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Vermilion snapper (*Rhomboplites aurorubens*) larval indices of relative abundance from SEAMAP Fall Plankton Surveys, 1986 to 2012

David S. Hanisko[1], Adam Pollack[2] and Glenn Zapfe[1]

[1] NOAA Fisheries, Southeast Fisheries Science Center,
Mississippi Laboratories, Pascagoula, MS

[2] Riverside Technology, Inc.
NOAA Fisheries, Southeast Fisheries Science Center,
Mississippi Laboratories, Pascagoula, MS

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 vermilion snapper (Rhomboplites aurorubens) larvae captured during these surveys were initially reviewed as a potential fishery-independent index to reflect trends in the relative spawning stock size of vermilion snapper during the Southeast Data, Assessment and Review 9 (SEDAR 9) process. Preliminary analysis examined indices of raw abundance and larval abundance corrected for inter-annual differences in age/size composition, but found little differences in trends between them. Three abundance indices are presented in this document: entire Gulf of Mexico, Western Gulf of Mexico and Eastern Gulf of Mexico. All indices are based on larvae greater than 3.4 mm and less than 6.5 mm in body length to account for identification uncertainty of smaller snapper larvae and the effects of gear avoidance by larger rarely caught larvae.*

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 vermilion snapper (*Rhomboplites aurorubens*) larvae captured during these surveys were initially reviewed as a potential fishery-independent index to reflect trends in the relative spawning stock size of vermilion snapper during the Southeast Data, Assessment and Review 9 (SEDAR) process. At that time, the index working group recommended the development of indices of larval abundance based on bongo net samples collected during the SEAMAP Fall Plankton survey. They also discussed the need to develop an age or size corrected index of abundance to account for inter-annual differences in size (age) composition of vermilion snapper larvae over the index time series, and requested that both adjusted and unadjusted indices be developed for comparison. These indices were to be completed prior to the SEDAR 9 Assessment Workshop in August 2005. Due the destruction of the Southeast Fisheries Science

Center, Mississippi Laboratories (SEFSC), Pascagoula Facility by Hurricane Katrina the final indices were not completed in time for the SEDAR 9 final assessment and review.

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 vermilion snapper spawning season occurring April to October. Currently the time series available for analysis extends from 1986 to 2012. This document outlines the development of vermilion snapper larval indices of abundance for the eastern, western and U.S. GOM continental shelf.

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.

Vermilion snapper larvae are planktonic and were first identified and described from field collected specimens by Laroche (1977). Despite this initial description and the additional morphological characteristics described since (Lyczkowski-Shultz and Comyns 1992; Comyns and Lyczkowski-Shultz 1993; Drass et al. 2000; and Lindeman et al. 2005), vermilion snapper larvae cannot be consistently distinguished from the larvae of other snappers at sizes < 3.5 mm in length. Size at settlement is presumably ~20 mm (Lindemann et al. 2005). Nearly all specimens of larvae used in these analyses were re-examined by ichthyoplankton specialists at the SEFSC, Mississippi Laboratories following an established identification protocol to assure the accuracy and consistency of vermilion snapper identifications over the time series.

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 Fall Plankton Survey from 1986 to 2012 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 during the 1998, 2005 and 2008 surveys. Spatial coverage in the western GOM has been consistent over the time series with the exception of the three years impacted by tropical storms. In the eastern GOM, spatial coverage has been considerably more variable. Curtailed sampling during the 1988, 1989, 1992, 2002 and 2004 surveys resulted in large portions of the eastern GOM remaining un-sampled. Another source of spatial variability in the eastern GOM 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 during the Fall Plankton Survey 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 respective for the entire, western and eastern GOM. Indices of larval abundance developed for the western GOM include samples taken during at least 16 of the 24 years with consistent spatial coverage. Eastern and Gulfwide (GOM) indices of abundance include all samples taken during at least 13 of the 19 years of with consistent spatial coverage.

Catch Curves, Aging of Larvae and Mortality Estimates

Estimates of total larval abundance of each size class (catch curves) using all index samples were developed for larval vermilion snapper by summing the abundance estimate 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 3.5 mm and greater than 6.4 mm in length were excluded from analysis due to identification uncertainty of smaller snapper larvae and the gear avoidance of larger rarely caught larvae.

Vermilion snapper larvae from SEAMAP collections are not aged, but several studies have examined their age and growth. Comyns (1997) and Comyns *et al.* (2003) determined individual growth rates of vermilion snapper larvae collected from seven stations during September 1991 and ten stations during September 1992 in the northern GOM. Age and lengths (2.4 mm to 6.5 mm) of vermilion snapper larvae (n=231) captured during these cruises were obtained from the authors of these studies and used to develop a pooled growth rate using a least squares exponential regression model.

Length-at-age for vermilion snapper larvae resulted in the following relationship:

$$(1) \qquad l = 1.7499e^{0.0808t}$$

where l was length in mm and t is age in days. The r-squared value for this relationship was 0.8411.

Size classes were converted to age classes using the length-at-age relationship to assign an age to the mid-points of each 0.5mm 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 vermilion snapper mortality was then estimated from the descending limb of the catch curve. The instantaneous mortality rate (Z) was estimated as the slope of a non-linear least squares function relating the duration-corrected larval abundance and age (Ricker, 1975).

Index Construction

Delta-lognormal modeling methods were used to estimate relative abundance indices for vermilion 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).

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) $p = \dfrac{e^{X\beta+\varepsilon}}{1+e^{X\beta+\varepsilon}}$,

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

Distribution, Abundance and Size at Capture

A total of 2,147 vermilion snapper larvae were captured in 2,489 bongo net samples (index samples only) from 24 SEAMAP Fall Plankton surveys from 1986-2012. Captured larvae ranged from 1.8 to 20.0 mm BL with a mean of 4.3 mm and a median of 4.1 mm. Ninety-five per cent of all larvae collected were less than 6.2 mm. Larvae were taken in 28.2 % of samples with a mean CPUA of 3.8 larvae per 10 m^2 sea surface (Table 2). Station depths where larvae were captured ranged from 9 to 534 m with a mean station depth of 64 m and a median station depth of 48 m. Larvae were captured throughout the survey area but occurred 1.9 times more often at 3.9 times greater CPUA in the eastern GOM than in the western GOM (Table 2 and Figure 1). Daytime versus nighttime sampling closely reflected the expected ratios of light to dark, with 52.6% of samples taken during the day and 47.4% at night. Gear avoidance in bongo nets was apparent between day and night sampling. The mean abundance of vermilion snapper larvae was 2.2 times greater at night than during the day (Table 3).

Mortality Estimates

Data resolution did not allow for the development of annual mortality estimates. Catch curves were constructed using data pooled from all index samples for larvae greater than 3.4 mm (3.75 mm size class) and less than 6.5 mm (6.25 mm size class) (Figure 2). The descending limb of the catch curve was defined as size classes 4.25 mm to 6.25 mm (10.8 to 14.8 days old). Larval abundance in size classes 3.75 mm to 6.25 mm accounted for 74.6 % of the total larval abundance from all index samples and the descending limb of the catch curve accounted for 53.5 %. The larval daily loss rate (Z) based on duration corrected larval abundance of the descending limb of the catch curve was estimated as -0.4266 (F = 0 .0039, Figure 3). The daily mortality rate was then used to back calculate abundances to the number of 10.8 day old larvae.

Indices of Abundance

Three preliminary Gulf of Mexico (Gulfwide) delta-lognormal indices of abundance were constructed to examine the effects of incorporating fully identifiable larvae below the peak of the catch curve at 4.25 mm and inter-annual differences in the age composition of larvae. The baseline index utilizes all size classes from 3.75 mm to 6.25 mm, the restricted baseline utilizes all size classes 4.25 to 6.25 mm (descending limb of catch curve) and an age-corrected index utilizing the same size classes as the restricted baseline but with abundance back calculated to a 10.8 day old larvae. All three indices were highly correlated indicating little effect of the inclusion of larvae below the peak of the catch curve and inter-annual differences in the age/size composition of larvae (Figure 4, Table 4). Based on these findings, final entire Gulf of Mexico (GOM), Western Gulf of Mexico (WGOM) and Eastern Gulf of Mexico (EGOM) delta-lognormal indices of abundance were developed utilizing all larvae greater than 3.4 mm and less than 6.5 mm without age-correction.

The GOM index of larval vermilion snapper CPUA is presented in Table 5 and Figure 5. The backward selection procedure retained year, time of day and subregion in the binomial submodel, and year, time of day, subregion and depth in the lognormal submodel (Table 6). The AIC for the binomial and lognormal submodels were 9717.0 and 1240.2, respectively. The diagnostic plots for the lognormal submodels are show in Figure 6, and indicated the distribution of the residuals is approximately normal.

The WGOM index of larval vermilion snapper CPUA is presented in Table 7 and Figure 7. The backward selection procedure retained year, time of day and subregion in the binomial submodel, and year and time of day in the lognormal submodel (Table 6). The AIC for the binomial and lognormal submodels were 5970.3 and 347.0, respectively. The diagnostic plots for the lognormal submodels are show in Figure 6, and indicated the distribution of the residuals is approximately normal.

The EGOM index of larval vermilion snapper CPUA is presented in Table 8 and Figure 8. The backward selection procedure retained year, time of day and subregion in the binomial submodel, and year, time of day, subregion and depth in the lognormal submodel (Table 6). The AIC for the binomial and lognormal submodels were 4914.3 and 917.3, respectively. The diagnostic plots for the lognormal submodels are show in Figure 6, and indicated the distribution of the residuals is approximately normal.

GOM and EGOM trends were similar, with the GOM index driven by the four times greater abundance of larval vermilion snapper found in the eastern GOM. Both indices showed increased abundance during the early and latter part of the time series. However, the high degree of variability of annual means and the reduction in years with full sampling coverage in the eastern GOM make it difficult to discern any real pattern. The WGOM index showed a gradual increase in larval abundance from 1986 to 2012 but with a large degree of uncertainty.

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

Factors	Levels	Description
Year	*24*	*1986-1997, 1999-2004, 2006-2007 and 2009-2012*
SubRegion	*4*	*TX = Texas (>93.80 Degrees W Longitude)* *LA = Louisiana (> 89.17 and <= 93.80 Degrees W Longitude)* *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. Nominal catch per unit area (CPUA) and proportion positive of larval vermilion snapper in bongo net samples (index samples only) for the entire, western and eastern GOM.

Region	N	CPUA	SE CPUA	Proportion Positive	SE Proportion Positive
West	1187	1.5226	0.1280	0.1929	0.0115
East	1302	5.9424	0.4136	0.3625	0.0133
GOM	2489	3.8346	0.2291	0.2816	0.0090

Table 3. Nominal catch per unit area (CPUA) and proportion positive of larval vermilion snapper in bongo net samples (index samples only) by time of day.

Time of Day	N	CPUA	SE CPUA	Proportion Positive	SE Proportion Positive
Day	1310	2.4551	0.2086	0.2259	0.0116
Night	1179	5.3674	0.4201	0.3435	0.0138

Table 4. Correlation among the preliminary baseline, restricted baseline and age-corrected Gulf of Mexico indices of vermilion snapper larval abundance.

	Baseline	*Restricted Baseline*	*Age Corrected*
Baseline	1.0000		
Restricted Baseline	0.9613	1.0000	
Age Corrected	0.8699	0.9461	1.0000

Table 5. SEAMAP Fall Plankton Survey indices of larval vermilion snapper (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 of 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	0.11538	104	1.17113	0.50284	0.36743	0.24679	1.02455
1987	0.25439	114	2.75893	1.18459	0.23420	0.74619	1.88055
1988							
1989							
1990	0.28571	70	1.86322	0.80000	0.27663	0.46476	1.37706
1991	0.32432	74	3.65709	1.57023	0.25145	0.95696	2.57650
1992							
1993	0.22857	105	1.33481	0.57312	0.25339	0.34799	0.94389
1994	0.25424	118	2.16444	0.92934	0.22826	0.59213	1.45857
1995	0.20000	115	1.43468	0.61600	0.26461	0.36612	1.03643
1996	0.24138	116	2.00168	0.85945	0.23706	0.53842	1.37190
1997	0.28696	115	2.18097	0.93643	0.21547	0.61157	1.43386
1998							
1999	0.18966	116	1.45551	0.62495	0.26985	0.36776	1.06199
2000	0.21930	114	1.74359	0.74864	0.25221	0.45559	1.23019
2001	0.24074	108	1.94742	0.83615	0.24639	0.51454	1.35880
2002							
2003	0.26724	116	3.05887	1.31337	0.22434	0.84317	2.04579
2004							
2005							
2006	0.25225	111	2.90342	1.24663	0.23433	0.78509	1.97950
2007	0.23529	119	3.65689	1.57014	0.23647	0.98477	2.50348
2008							
2009	0.23529	119	2.76832	1.18862	0.23719	0.74444	1.89782
2010	0.25862	116	2.65034	1.13796	0.22773	0.72580	1.78418
2011	0.28829	111	2.61264	1.12178	0.21944	0.72701	1.73091
2012	0.27434	113	2.88743	1.23976	0.22331	0.79750	1.92728

Table 6. Summary of final delta-lognormal models from the backward selection procedure for theentire Gulf of Mexico, Western Gulf of Mexico and Eastern Gulf of Mexico vermilion snapper indices of abundance.

