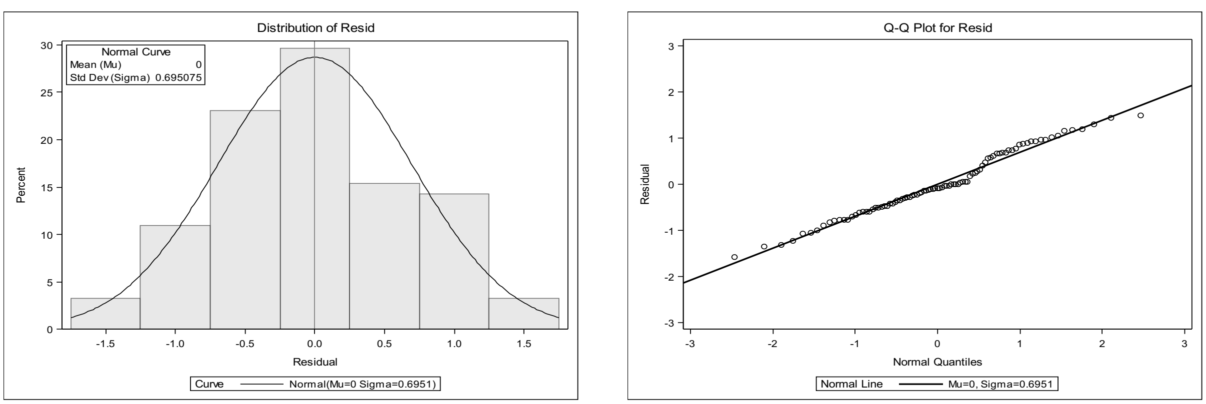


Figure 4. Diagnostic plots for the lognormal submodels of the western (WGOM, top), eastern (EGOM, middle) and EGOM Continuity (EGOM Continuity, bottom) indices of abundance: Left column shows the frequency distribution of log (CPUA) on positive stations and the right column the cumulative normalized residuals (QQ plot).

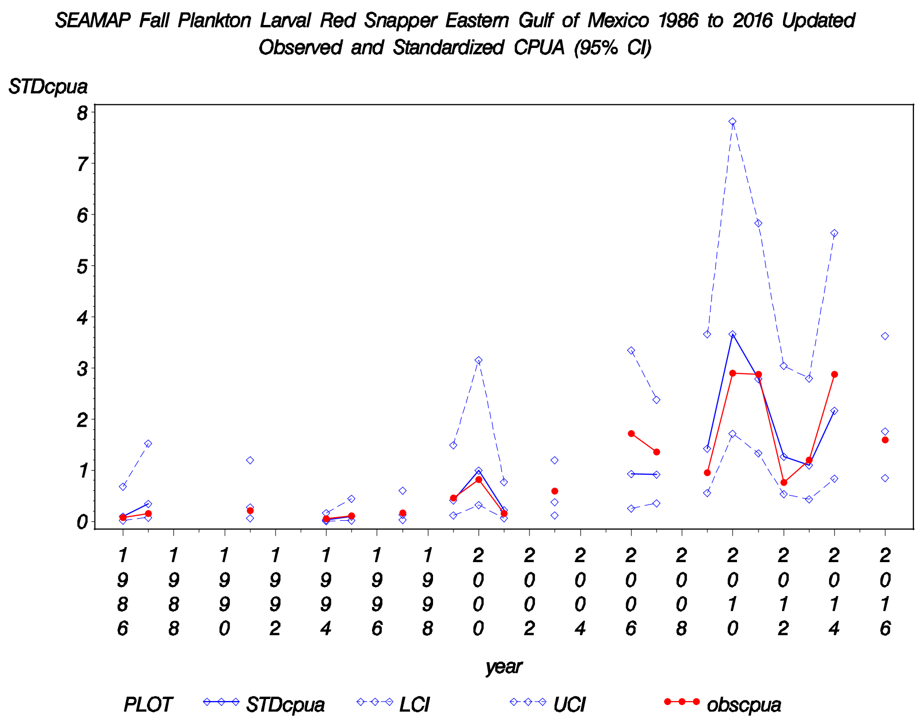


Figure 5. Annual index of larval Red Snapper abundance from SEAMAP Fall Plankton Surveys from 1986 to 2016 for the eastern Gulf of Mexico.

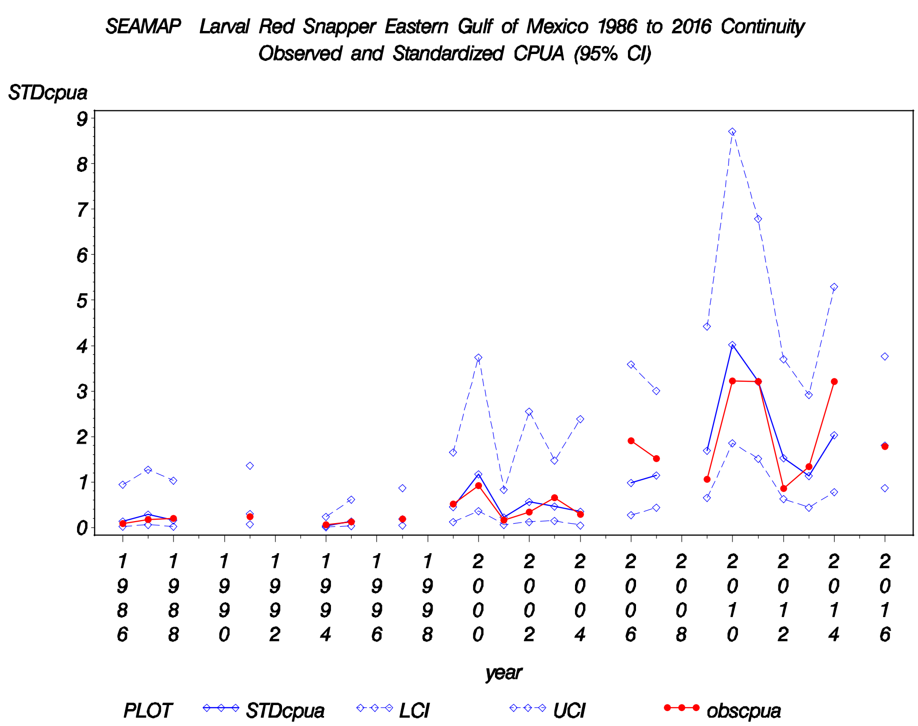
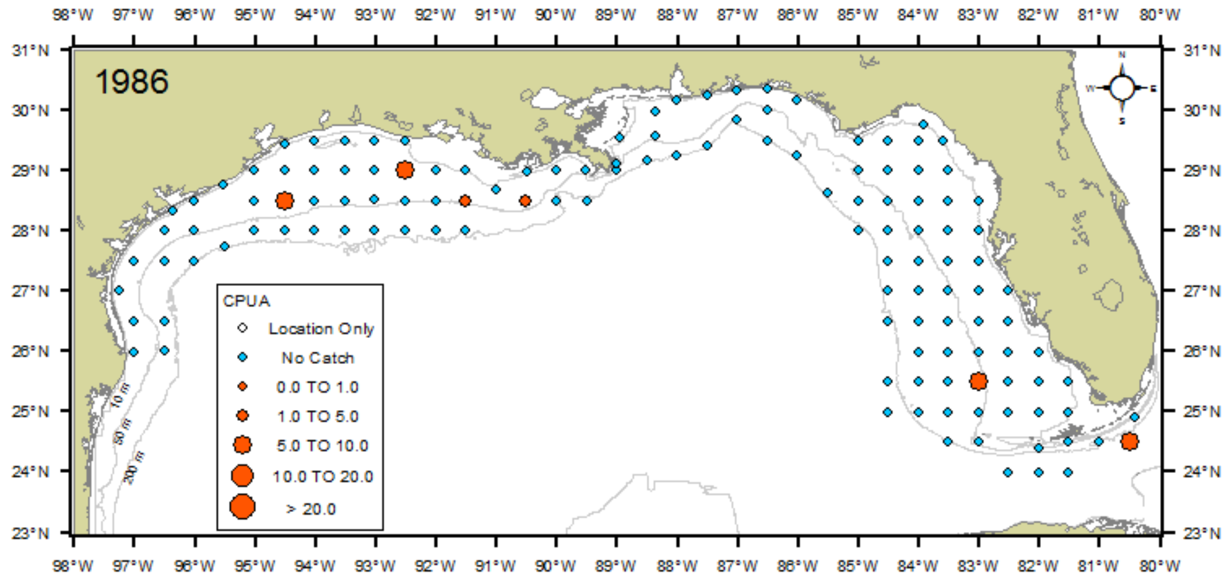
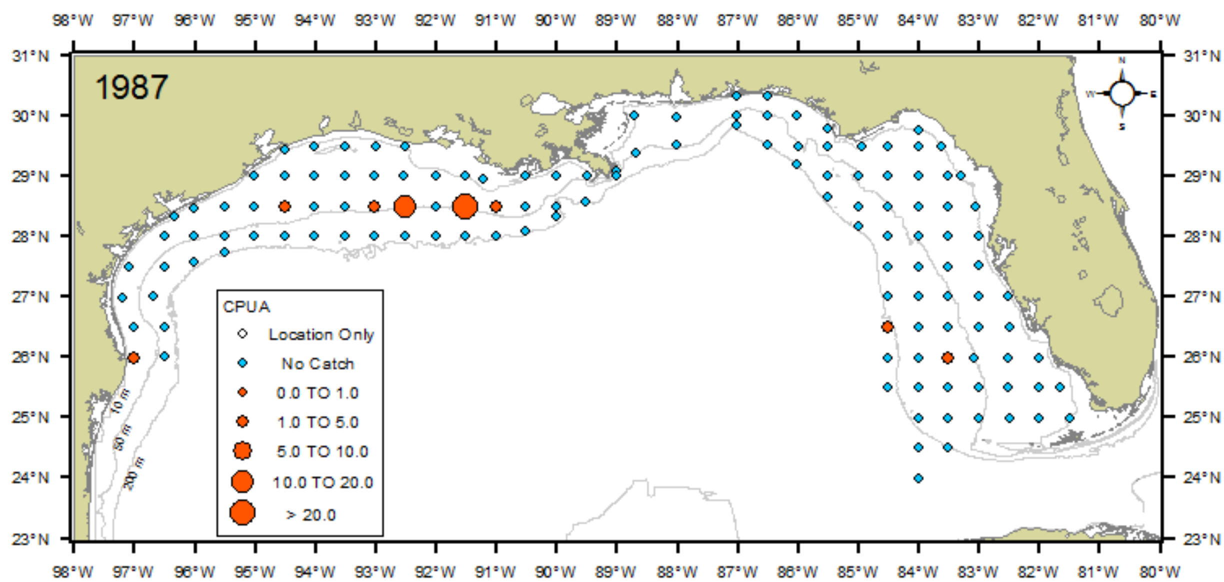
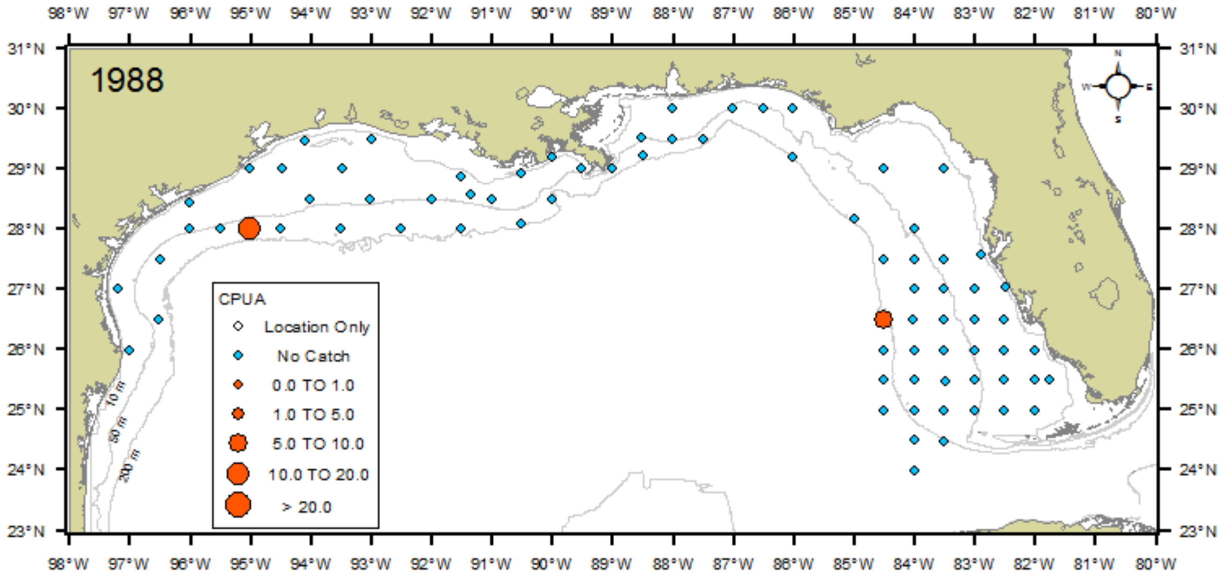