Gulf of Mexico

	Binomial Submodel Type 3 Tests(AIC=9717.0)						*Lognormal Submodel Type 3 Tests (AIC=1240.2)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
YEAR	18	2051	19.26	1.07	0.3761	0.377	18	480	2.35	0.0014
TOD	1	2051	41.19	41.19	<.0001	<.0001	1	480	12.69	0.0004
SUBREGION	3	2051	87.54	29.18	<.0001	<.0001	3	480	9.06	<.0001
DEPTH				Dropped			1	480	18.11	<.0001

Western Gulf of Mexico

	Binomial Submodel Type 3 Tests(AIC=5970.3)						*Lognormal Submodel Type 3 Tests (AIC=347.0)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
YEAR	23	1161	28.01	1.22	0.2156	0.2187	23	156	0.77	0.7606
TOD	1	1161	31.81	31.81	<.0001	<.0001	1	156	5.9	0.0163
SUBREGION	1	1161	16.12	16.12	<.0001	<.0001			Dropped	
DEPTH				Dropped					Dropped	

Eastern Gulf of Mexico

	Binomial Submodel Type 3 Tests(AIC=4914.3)						*Lognormal Submodel Type 3 Tests (AIC=917.3)*			
Effect	*Num DF*	*Den DF*	*Chi-Square*	*F Value*	*Pr > ChiSq*	*Pr > F*	*Num DF*	*Den DF*	*F Value*	*Pr > F*
YEAR	18	1085	23.55	1.31	0.1704	0.1733	18	333	2.6	0.0004
TOD	1	1085	18.4	18.4	<.0001	<.0001	1	333	7.7	0.0058
SUBREGION	1	1085	5.78	5.78	0.0162	0.0163	1	333	4.16	0.0422
DEPTH				Dropped			1	333	15.44	0.0001

Table 7. SEAMAP Fall Plankton Survey indices of larval vermilion snapper (Western 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 of 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	0.08163	49	0.51886	0.52588	0.57279	0.18122	1.52603
1987	0.10909	55	0.79715	0.80794	0.46630	0.33274	1.96178
1988	0.03571	28	0.18562	0.18814	1.13083	0.03063	1.15546
1989	0.10714	28	0.55610	0.56363	0.65210	0.17138	1.85368
1990	0.09677	31	0.42209	0.42780	0.66037	0.12844	1.42491
1991	0.12903	31	0.52174	0.52880	0.56481	0.18460	1.51475
1992	0.20000	55	0.93544	0.94810	0.33684	0.49215	1.82645
1993	0.09091	55	0.63784	0.64648	0.51385	0.24553	1.70217
1994	0.16364	55	1.35212	1.37042	0.37111	0.66811	2.81099
1995	0.18182	55	1.20206	1.21833	0.34992	0.61739	2.40421
1996	0.18182	55	1.13056	1.14585	0.35167	0.57880	2.26845
1997	0.24074	54	1.53118	1.55190	0.30212	0.85931	2.80268
1998							
1999	0.07273	55	0.50719	0.51405	0.57221	0.17731	1.49031
2000	0.20000	55	1.63270	1.65480	0.33856	0.85628	3.19796
2001	0.10638	47	0.56364	0.57127	0.50747	0.21931	1.48807
2002	0.16667	54	0.89136	0.90342	0.37064	0.44082	1.85148
2003	0.16667	54	1.36132	1.37974	0.37321	0.67010	2.84090
2004	0.14815	54	0.87934	0.89124	0.40111	0.41163	1.92967
2005							
2006	0.19231	52	1.28442	1.30180	0.35305	0.65592	2.58368
2007	0.10909	55	0.76627	0.77663	0.46201	0.32223	1.87184
2008							
2009	0.18182	55	1.74294	1.76653	0.35408	0.88839	3.51264
2010	0.13208	53	1.07187	1.08637	0.42705	0.47915	2.46313
2011	0.29787	47	2.05620	2.08402	0.28358	1.19490	3.63472
2012	0.16364	55	1.13155	1.14686	0.37617	0.55401	2.37412

Table 8. SEAMAP Fall Plankton Survey indices of larval vermilion snapper (Eastern 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 of 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	0.14545	55	1.94152	0.51302	0.45746	0.21454	1.22676
1987	0.38983	59	5.24232	1.38521	0.26096	0.82902	2.31453
1988							
1989							
1990	0.43590	39	3.46454	0.91545	0.29091	0.51769	1.61883
1991	0.46512	43	7.43288	1.96403	0.26732	1.16132	3.32159
1992							
1993	0.38000	50	2.29861	0.60738	0.27922	0.35113	1.05062
1994	0.33333	63	3.10371	0.82011	0.27407	0.47876	1.40484
1995	0.21667	60	1.56019	0.41226	0.35703	0.20621	0.82419
1996	0.29508	61	2.92894	0.77393	0.29869	0.43131	1.38873
1997	0.32787	61	2.64616	0.69921	0.28029	0.40340	1.21192
1998							
1999	0.29508	61	2.59785	0.68644	0.29826	0.38286	1.23075
2000	0.23729	59	1.82842	0.48313	0.34157	0.24862	0.93887
2001	0.34426	61	3.52790	0.93220	0.27324	0.54505	1.59435
2002							
2003	0.35484	62	4.96316	1.31145	0.26681	0.77620	2.21579
2004							
2005							
2006	0.30508	59	4.67071	1.23417	0.29391	0.69399	2.19480
2007	0.34375	64	7.29752	1.92827	0.26572	1.14365	3.25119
2008							
2009	0.28125	64	3.97724	1.05093	0.29906	0.58527	1.88707
2010	0.36508	63	4.44201	1.17374	0.25848	0.70579	1.95194
2011	0.28125	64	3.12855	0.82668	0.29852	0.46085	1.48289
2012	0.37931	58	4.85326	1.28241	0.26468	0.76210	2.15795

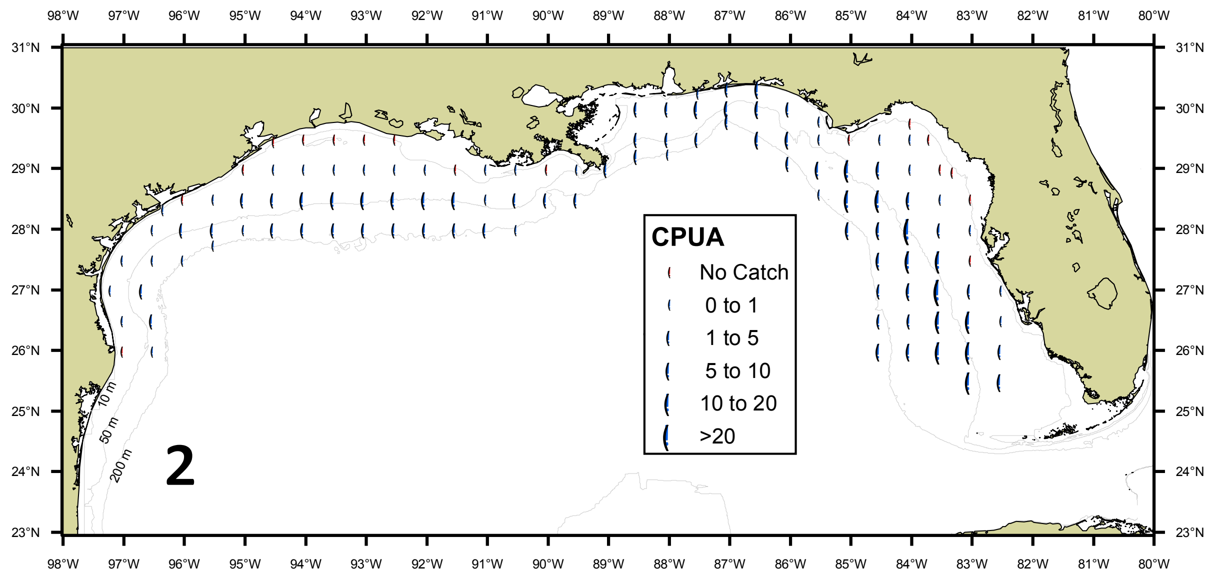


Figure 1. Mean number of vermilion snapper larvae under 10 m^2 sea surface (CPUA) captured during SEAMAP Fall Plankon Survey 1986 to 2012 in bongo net index samples.

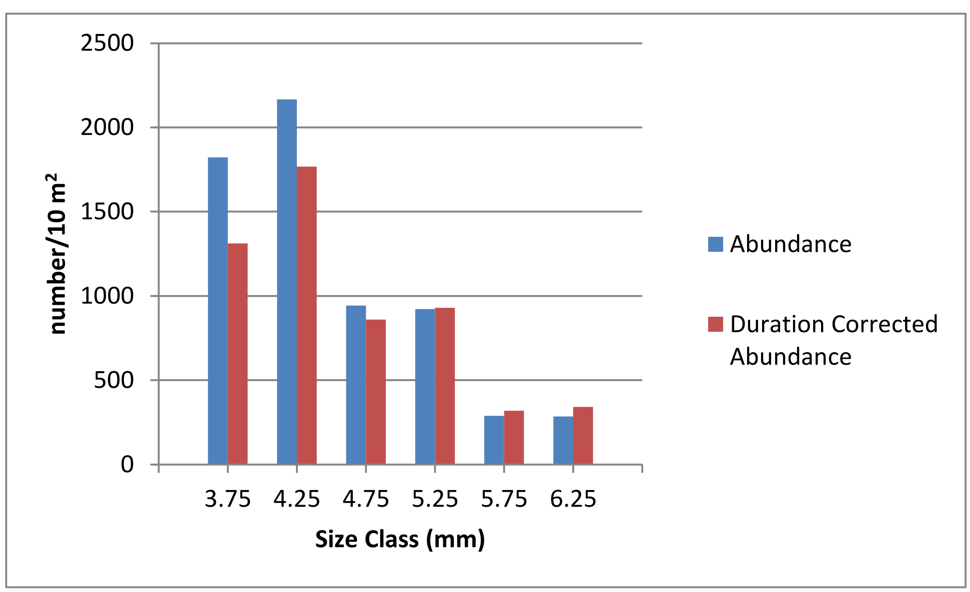


Figure 2. Vermilion snapper total abundance and total duration corrected abundance by 0.5 mm size classes.

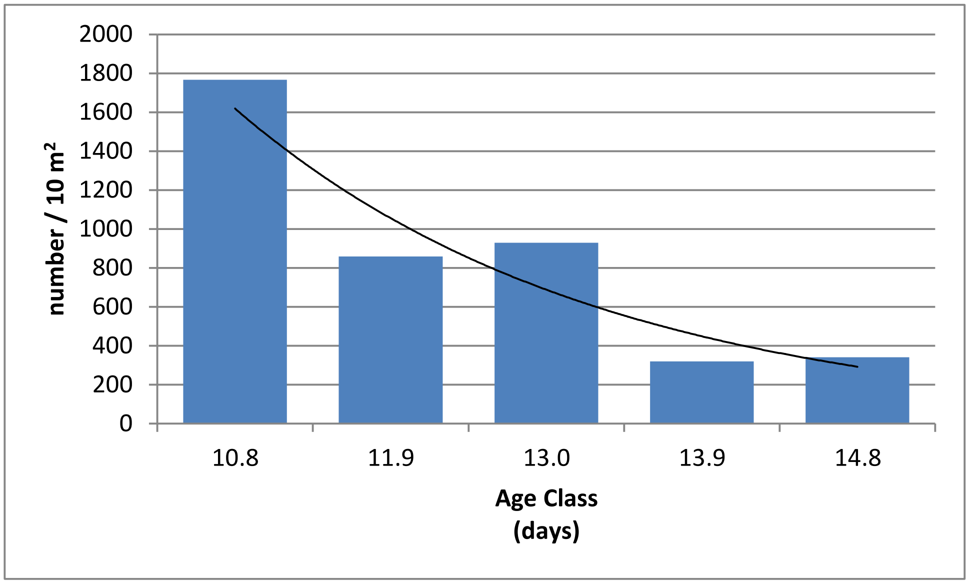


Figure 3. Age distribution (age at size class midpoint) of larval vermilion snapper catch and the resulting daily loss rate curve (Z = -0.4266).

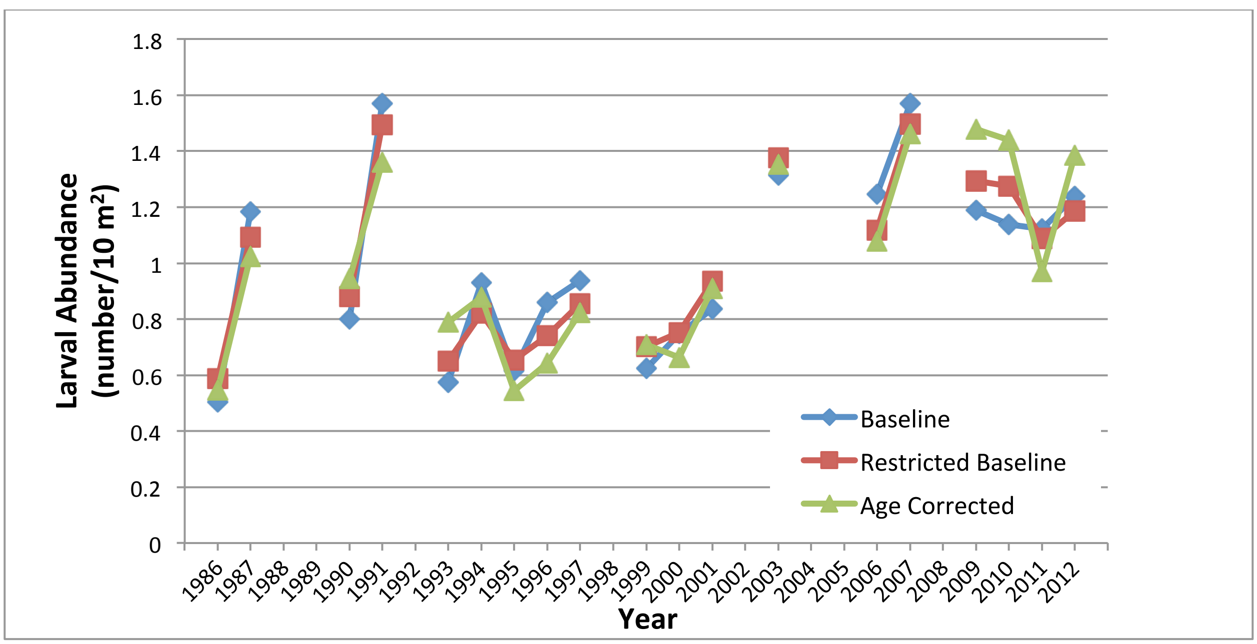


Figure 4. Preliminary baseline, restricted baseline and age-corrected Gulf of Mexico delta-lognormal indices of vermilion snapper larval abundance. Indices are scaled to the mean of their respective time series.

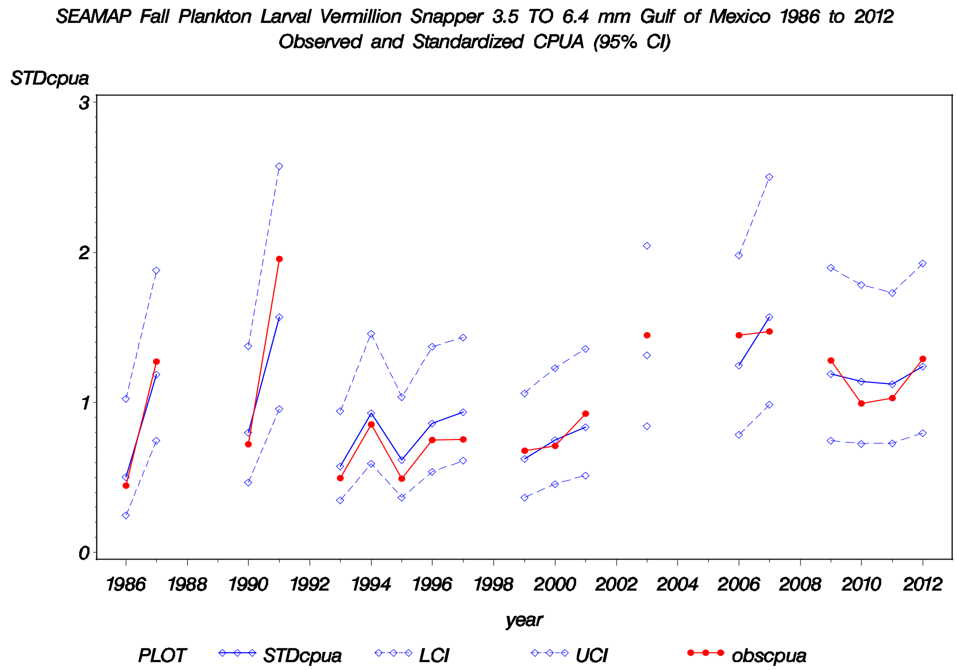
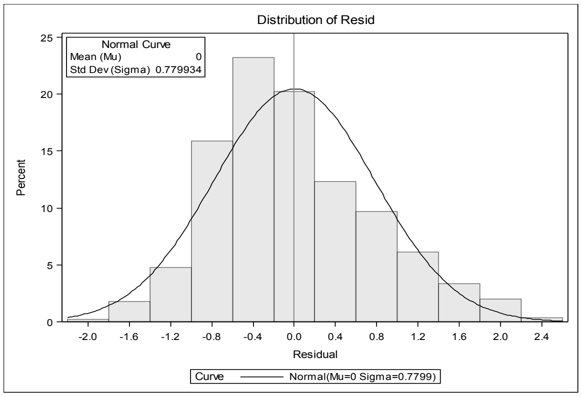
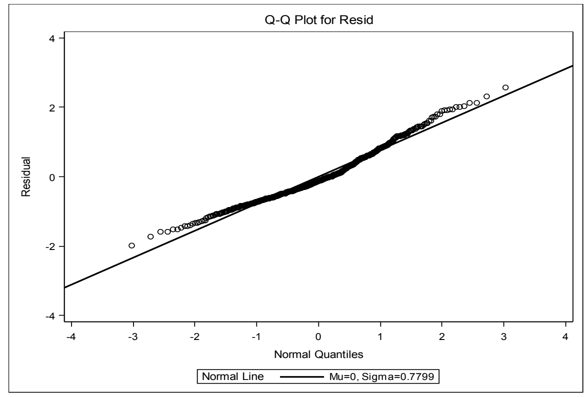


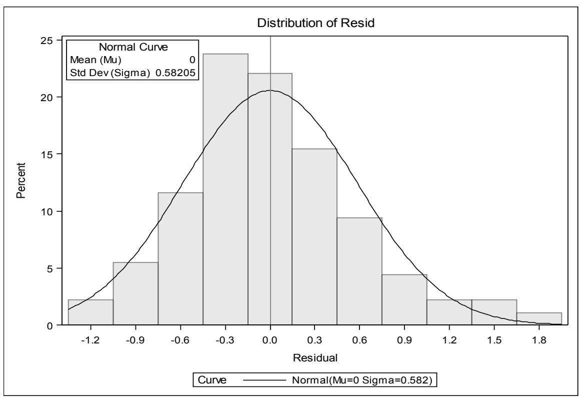
Figure 5. Annual index of larval vermilion snapper abundance from SEAMAP Fall Plankton Surveys from 1986 – 2012 for the entire Gulf of Mexico.

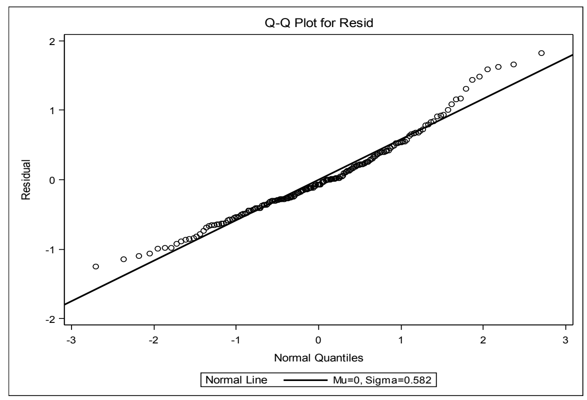
Gulf of Mexico



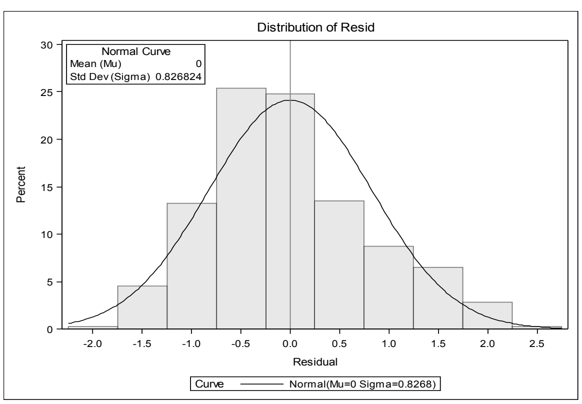


Western Gulf of Mexico





Eastern Gulf of Mexico



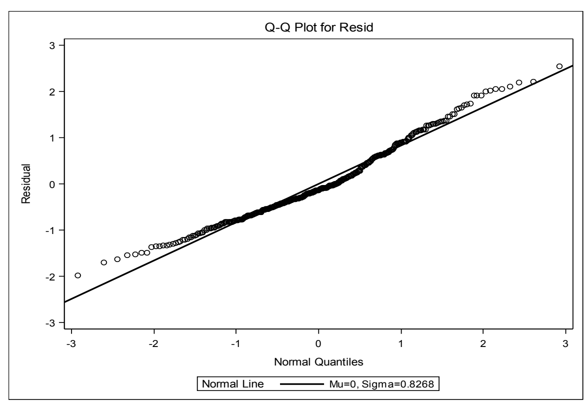


Figure 6. Diagnostic plots for the lognormal submodels of the Gulf of Mexico (top), Western Gulf of Mexico (middle) and Eastern Gulf of Mexico (bottom) indices of abundance: Left column shows he frequency distribution of log(CPUA) on positive stations and the right column the cumulative normalized residuals (QQ plot).

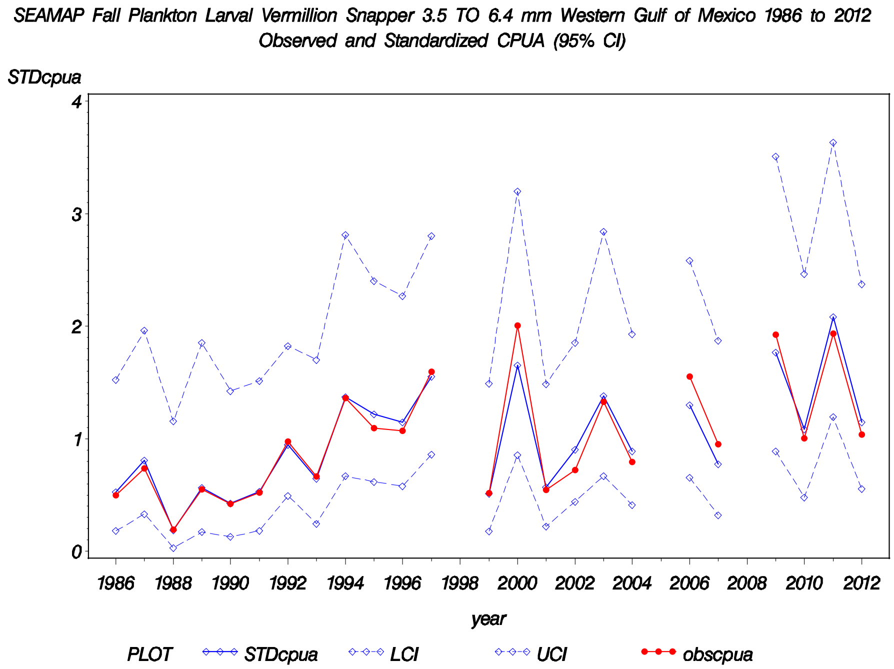


Figure 7. Annual index of larval vermilion snapper abundance from SEAMAP Fall Plankton Surveys from 1986 – 2012 for the Western Gulf of Mexico.