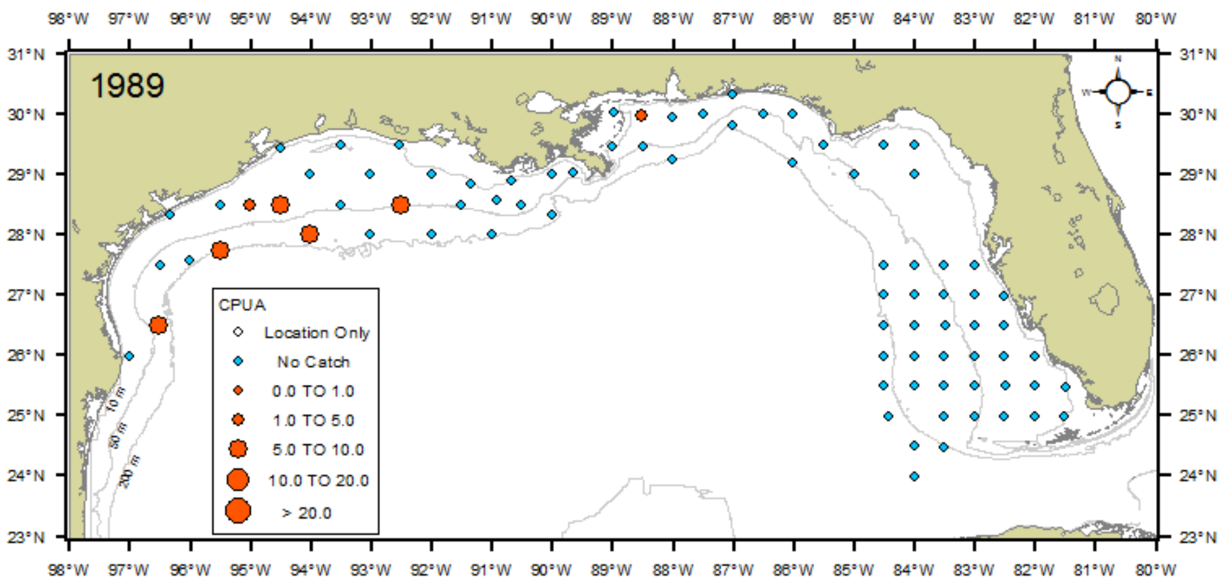
Figure 6. Annual index of larval Red Snapper abundance from SEAMAP Fall Plankton Surveys from 1986 to 2016 for the eastern Gulf of Mexico.WHAT IS THE DIFFERENCE FROM THE PLOT ABOVE?

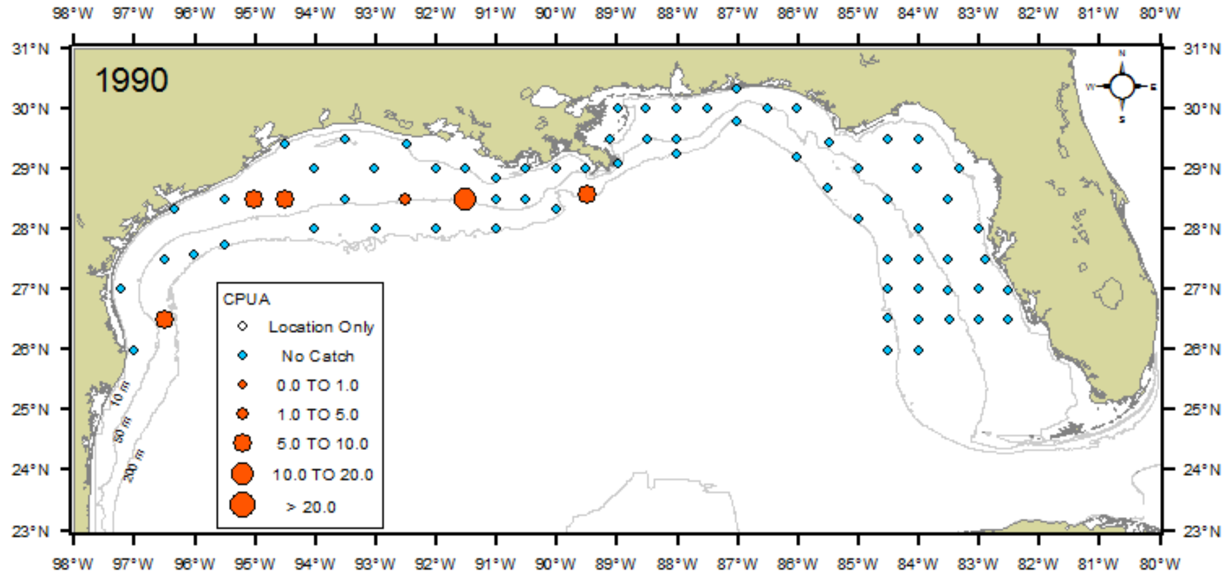
Appendix Figure 1. Annual survey effort and nominal catch per unit area (CPUA) of Red Snapper from the SEAMAP Fall Plankton Survey conducted from 1986-2016. CPUA is expressed as the number of larvae under 10 m^2. CPUA of red snapper in not yet currently available for 2015.