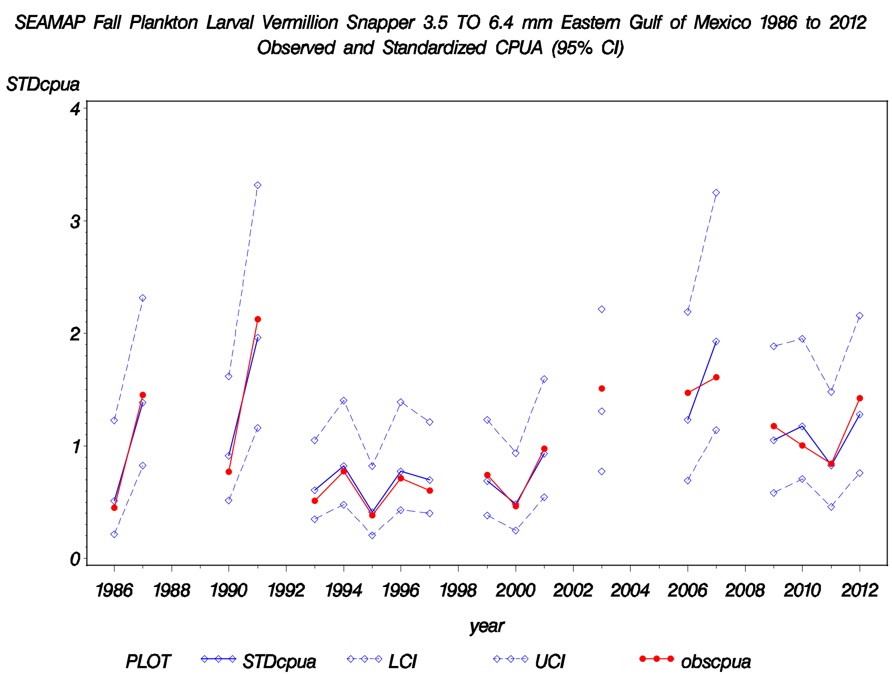
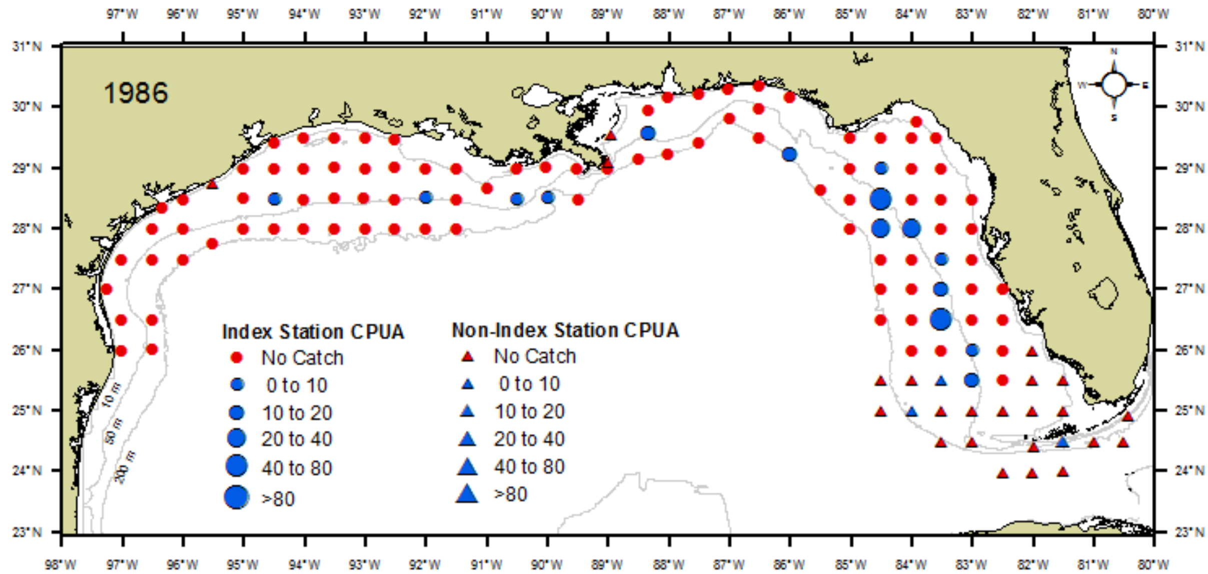
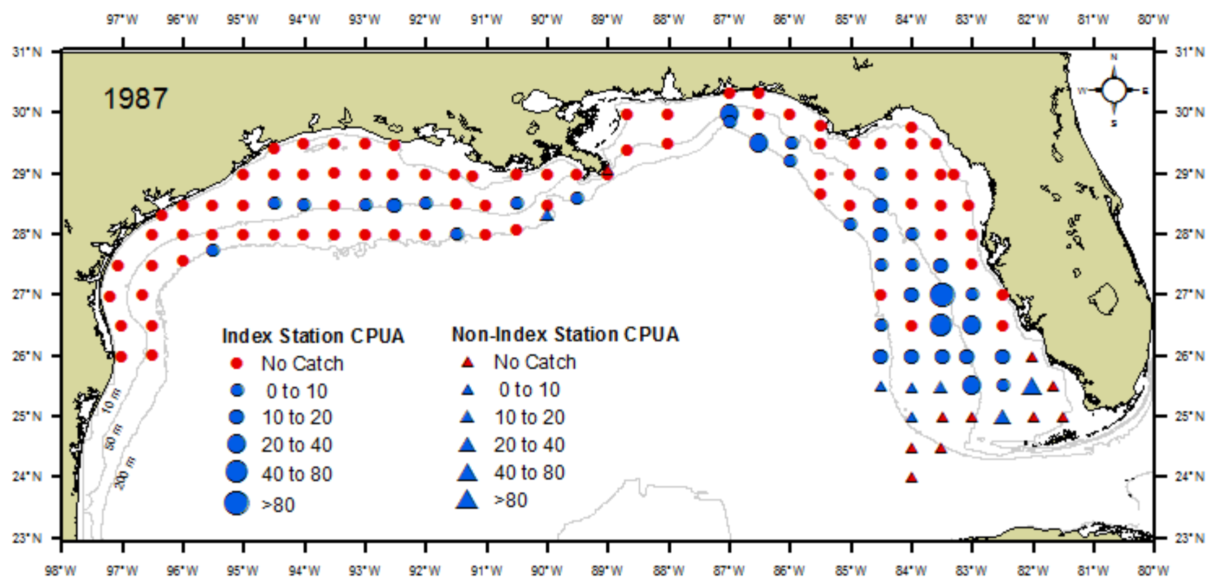
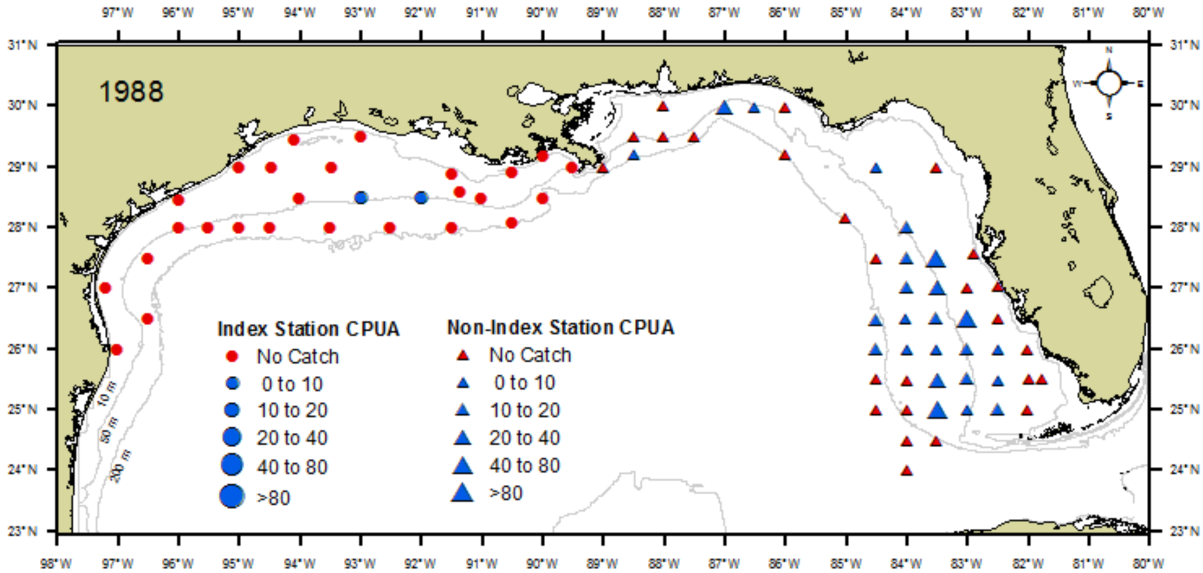


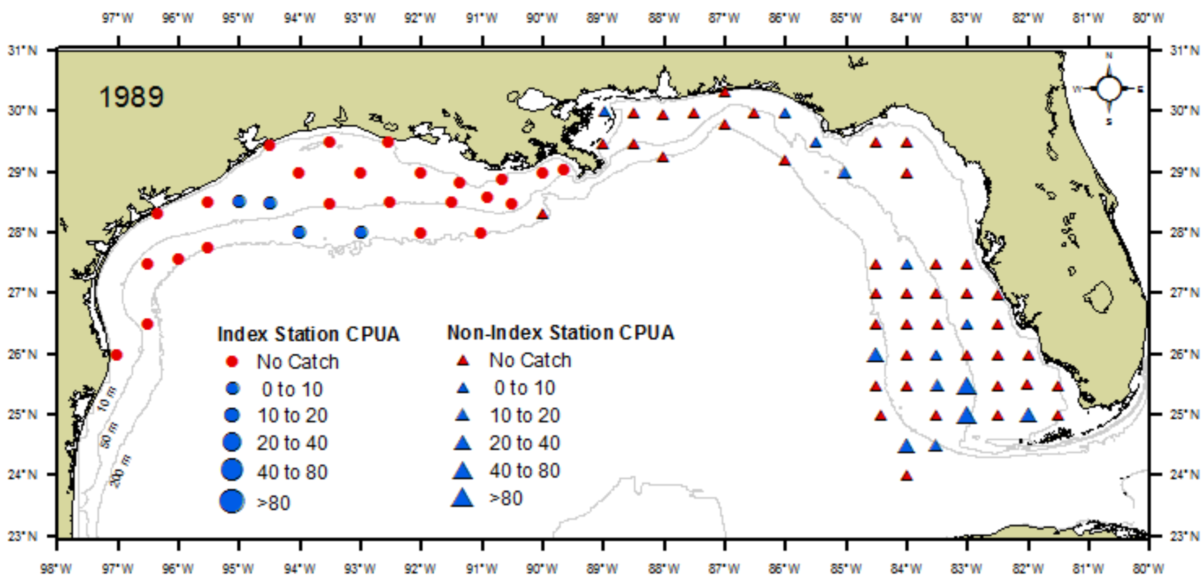
Figure 8. Annual index of larval vermilion snapper abundance from SEAMAP Fall Plankton Surveys from 1986 – 2012 for the Eastern Gulf of Mexico.

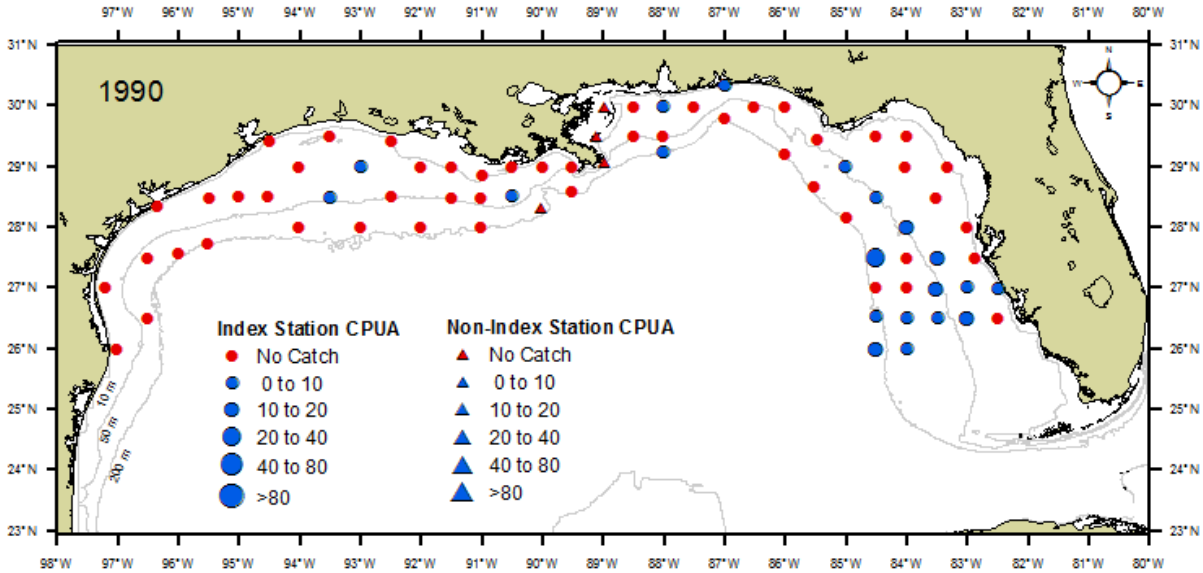
Appendix Figure 1. Annual survey effort and catch per unit area (CPUA) of vermilion snapper from the SEAMAP Fall Plankton Survey conducted from 1986-2012. CPUA is expressed as the number of larvae under 10 m^2.






1988
Index Station CPUA
No Catch
0 to 10
10 to 20
20 to 40
40 to 80
>80
Non-Index Station CPUA
No Catch
0 to 10
10 to 20
20 to 40
40 to 80
>80
10 m
50 m
200 m


1989
Index Station CPUA
No Catch
0 to 10
10 to 20
20 to 40
40 to 80
>80
Non-Index Station CPUA
No Catch
0 to 10
10 to 20
20 to 40
40 to 80
>80
10 m
50 m
200 m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No Catch
0 to 10
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20 to 40
40 to 80
>80
Non-Index Station CPUA
No Catch
0 to 10
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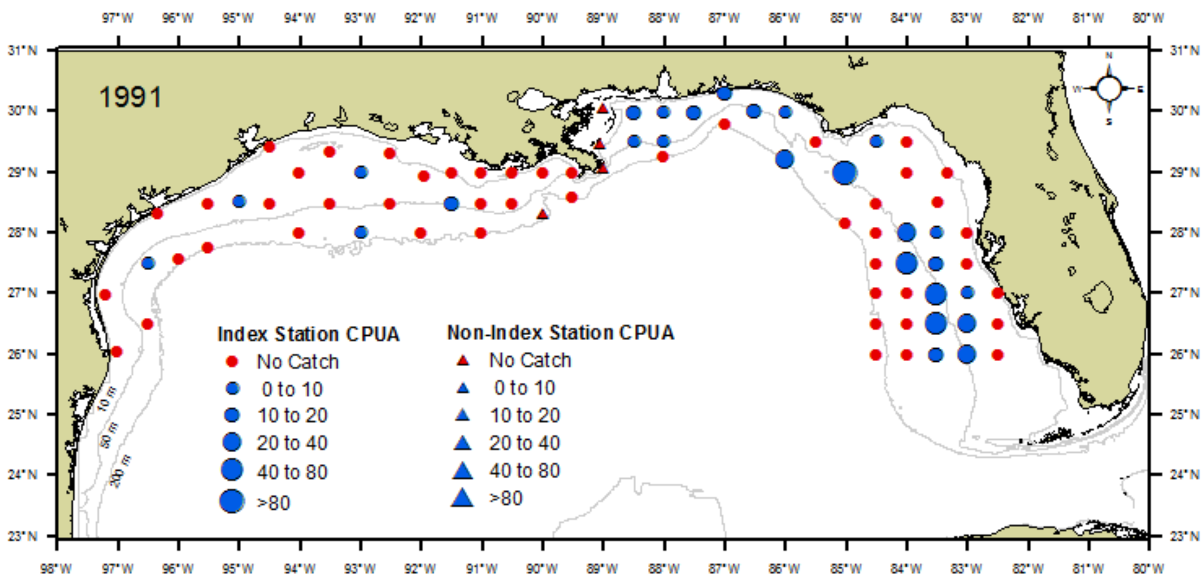
40 to 80
>80
10 m
50 m
200 m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No Catch
0 to 10
10 to 20
20 to 40
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Non-Index Station CPUA
No Catch
0 to 10
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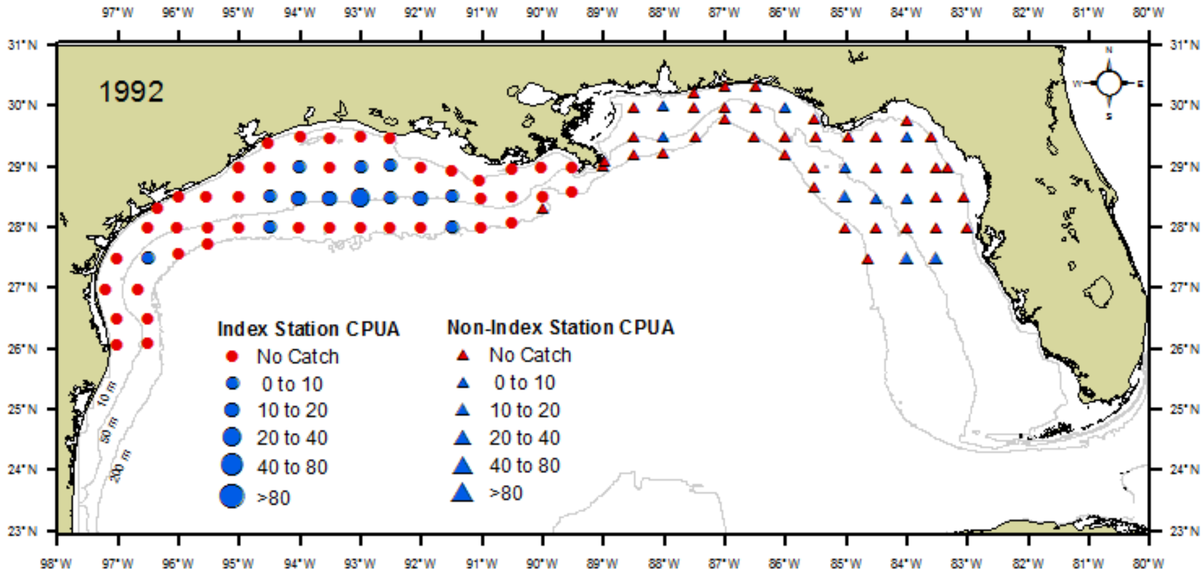
20 to 40
40 to 80
>80
10 m
50 m
200 m



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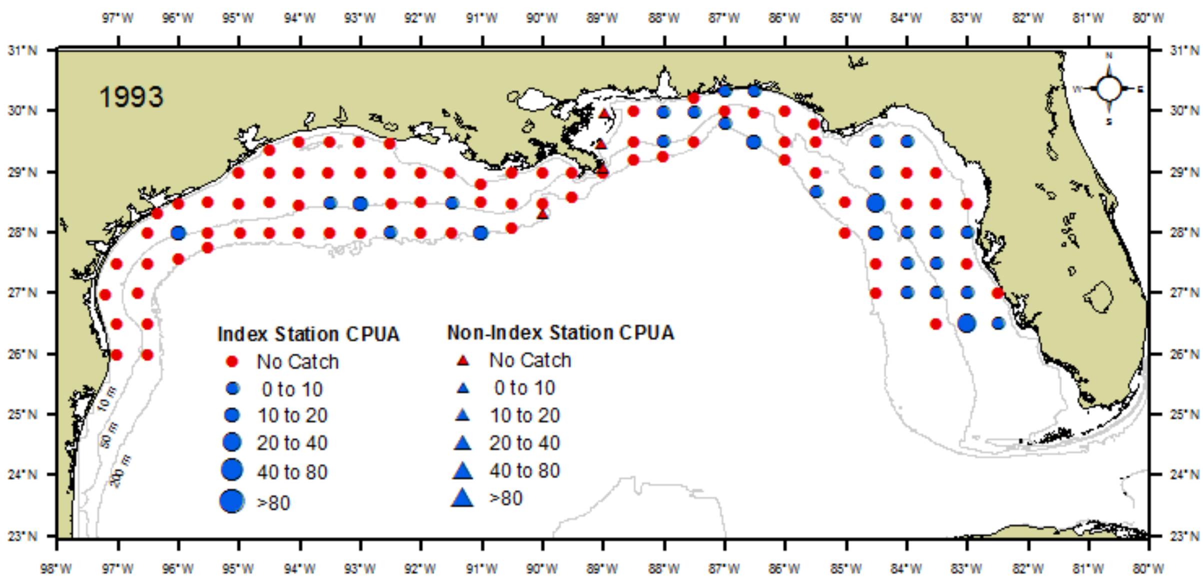
>80