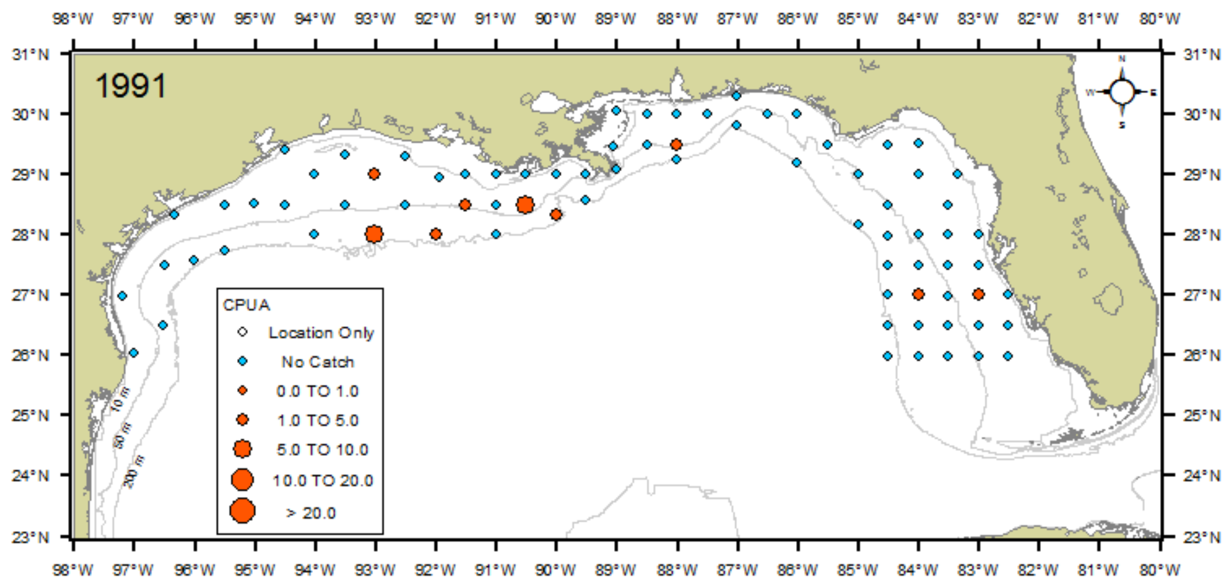


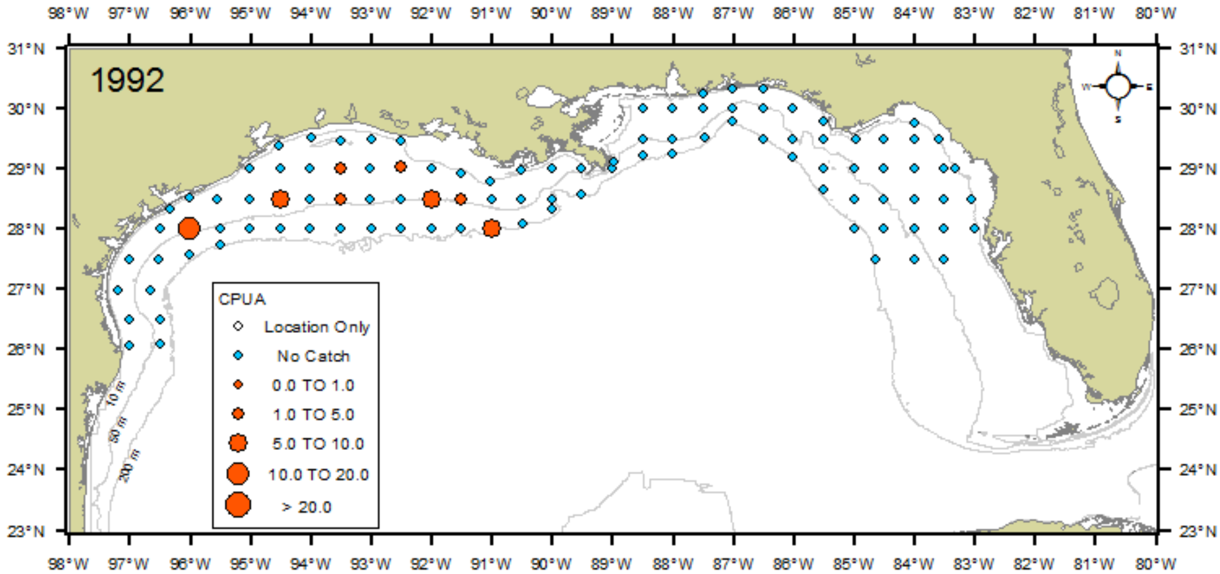


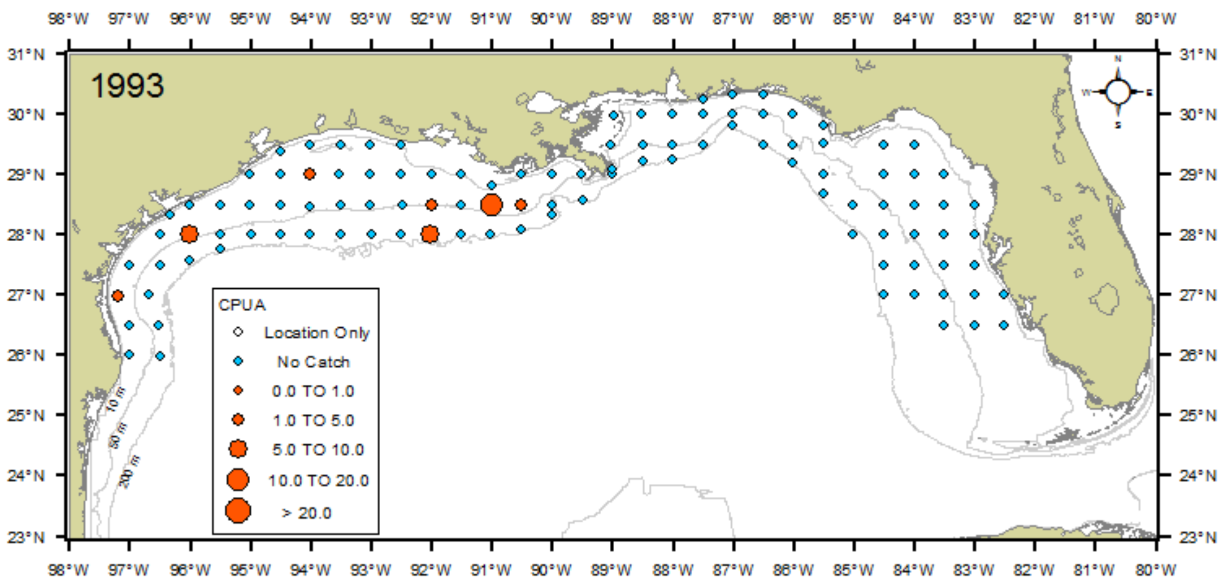

1988
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m

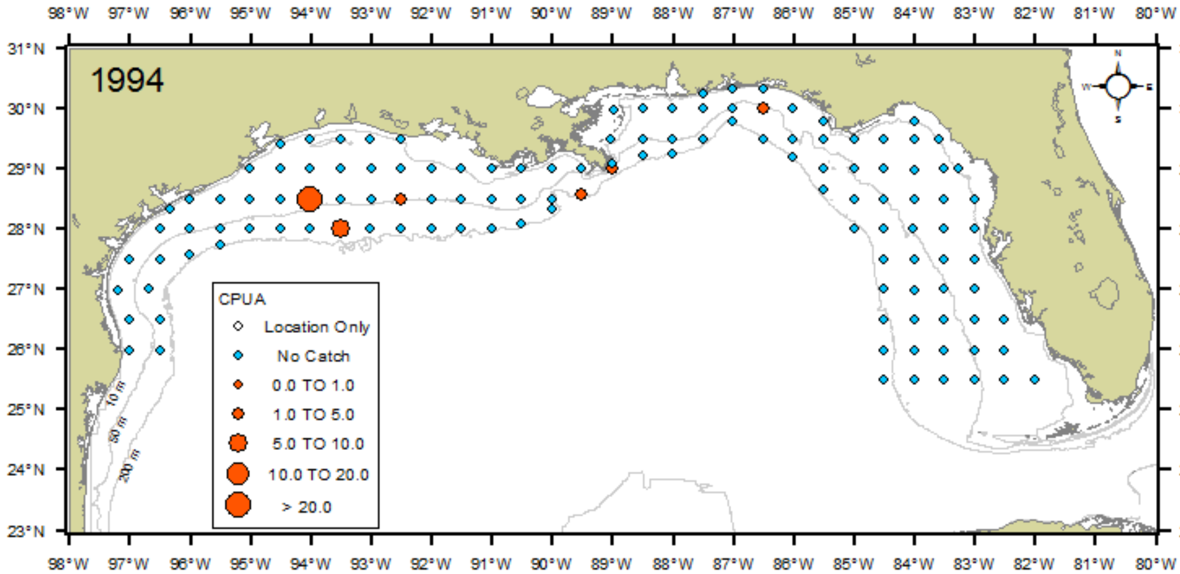

1989
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m

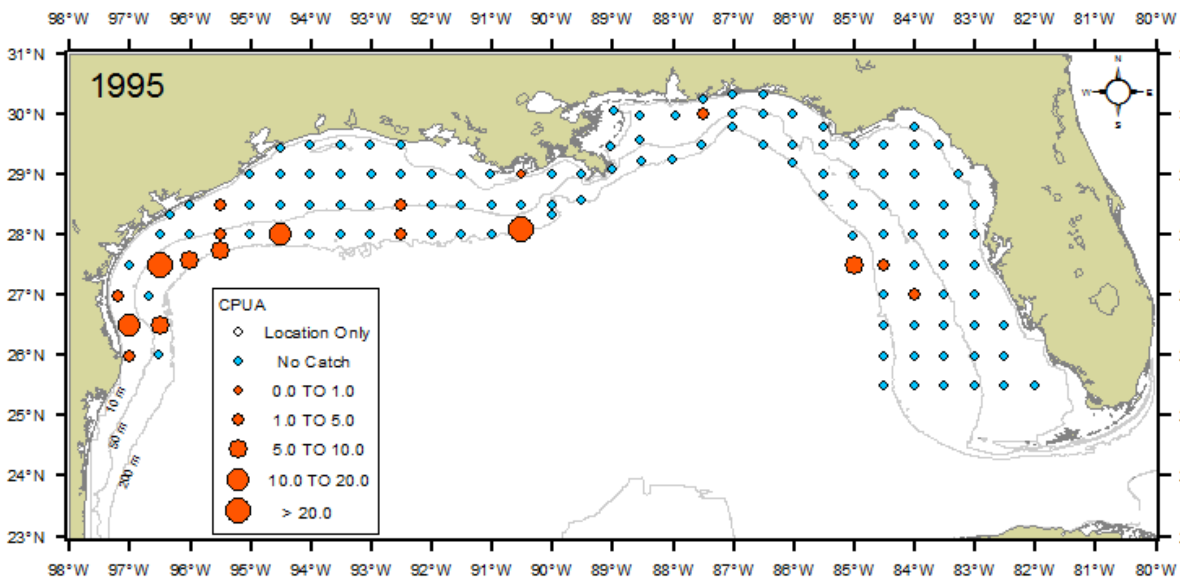

1990
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m

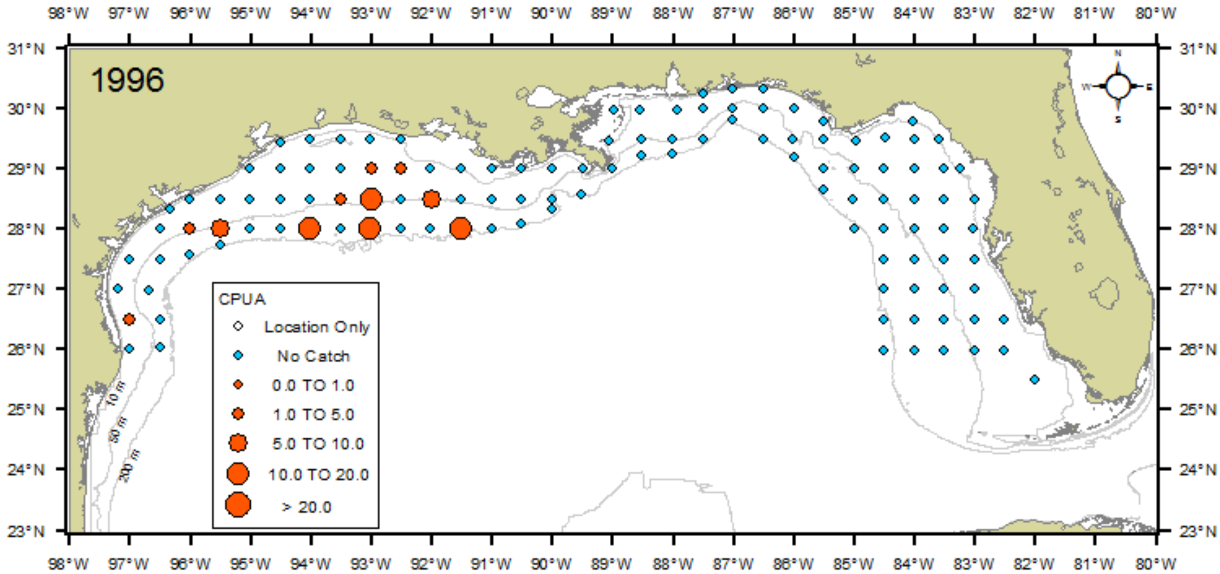

1991
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m