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Non-Index Station CPUA
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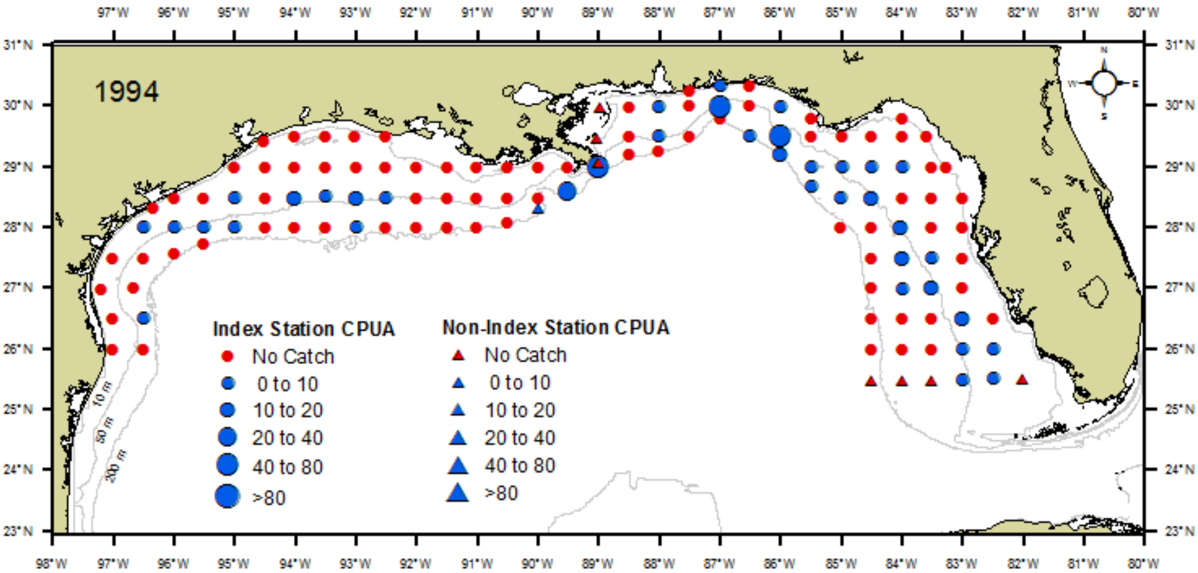
40 to 80
>80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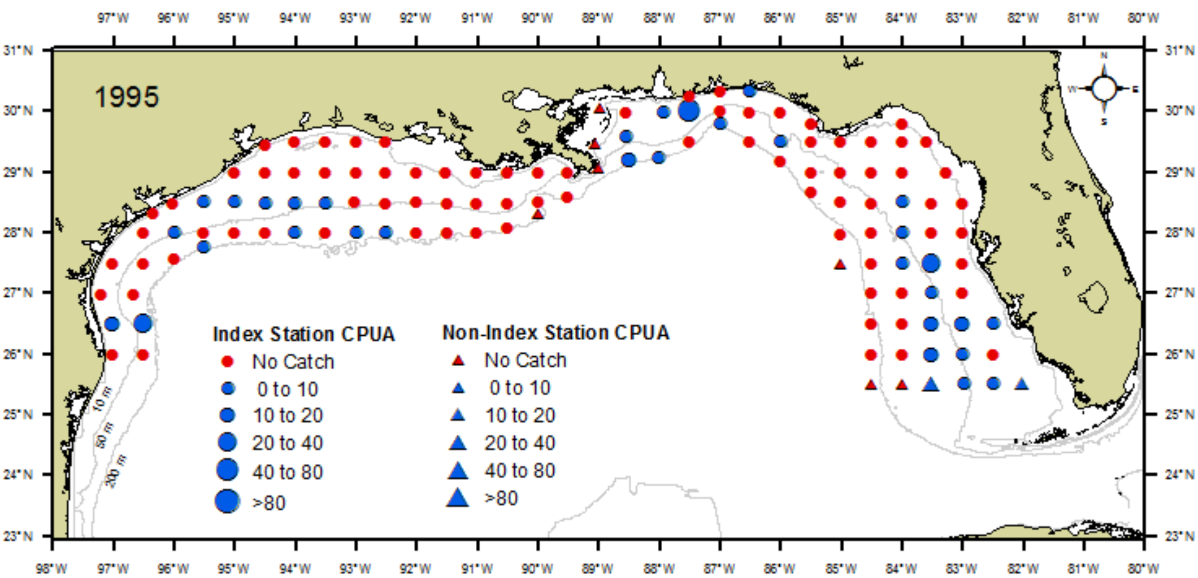
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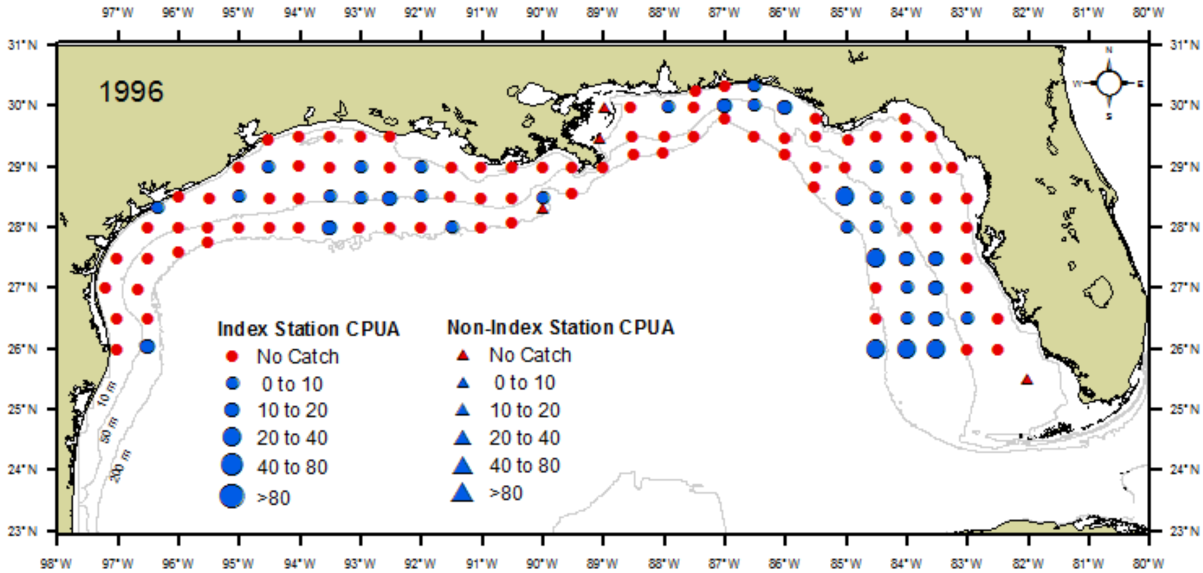
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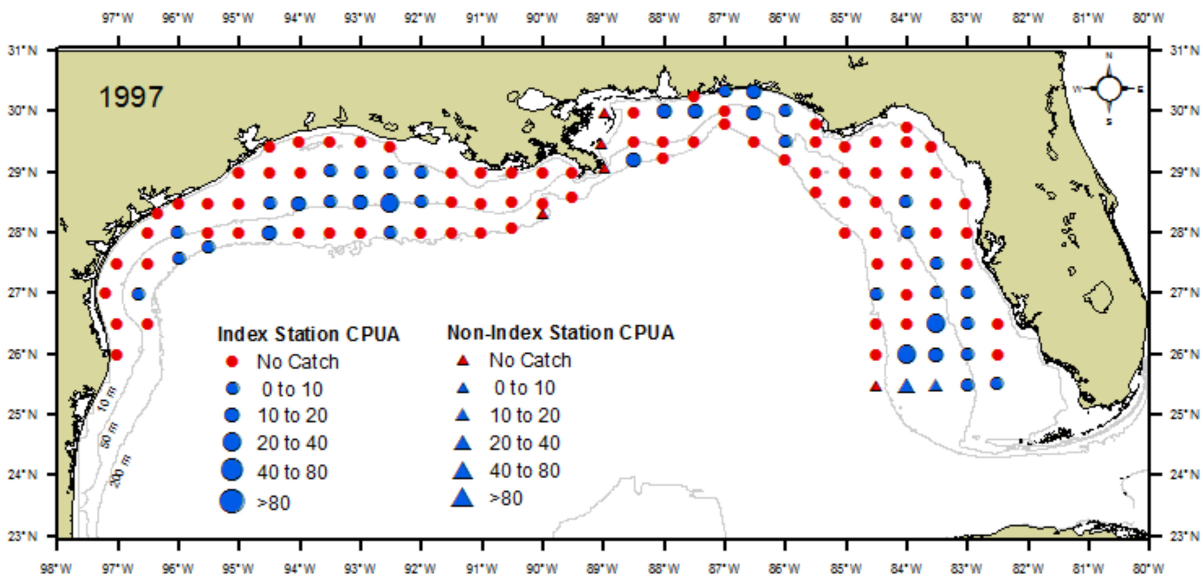
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Non-Index Station CPUA
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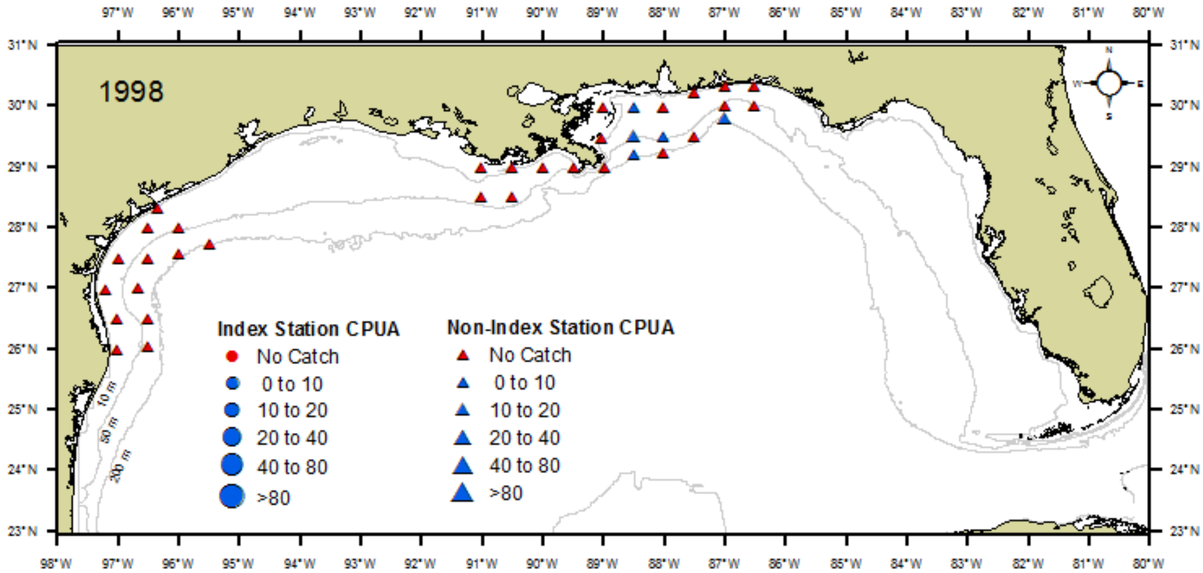
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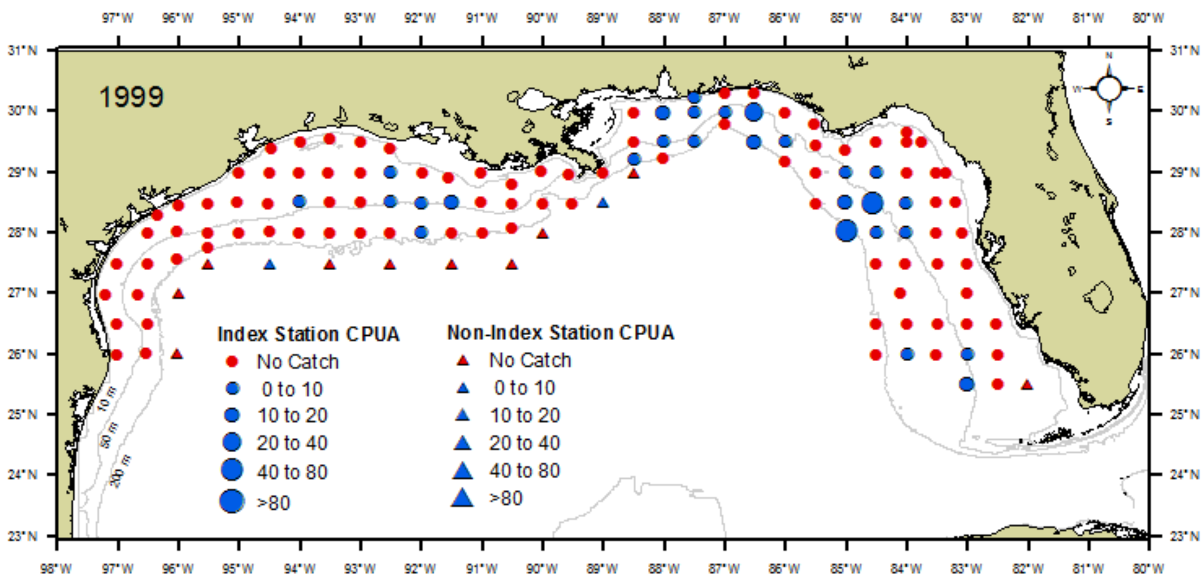
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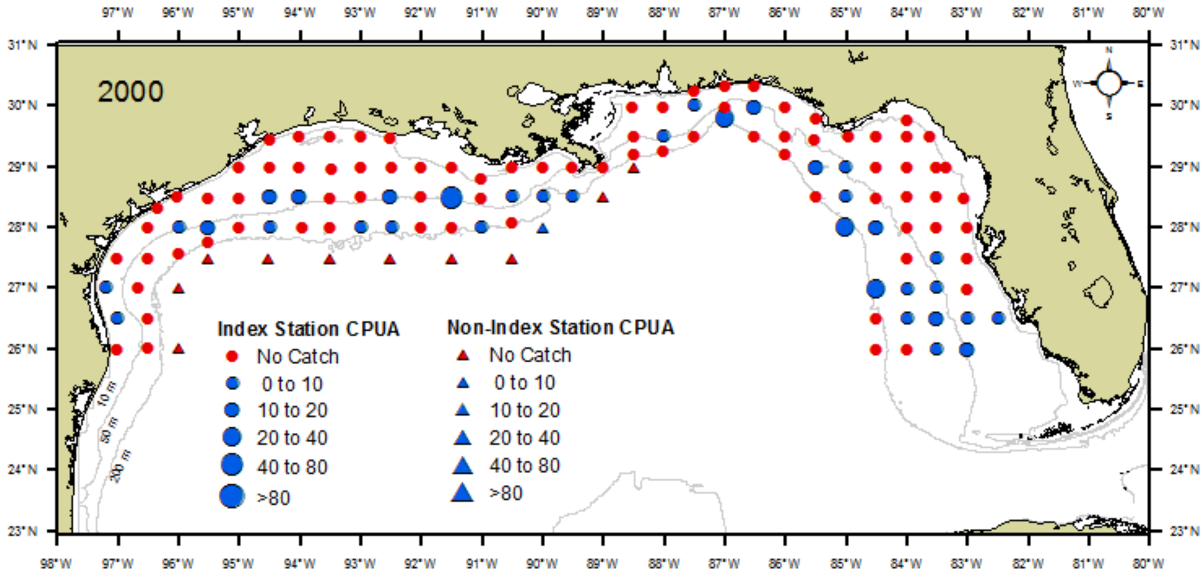
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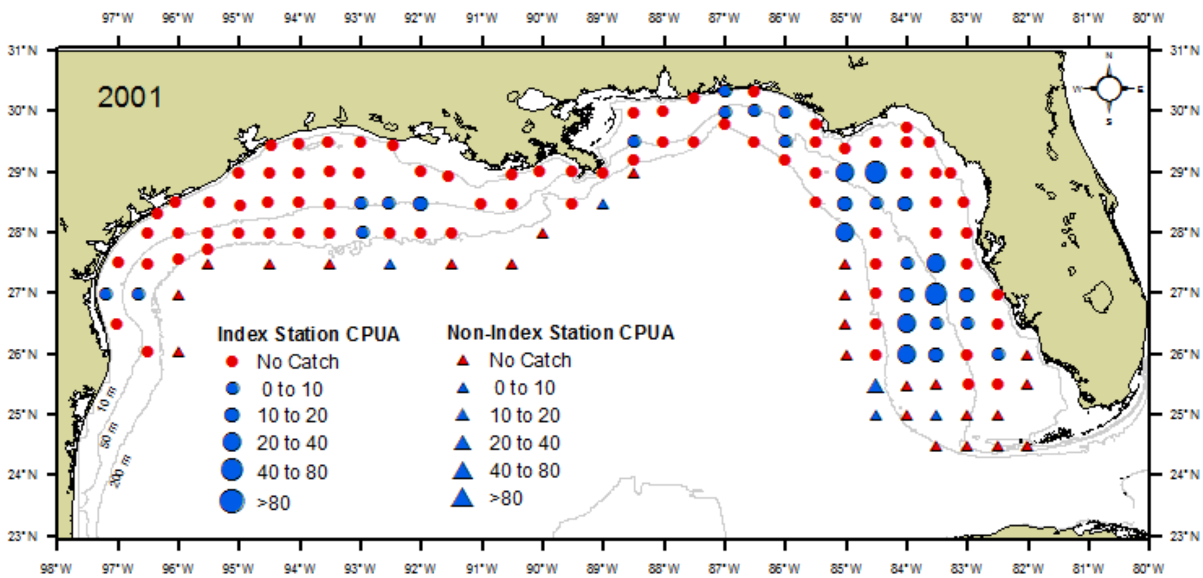
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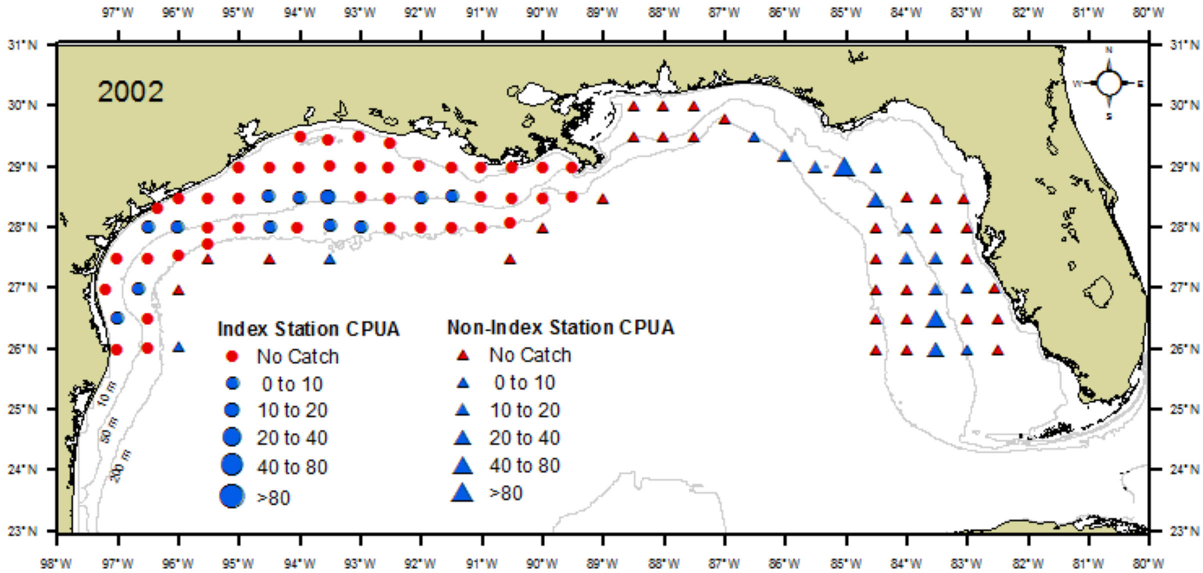
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Non-Index Station CPUA
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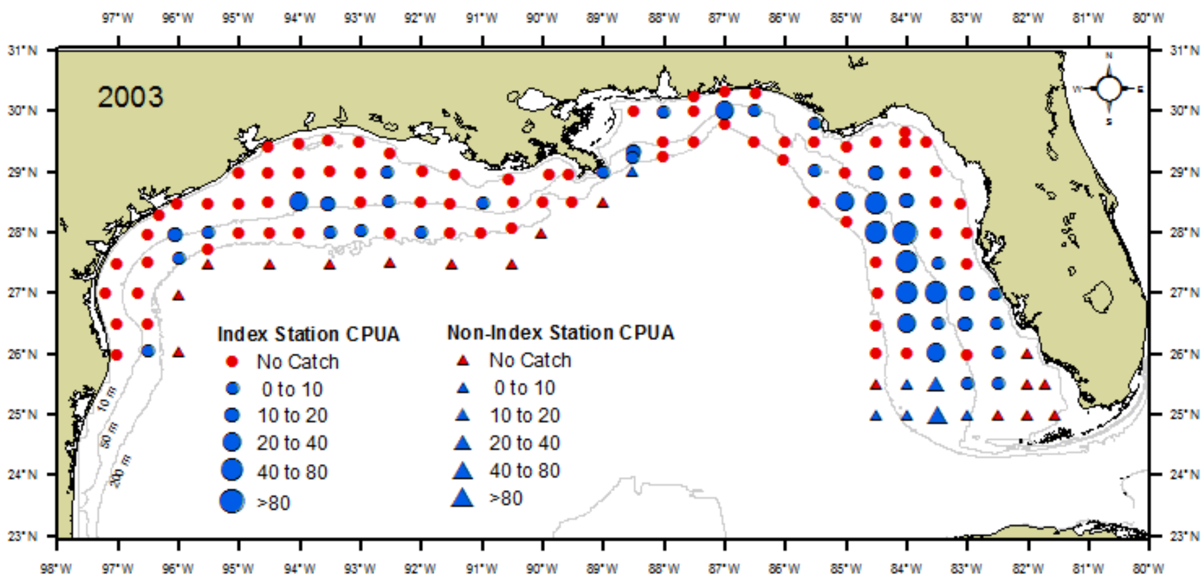
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Non-Index Station CPUA
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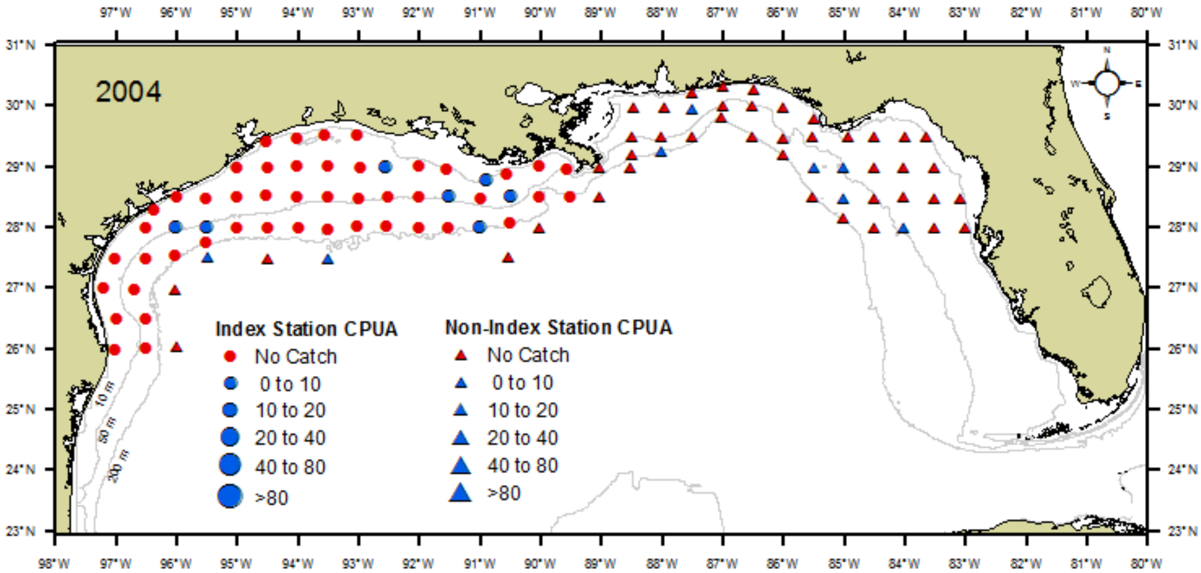
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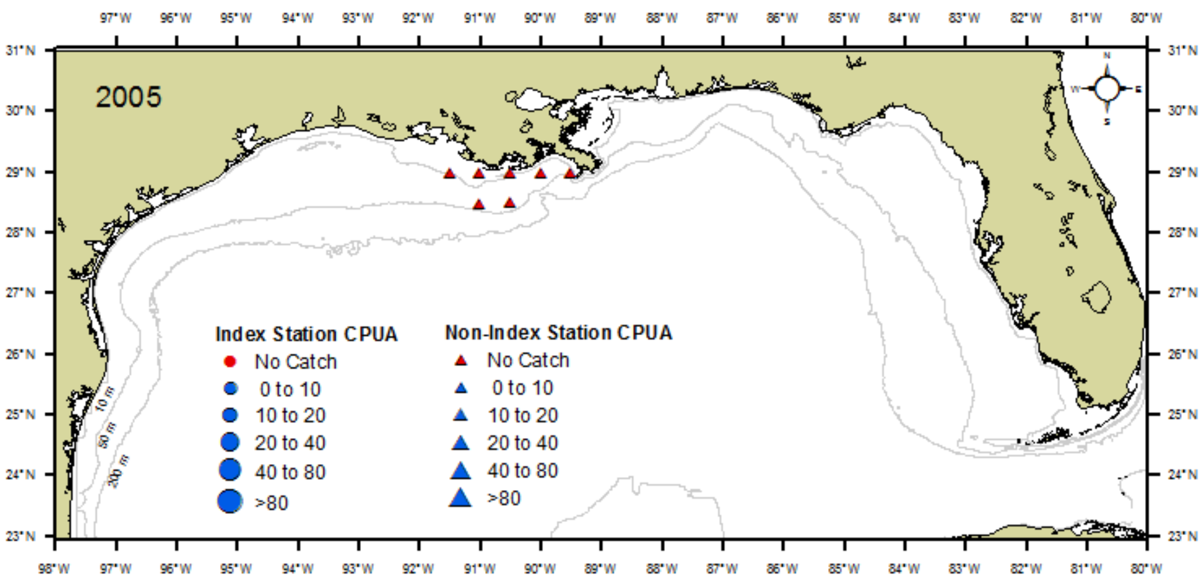
40 to 80
>80
10 m
50 m
200 m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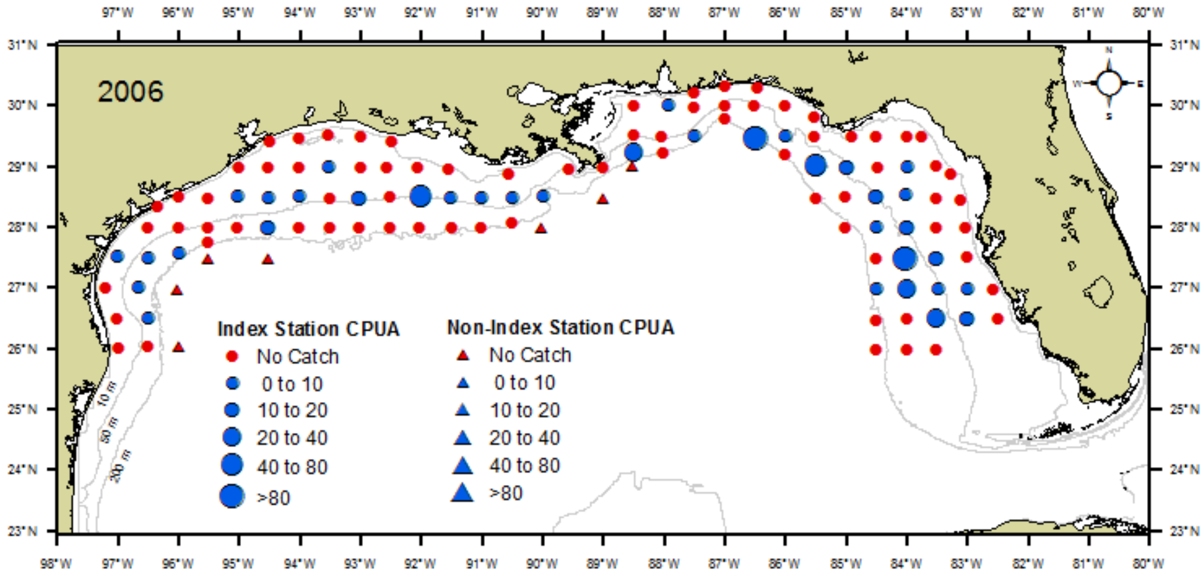
10 m
50 m
200 m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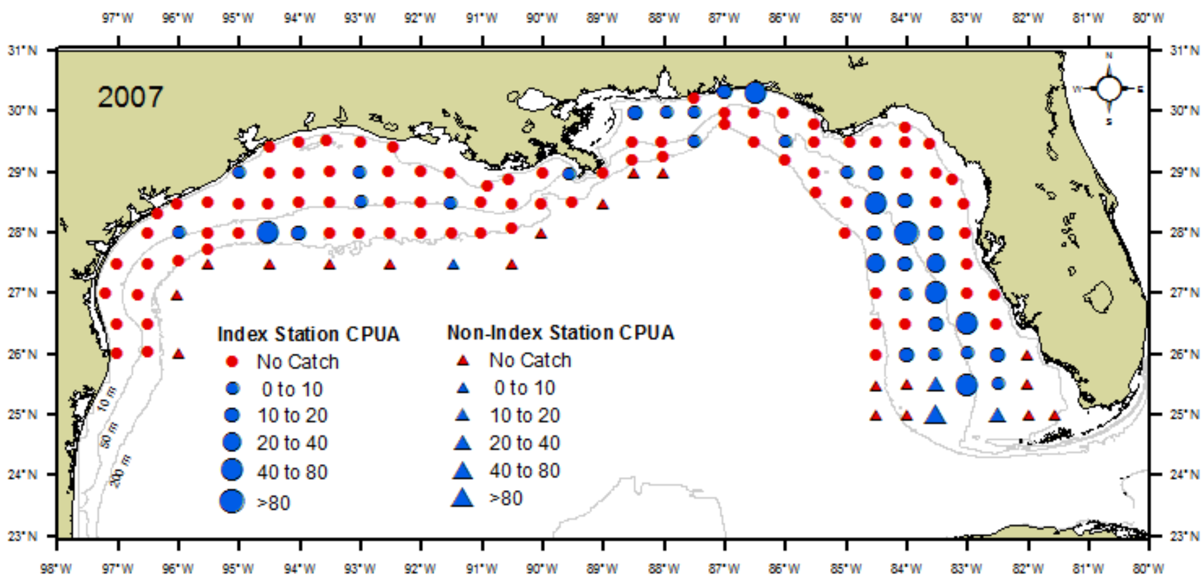
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Non-Index Station CPUA
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40 to 80
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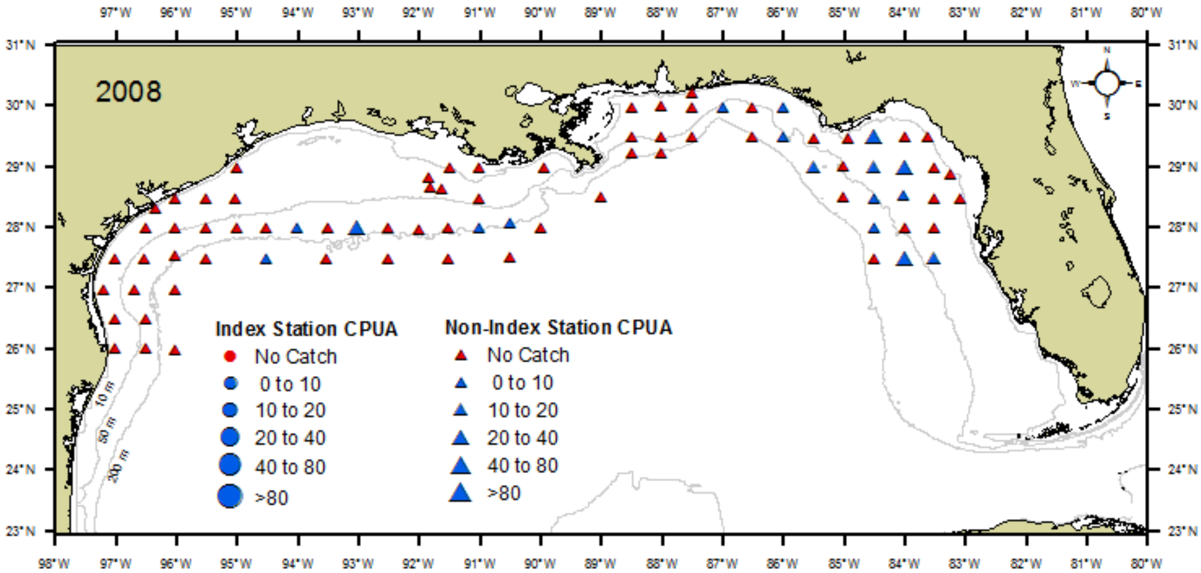
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10 to 20
20 to 40
40 to 80
>80
Non-Index Station CPUA
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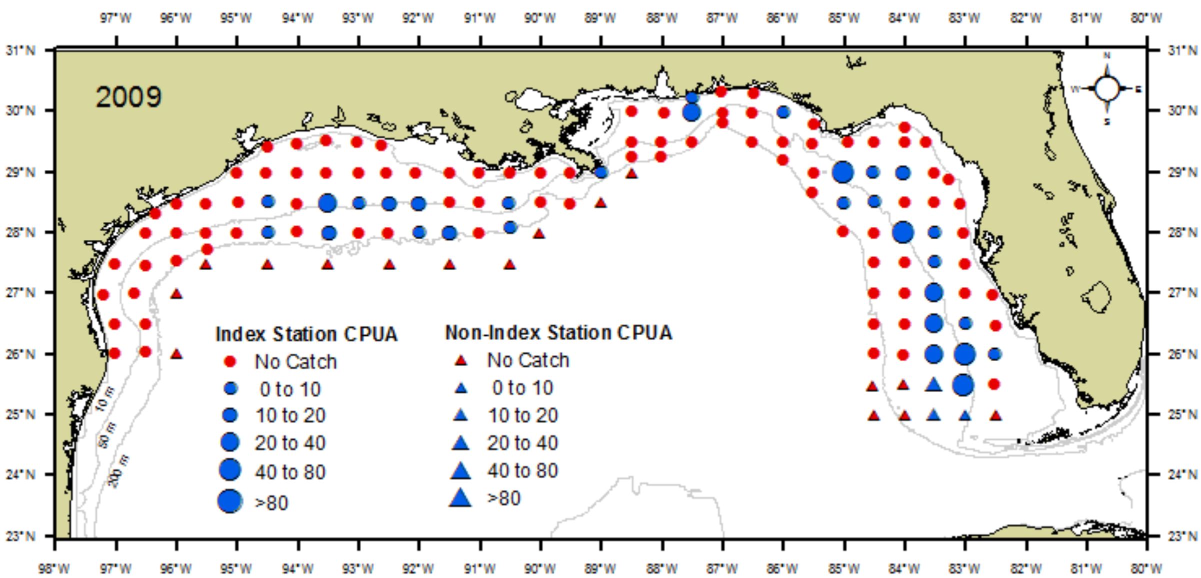
20 to 40
40 to 80
>80
10 m
50 m
200 m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No Catch
0 to 10
10 to 20
20 to 40
40 to 80
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Non-Index Station CPUA
No Catch
0 to 10
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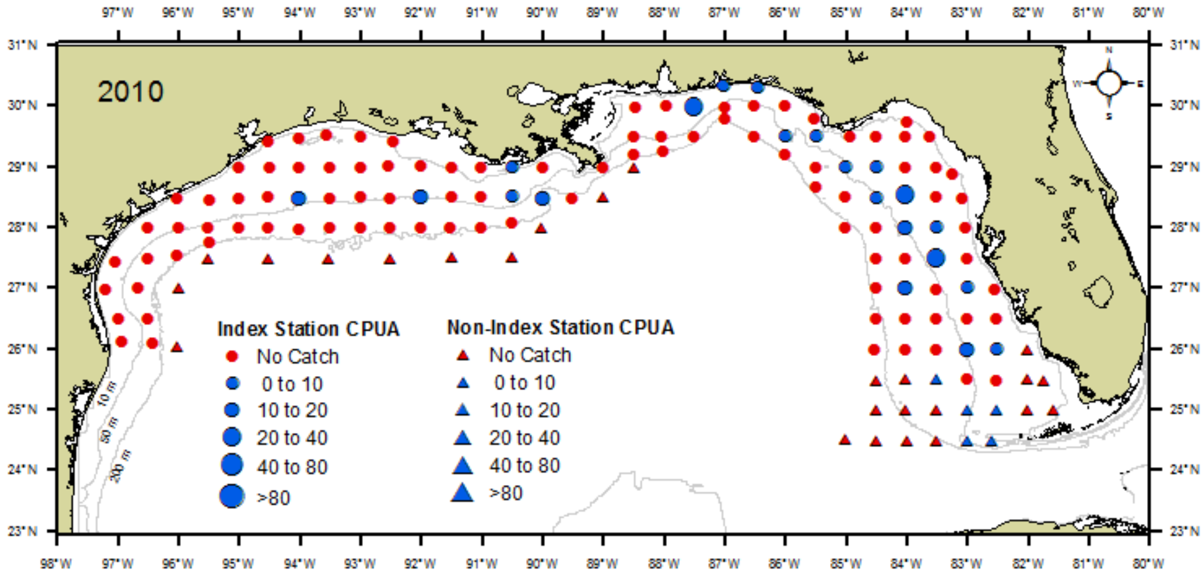
>80
10 m
50 m
200 m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No Catch
0 to 10
10 to 20
20 to 40
40 to 80
>80
Non-Index Station CPUA
No Catch
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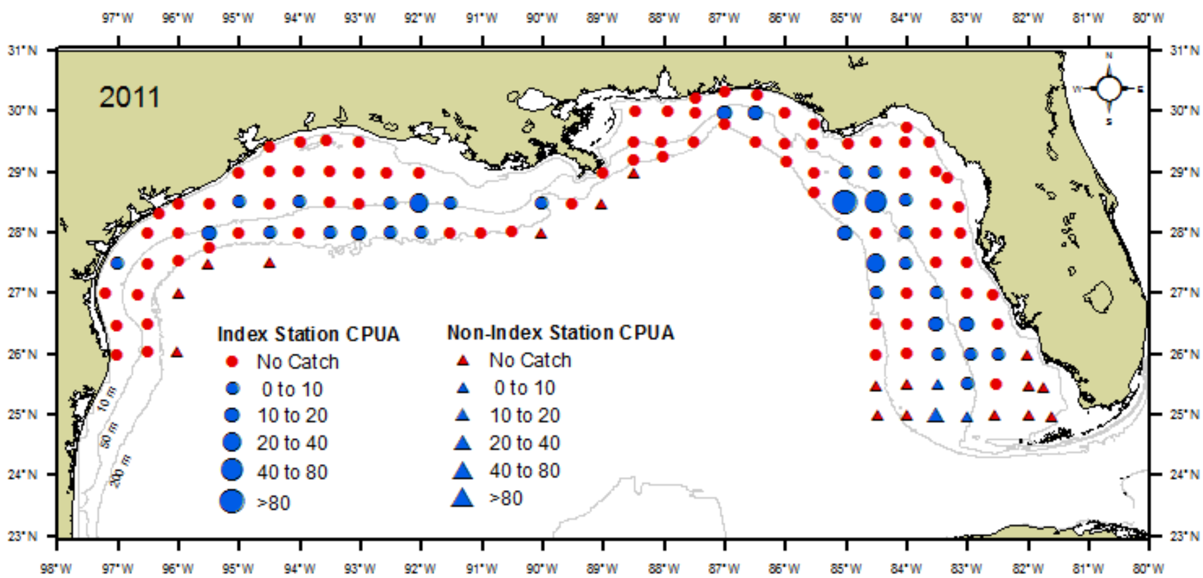
20 to 40
40 to 80
>80