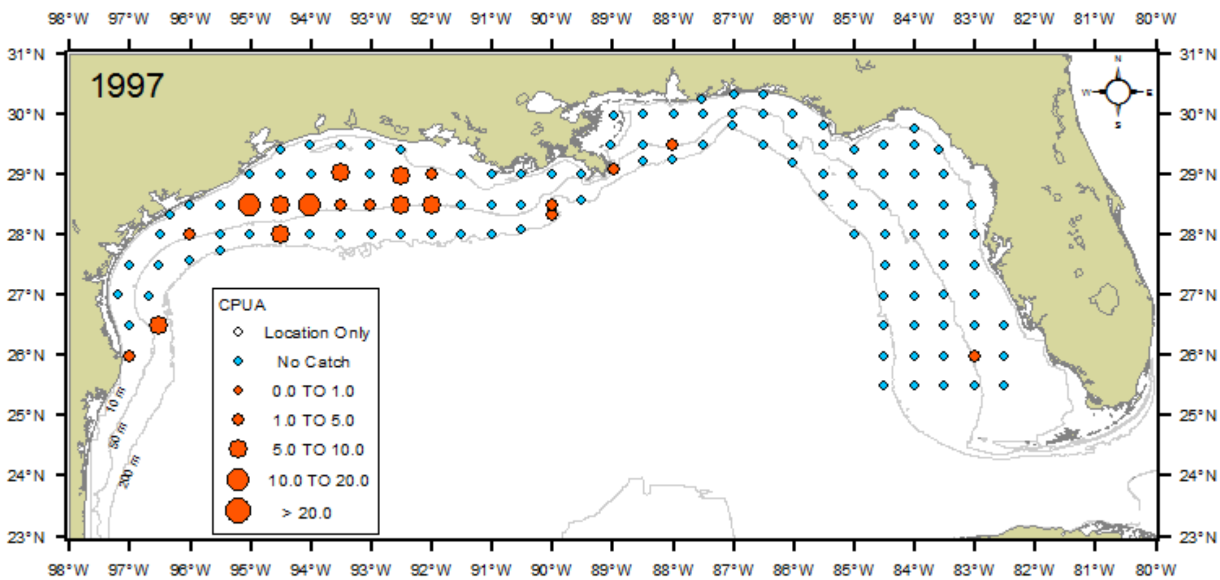

1992
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m
98°W 97°W 96°W 95°W 94°W 93°W 92°W 91°W 90°W 89°W 88°W 87°W 86°W 85°W 84°W 83°W 82°W 81°W 80°W
31°N 30°N 29°N 28°N 27°N 26°N 25°N 24°N 23°N

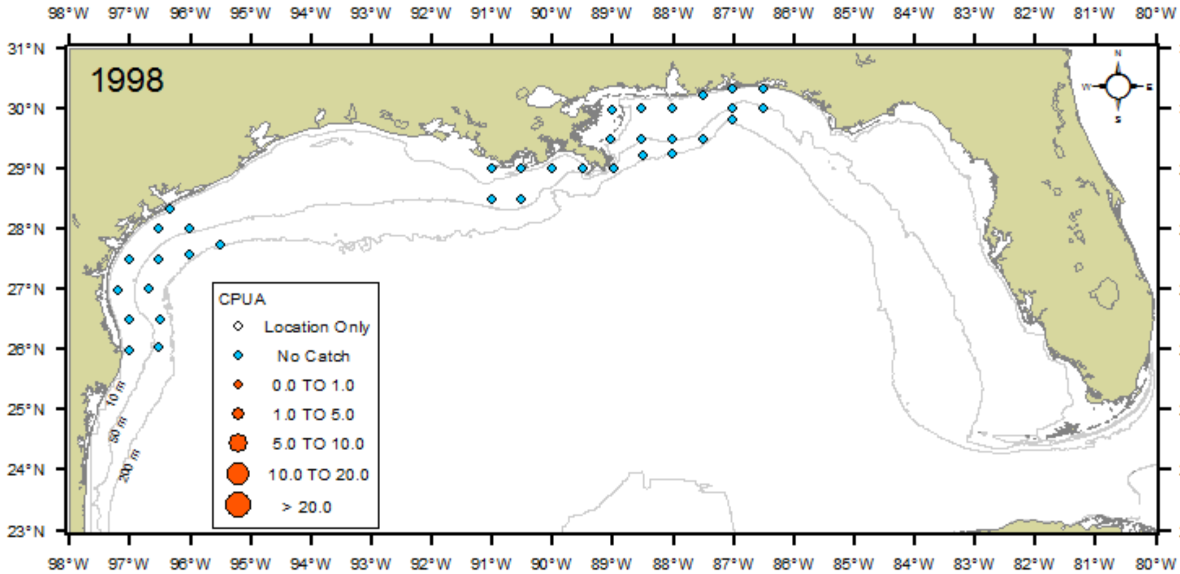

1993
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m
98°W 97°W 96°W 95°W 94°W 93°W 92°W 91°W 90°W 89°W 88°W 87°W 86°W 85°W 84°W 83°W 82°W 81°W 80°W
31°N 30°N 29°N 28°N 27°N 26°N 25°N 24°N 23°N