2011
Index Station CPUA
No Catch
0 to 10
10 to 20
20 to 40
40 to 80
>80
Non-Index Station CPUA
No Catch
0 to 10
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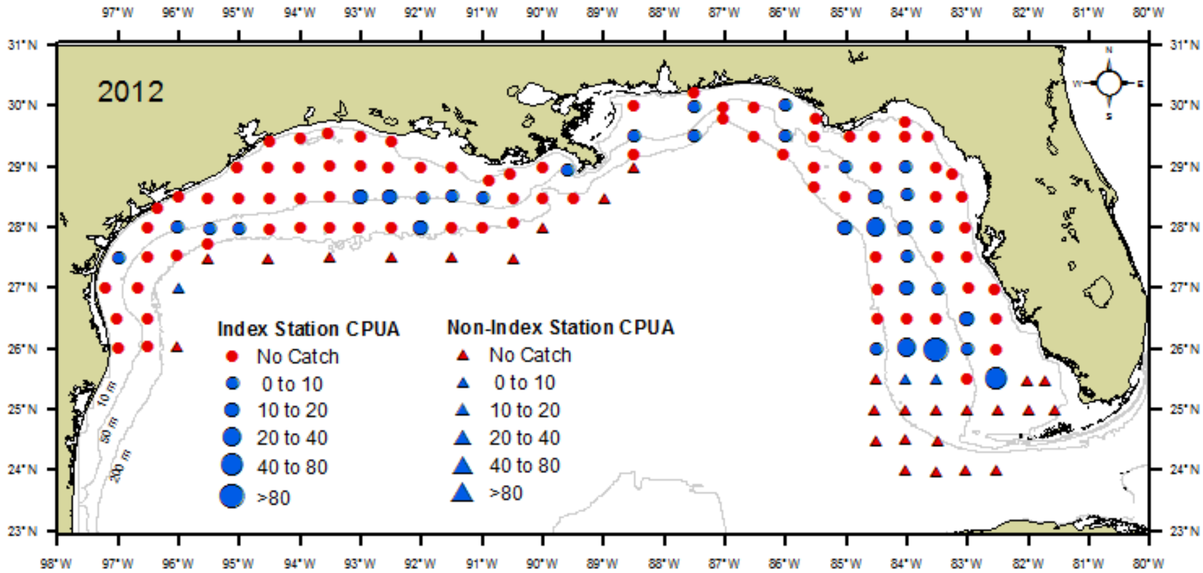
20 to 40
40 to 80
>80


2012
Index Station CPUA
No Catch
0 to 10
10 to 20
20 to 40
40 to 80
>80
Non-Index Station CPUA
No Catch
0 to 10
10 to 20
20 to 40
40 to 80
>80
10 m
50 m
200 m