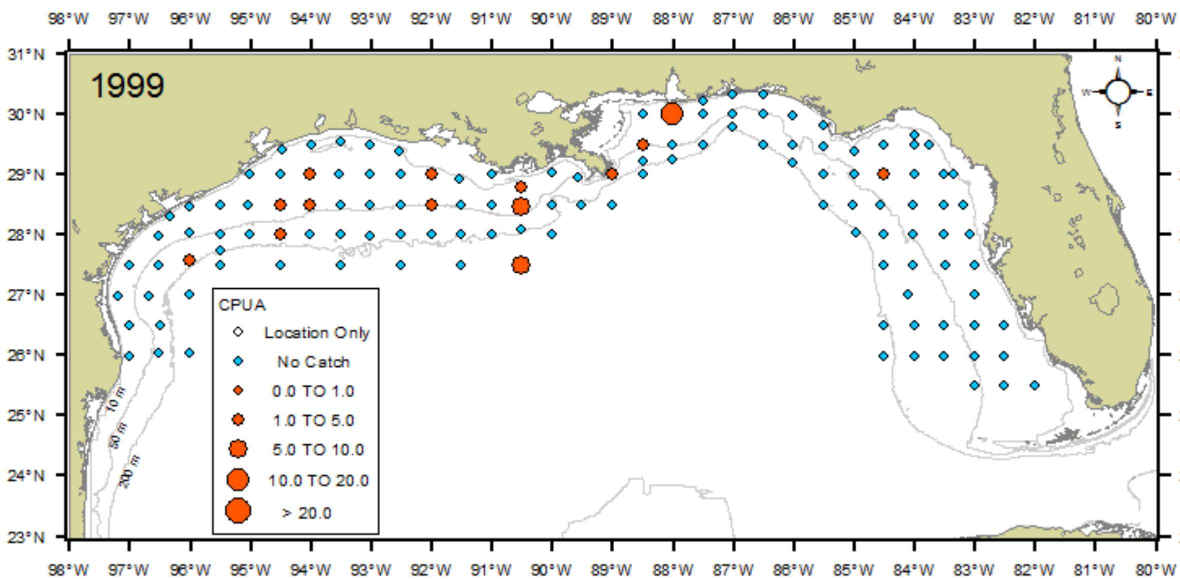

1994
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m

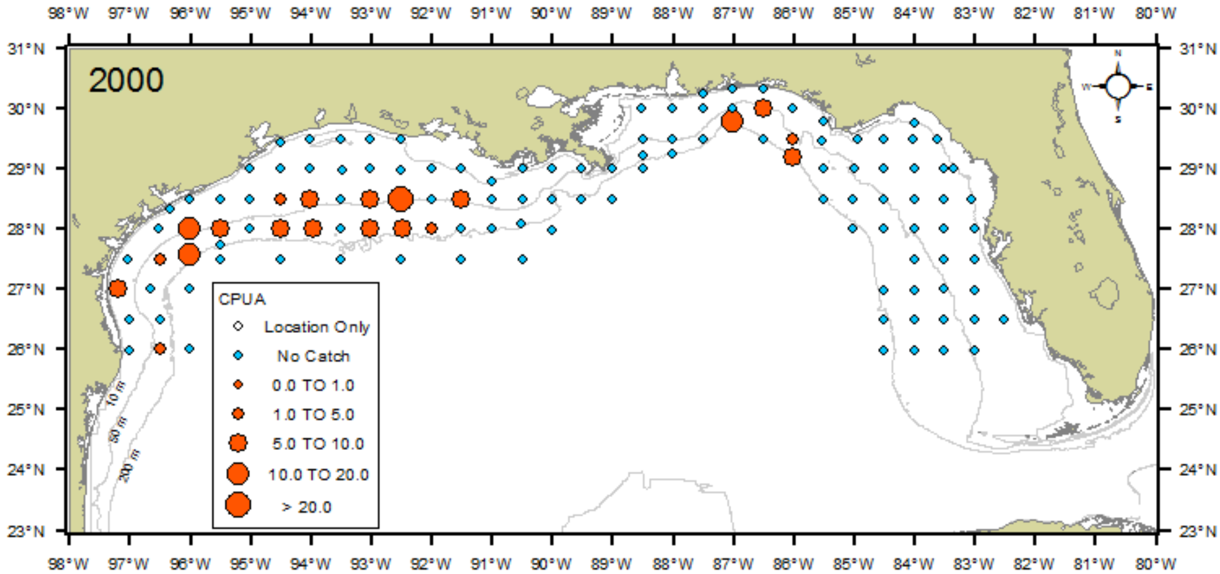

1995
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m

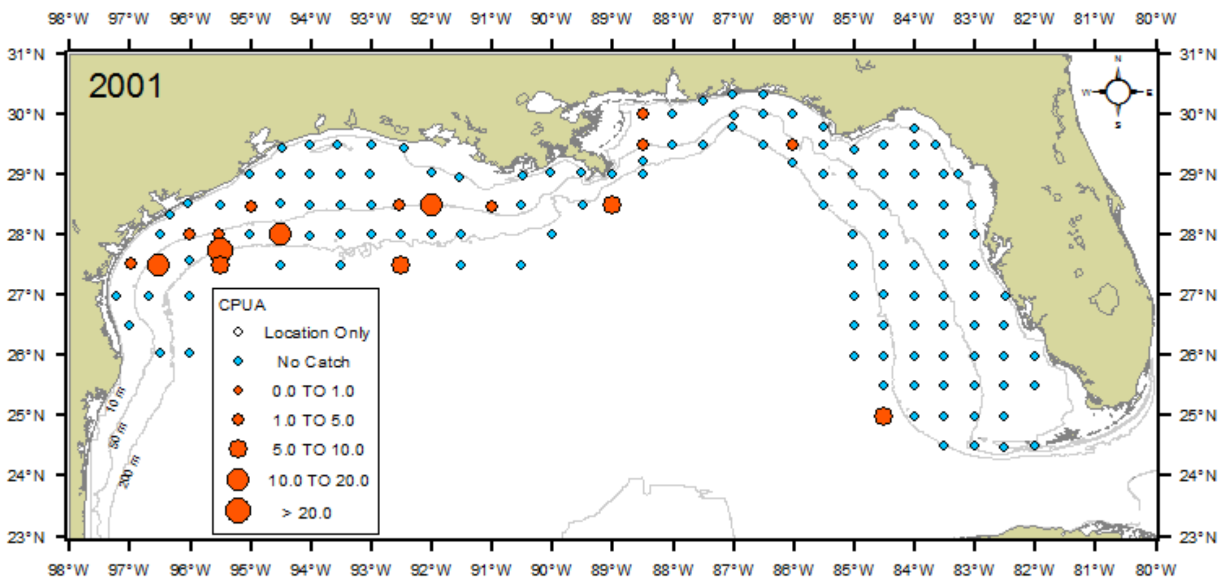

1996
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m
98°W 97°W 96°W 95°W 94°W 93°W 92°W 91°W 90°W 89°W 88°W 87°W 86°W 85°W 84°W 83°W 82°W 81°W 80°W
31°N 30°N 29°N 28°N 27°N 26°N 25°N 24°N 23°N

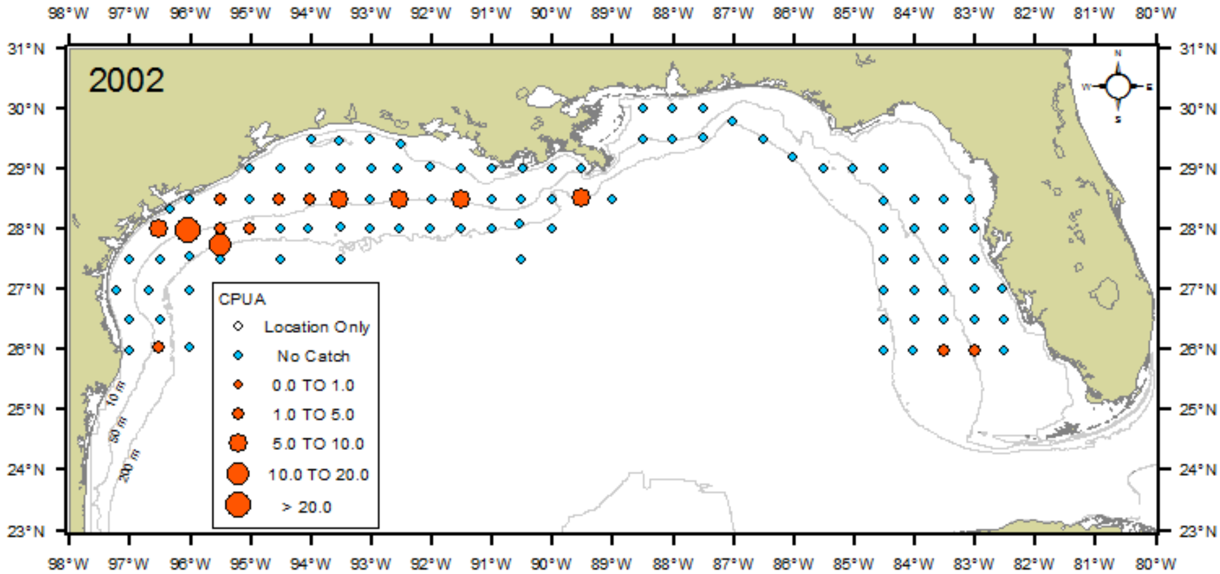

1997
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m
98°W 97°W 96°W 95°W 94°W 93°W 92°W 91°W 90°W 89°W 88°W 87°W 86°W 85°W 84°W 83°W 82°W 81°W 80°W
31°N 30°N 29°N 28°N 27°N 26°N 25°N 24°N 23°N

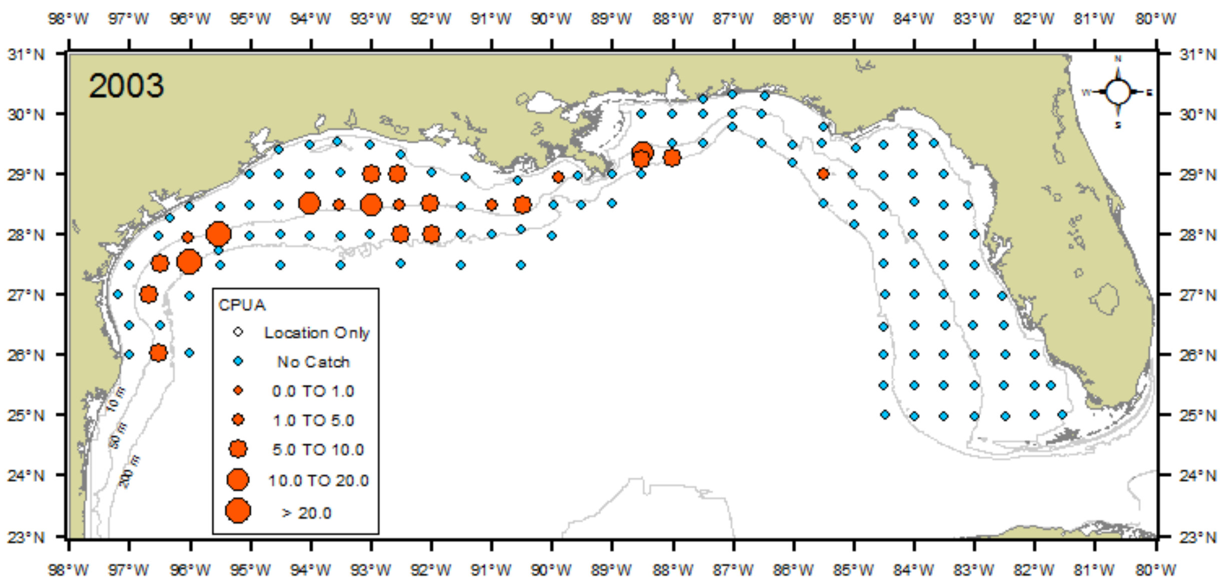

1998
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m

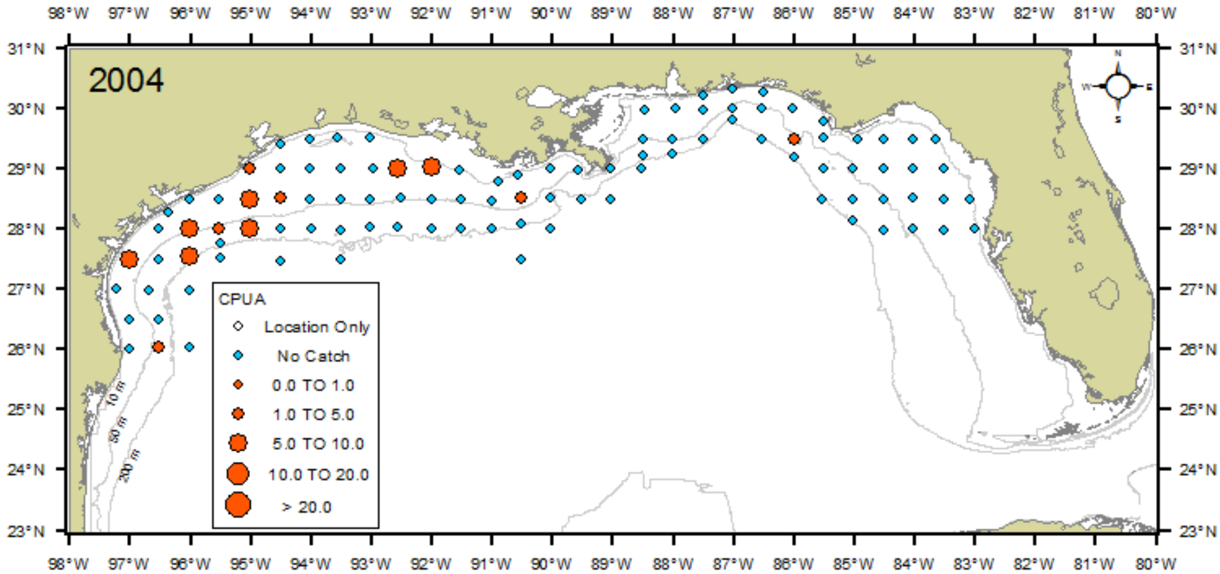

1999
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m

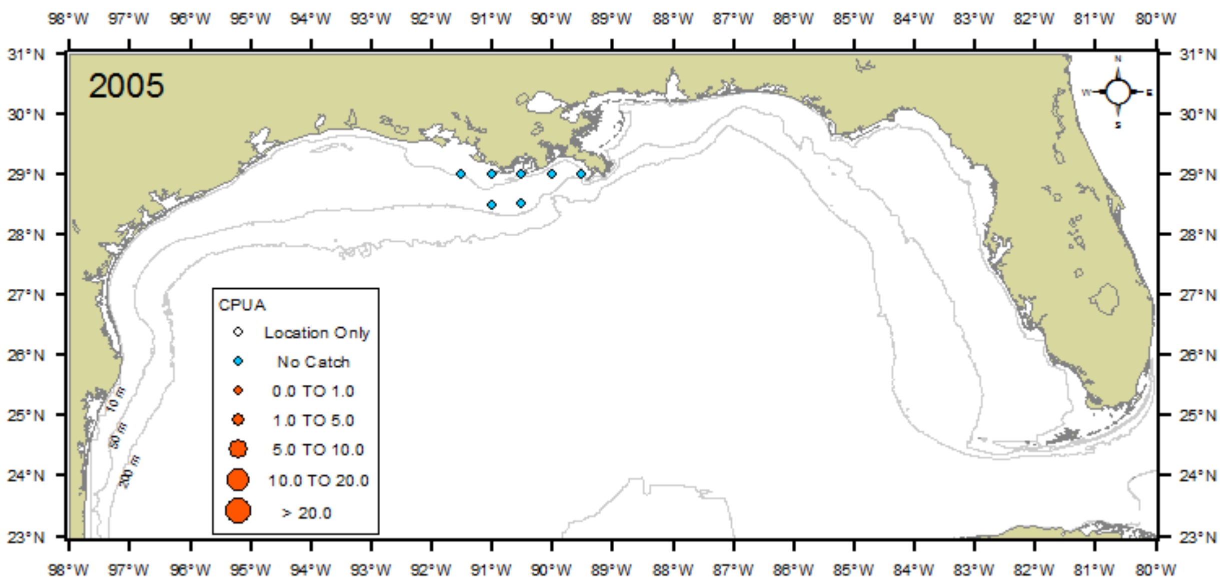

2000
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m

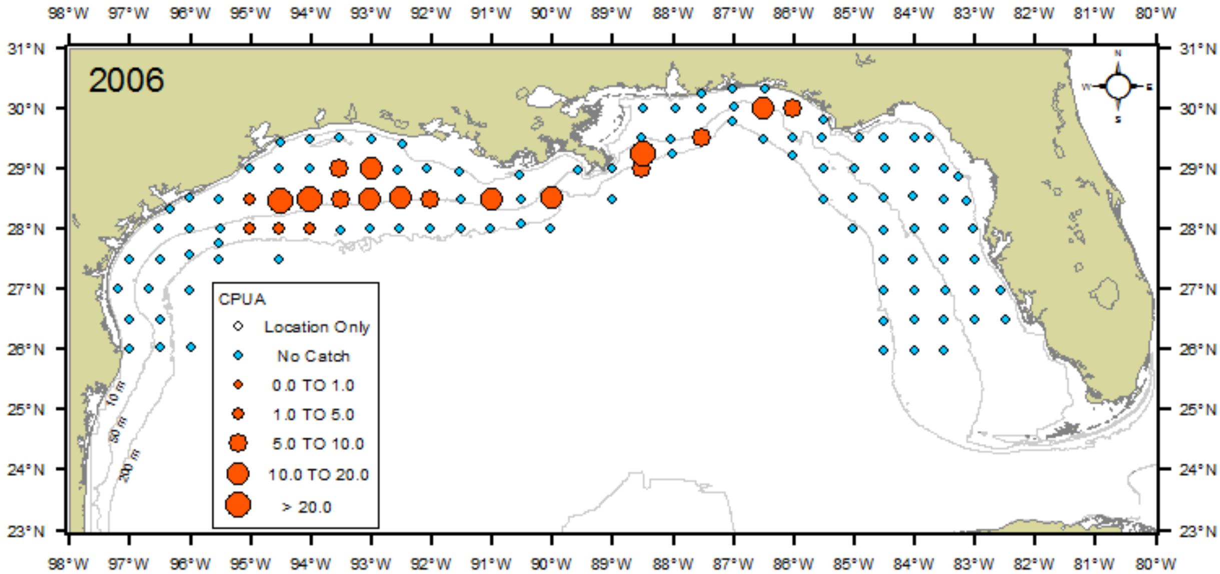

2001
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m

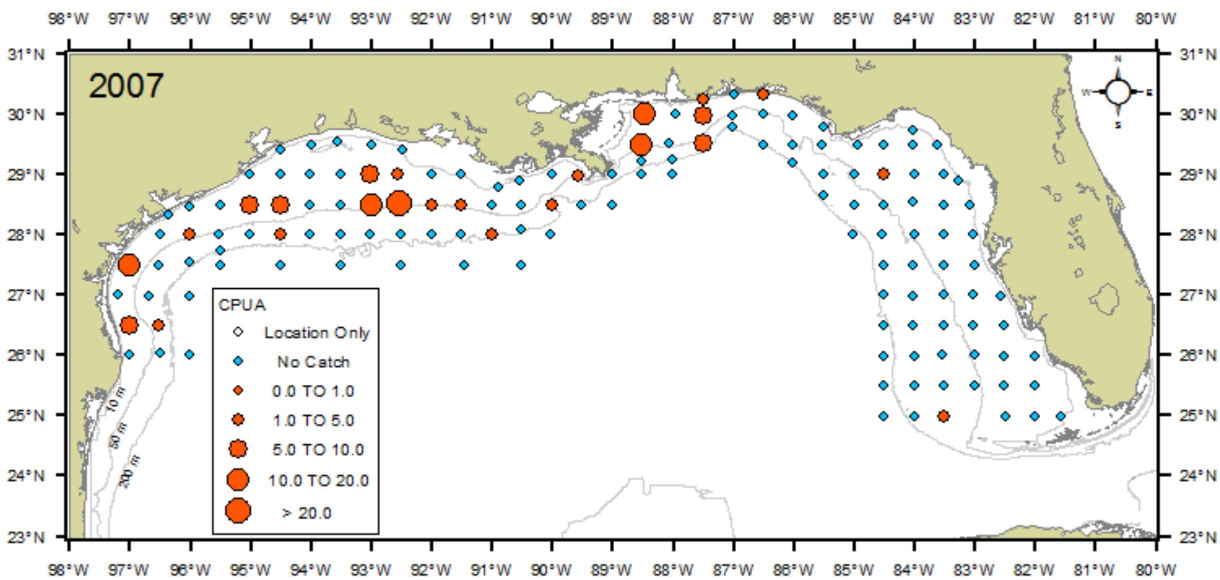

2002
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m
98°W 97°W 96°W 95°W 94°W 93°W 92°W 91°W 90°W 89°W 88°W 87°W 86°W 85°W 84°W 83°W 82°W 81°W 80°W
31°N 30°N 29°N 28°N 27°N 26°N 25°N 24°N 23°N


2003
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m
98°W 97°W 96°W 95°W 94°W 93°W 92°W 91°W 90°W 89°W 88°W 87°W 86°W 85°W 84°W 83°W 82°W 81°W 80°W
31°N 30°N 29°N 28°N 27°N 26°N 25°N 24°N 23°N


2004
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m
98°W 97°W 96°W 95°W 94°W 93°W 92°W 91°W 90°W 89°W 88°W 87°W 86°W 85°W 84°W 83°W 82°W 81°W 80°W
31°N 30°N 29°N 28°N 27°N 26°N 25°N 24°N 23°N


2005
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m
98°W 97°W 96°W 95°W 94°W 93°W 92°W 91°W 90°W 89°W 88°W 87°W 86°W 85°W 84°W 83°W 82°W 81°W 80°W
31°N 30°N 29°N 28°N 27°N 26°N 25°N 24°N 23°N


2006
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m


2007
CPUA
Location Only
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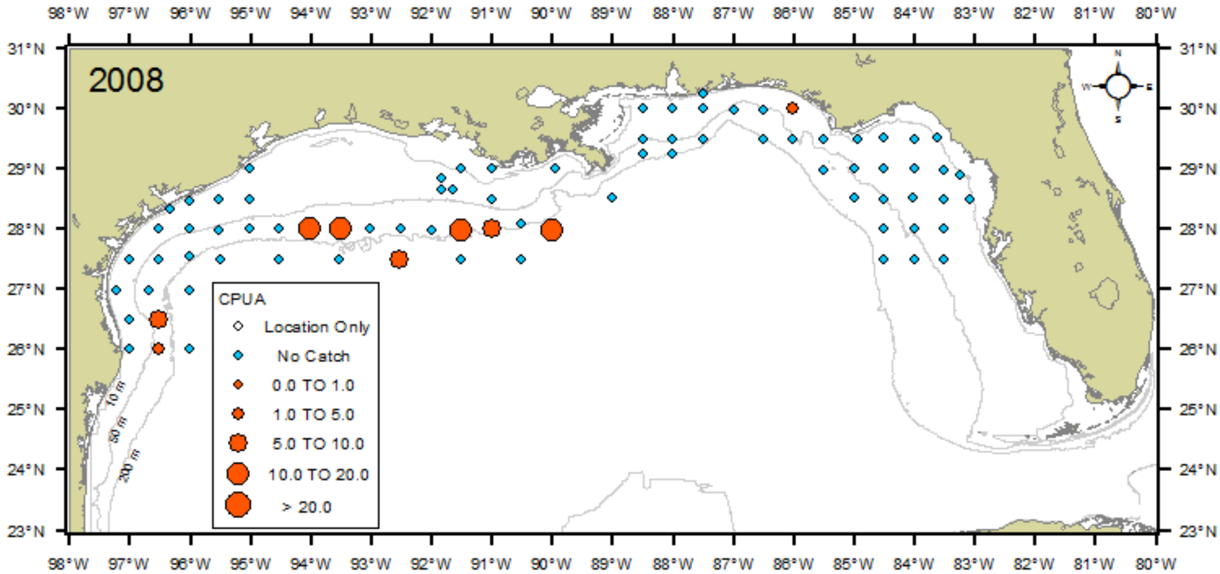
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m


2008
CPUA
Location Only
No Catch
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1.0 TO 5.0
5.0 TO 10.0
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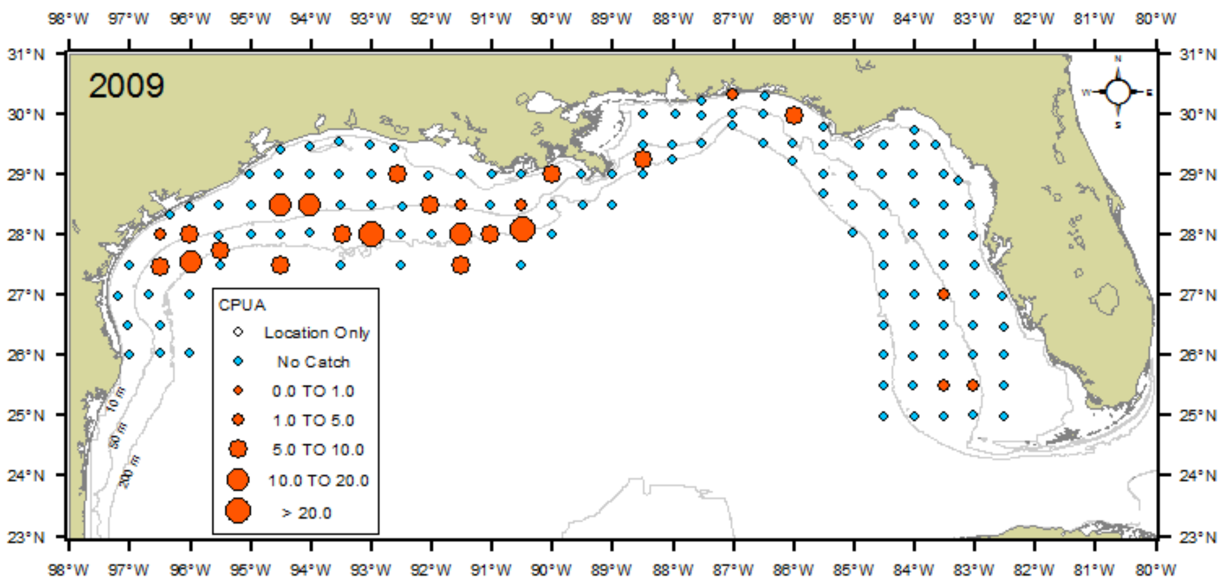
50 m
200 m


2009
CPUA
Location Only
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1.0 TO 5.0
5.0 TO 10.0
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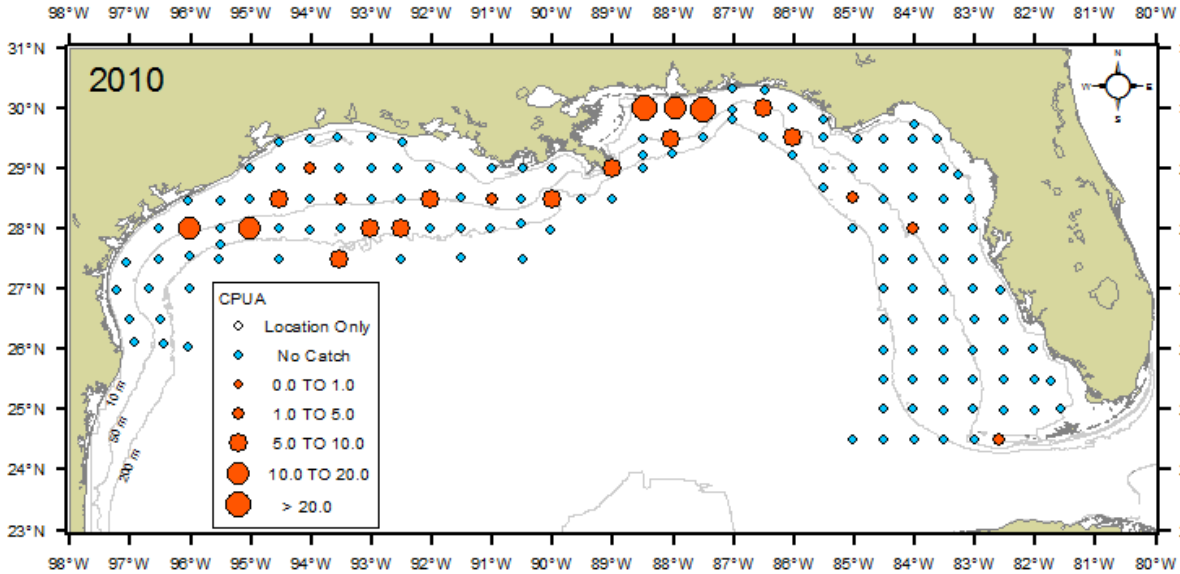
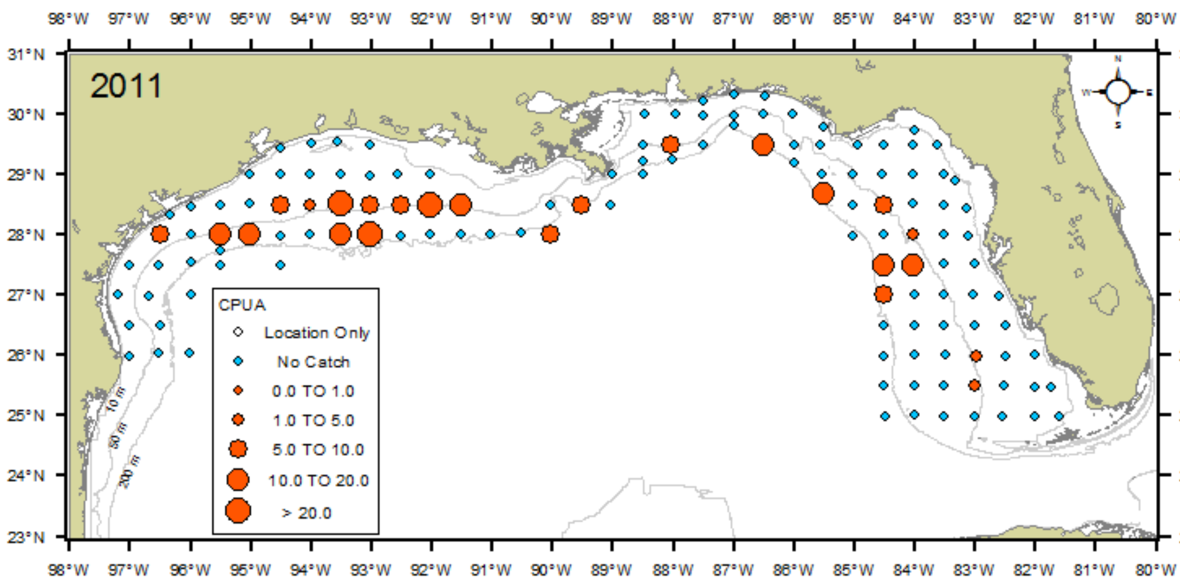
50 m
200 m



2010
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m
98°W 97°W 96°W 95°W 94°W 93°W 92°W 91°W 90°W 89°W 88°W 87°W 86°W 85°W 84°W 83°W 82°W 81°W 80°W
31°N 30°N 29°N 28°N 27°N 26°N 25°N 24°N 23°N



2011
CPUA
Location Only
No Catch
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1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m
98°W 97°W 96°W 95°W 94°W 93°W 92°W 91°W 90°W 89°W 88°W 87°W 86°W 85°W 84°W 83°W 82°W 81°W 80°W
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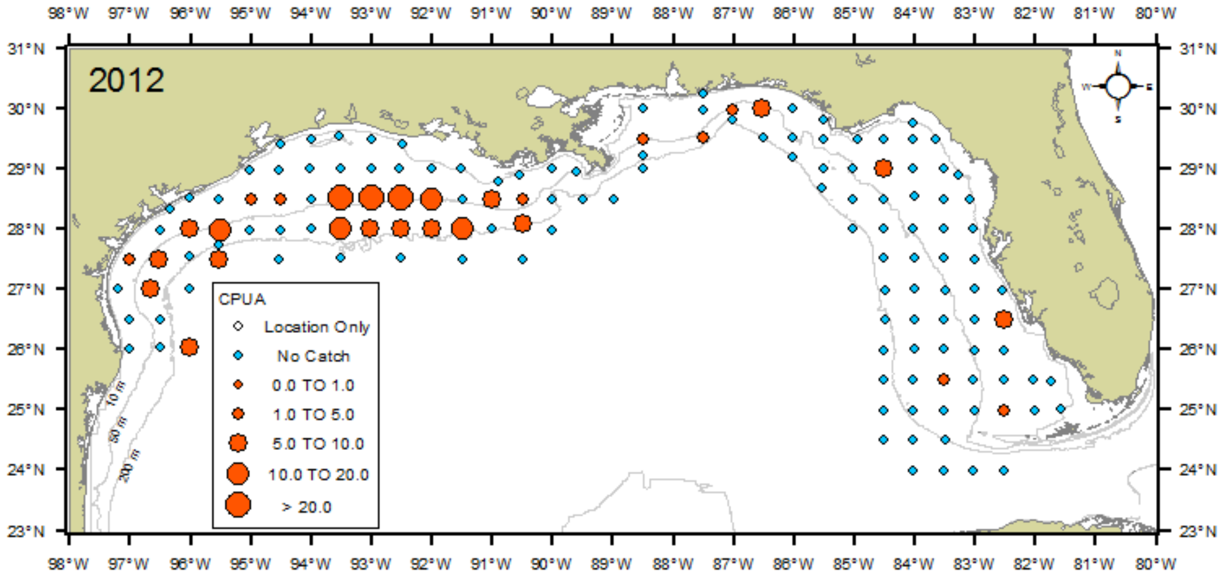
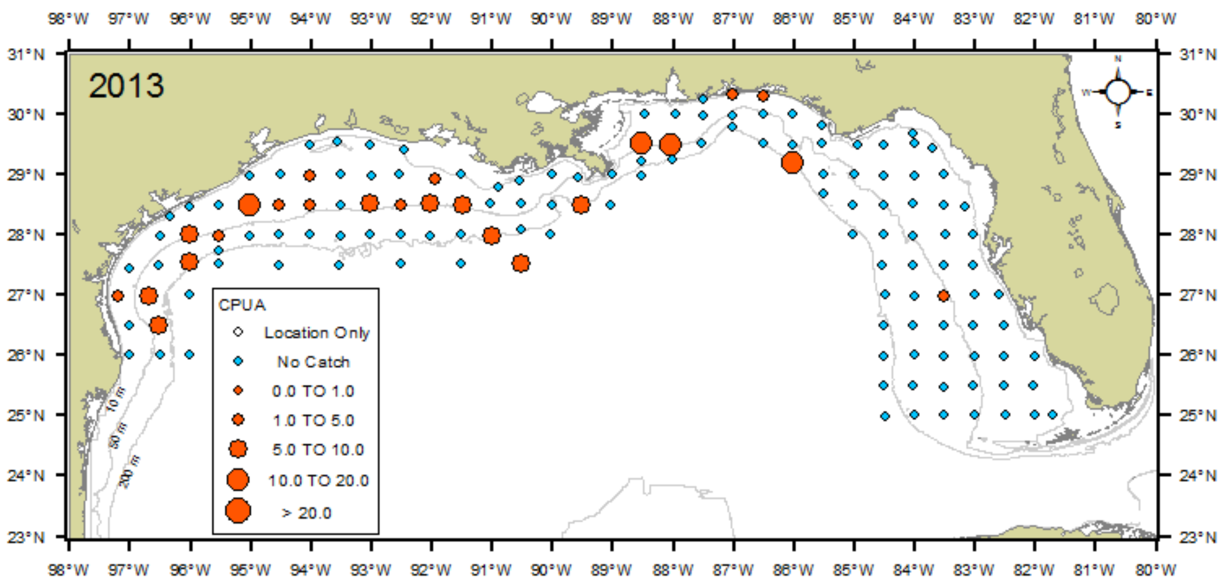
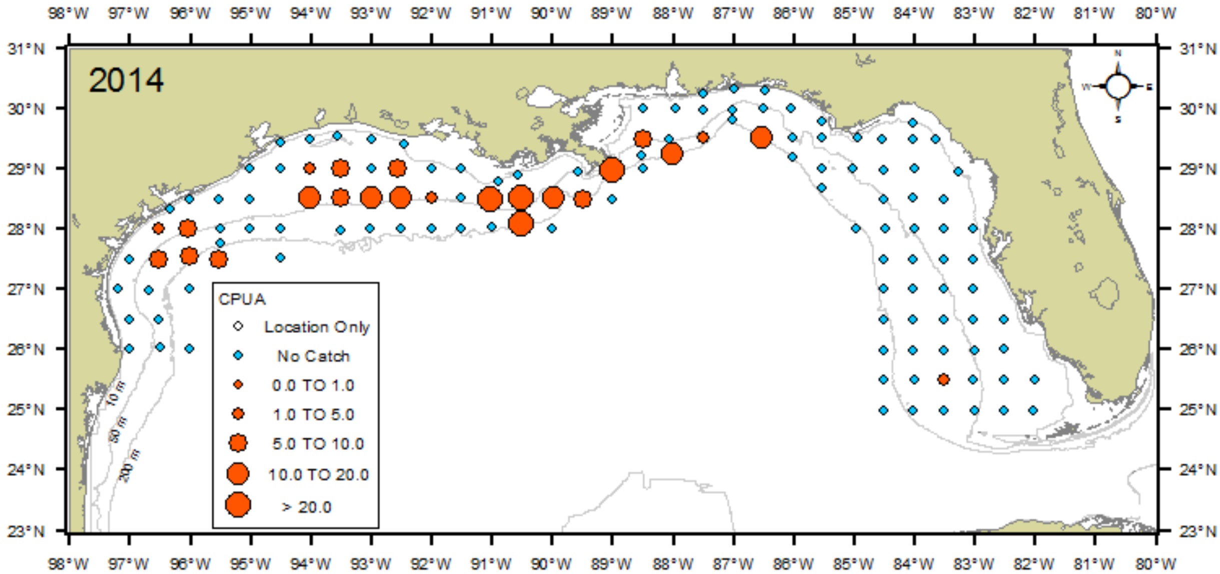
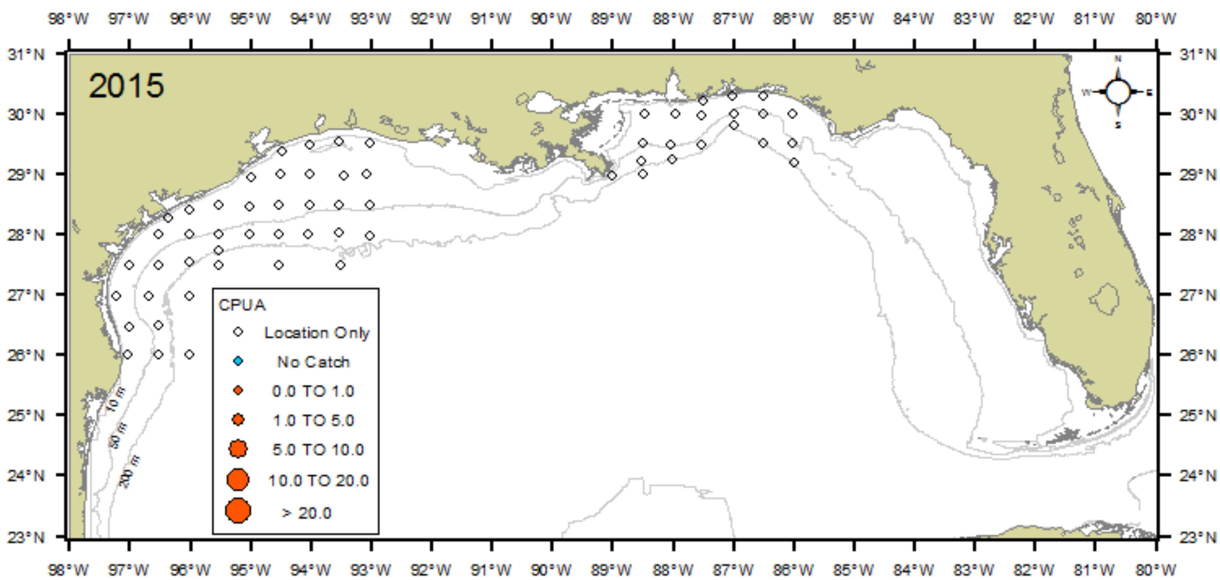
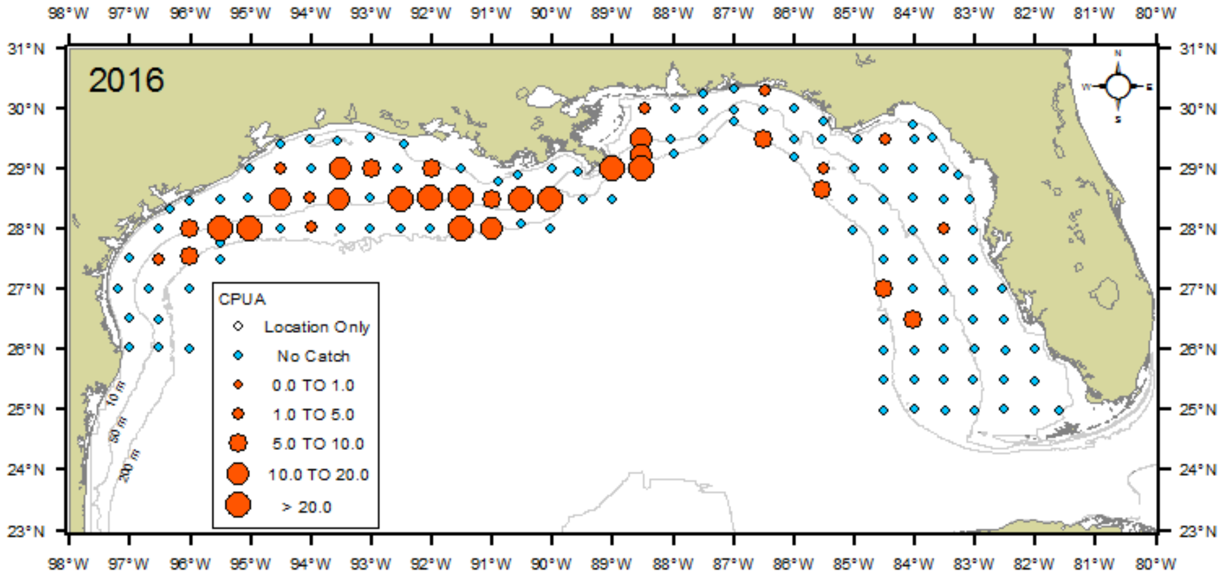

2012
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m
98°W 97°W 96°W 95°W 94°W 93°W 92°W 91°W 90°W 89°W 88°W 87°W 86°W 85°W 84°W 83°W 82°W 81°W 80°W
31°N 30°N 29°N 28°N 27°N 26°N 25°N 24°N 23°N


2013
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m
98°W 97°W 96°W 95°W 94°W 93°W 92°W 91°W 90°W 89°W 88°W 87°W 86°W 85°W 84°W 83°W 82°W 81°W 80°W
31°N 30°N 29°N 28°N 27°N 26°N 25°N 24°N 23°N


2014
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m


2015
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
10 m
50 m
200 m



2016
CPUA
Location Only
No Catch
0.0 TO 1.0
1.0 TO 5.0
5.0 TO 10.0
10.0 TO 20.0
> 20.0
98°W
97°W
96°W
95°W
94°W
93°W
92°W
91°W
90°W
89°W
88°W
87°W
86°W
85°W
84°W
83°W
82°W
81°W
80°W
31°N
30°N
29°N
28°N
27°N
26°N
25°N
24°N
23°N
10 m
50 m
200 m