Gulf menhaden (*Brevoortia patronus*) fishery-independent catch-rate trends for Lousiana

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Introduction

The Louisiana Department of Wildlife and Fisheries (LDWF) conducts routine standardized fishery-independent (FI) monitoring surveys across Louisiana's coastal zone to primarily measure relative abundance and size compositions of recreationally and commercially important marine species. For sampling purposes, coastal Louisiana is currently divided into five LDWF coastal study areas (CSAs). Current CSA definitions are as follows: CSA 1 – Mississippi State line to South Pass of the Mississippi River (Pontchartrain Basin); CSA 3 – South Pass of the Mississippi River to Bayou Lafourche (Barataria Basin); CSA 5 – Bayou Lafourche to eastern shore of Atchafalaya Bay (Terrebonne Basin); CSA 6 – Atchafalaya Bay to western shore of Vermillion Bay (Vermillion/Teche/Atchafalaya Basins); CSA 7 – western shore of Vermillion Bay to Texas State line (Mermentau/Calcasieu/Sabine Basins).

For purposes of this report, gulf menhaden indices of abundance (IOA) are developed from the LDWF marine inshore 16-foot trawl, bag seine, and experimental gillnet surveys.

Data Sources

16-foot Trawl Survey

The LDWF marine inshore 16-foot trawl survey is primarily used to sample peniad shrimp, blue crabs, and bottomfish in inshore bays and lakes. Sampling gear is a 16-foot flat otter trawl. Trawls are towed for ten minutes and all captured organisms are identified to species, enumerated, and up to 50 randomly selected individuals of each species are measured in 5mm total length (TL) intervals. Details of the trawl gear and its deployment can be found in LDWF (2002).

The survey has been conducted from 1967 to present at fixed sampling locations within each CSA. In October of 2010, additional fixed sampling locations were added to this survey allowing more spatial coverage within each CSA. Prior to July 2013, sampling was conducted weekly from March to October and semi-monthly from November to February. Beginning July 2013, sampling was reduced to monthly samples from January-March and August- November and semi-monthly samples from April-July and December.

To alleviate time-series biases associated with the addition of these new stations and the changes in survey methodology, two discrete time-series of catch-rates are developed. The first or the “old” time-series (1967-present) is developed by retaining long-term stations only for analyses (Figure 1). The second or the “new” time-series (2011-present) is developed by retaining all current sampling stations for analyses (Figure 2).

The size distribution of Gulf menhaden catches from 1967-2016 of the “old” time-series is also presented (Figure 3). Total lengths are converted to fork length (FL) using the Louisiana-specific relationship provided in SEDAR 32A (2013). Very few individuals >100mm FL are captured (~1%).

Annual juvenile IOAs of the “old” and “new” inshore trawl survey time-series are developed (details in *Abundance Indices* Section below).

Bag Seine Survey

The LDWF marine bag seine survey is primarily used to sample shellfish and juvenile finfish. Sampling gear is 50-foot bag seine. All captured organism are identified to species, enumerated, and up to 30 randomly selected individuals of specific species are measured to the nearest millimeter TL. Details of the seine gear and its deployment can be found in LDWF (2002).

The survey has been conducted from 1986 to present at fixed sampling locations. In October of 2010, additional fixed sampling locations were added to this survey allowing more spatial coverage within each CSA. Prior to October 2010, samples were collected monthly from January-August and twice monthly from September-December. Beginning in October 2010, sampling frequency changed to quarterly (i.e., mid-point of each quarter). In July 2014, sampling frequency reverted to monthly.

To alleviate time-series biases associated with the addition of these new stations and the changes in survey methodology, two discrete time-series of catch-rates are developed. The first or the “old” time-series (1986-present) is developed by retaining long-term stations only for analyses (Figure 1). The second or the “new” time-series (2011-present) is developed by retaining all current sampling stations for analyses (Figure 2).

The size distribution of Gulf menhaden catches from 1996-2016 of the “old” time-series is also presented (Figure 3). Length measurements of Gulf menhaden were not taken consistently across CSAs before 1996. However, very few Gulf menhaden >50mm FL are captured in the seine survey (~5%). Total lengths are converted to FL using the Louisiana-specific relationship provided in SEDAR 32A (2013).

Annual juvenile IOAs of the “old” and “new” bag seine survey time-series are developed (details in *Abundance Indices* Section below).

Experimental Gillnet Survey

The LDWF marine experimental gillnet survey is one of the primary gears used to sample inshore finfish. Sampling gear is 750-foot long gillnet made up of 5 panels of 2.0, 2.5, 3.0, 3.5, and 4.0 inch meshes. All captured organisms are identified to species, enumerated, and up to 30 randomly selected individuals of specific species are measured to the nearest millimeter TL. Details of the sampling gear and its deployment can be found in LDWF (2002).

The survey has been conducted from 1986 to April 2013 at fixed sampling locations within each CSA. The 2.5 and 3.5 inch mesh sizes, however, were not included in the survey until 1988. In October of 2010, additional fixed stations were added to this survey allowing more spatial coverage with each CSA. Beginning in April 2013, the survey design was modified where sampling locations are now selected randomly from the established stations within each CSA. Samples were collected twice monthly from April-September and monthly from October-March at the fixed sampling locations (1986 to March 2013) and at randomly selected locations from April 2013 to present.

To alleviate time-series biases associated with the addition of these new stations and the changes in survey methodology, two discrete time-series of catch-rates are developed. The first or the “old” time-series (1986-2012) is developed by retaining long-term stations only for analyses (Figure 1). The second or the “new” time-series (2011-present) is developed by retaining all current sampling stations for analyses (Figure 2).

Size distributions of Gulf menhaden catches from each mesh panel of the "old" time-series (1996-2012) are also presented (Figure 3). Length measurements of Gulf menhaden were not taken consistently across CSAs before 1996. Total lengths are converted to fork length (FL) using the Louisiana-specific relationship provided in SEDAR 32A (2013).

Annual adult IOAs of the "old" and "new" experimental gillnet survey time-series are developed (details in *Abundance Indices* Section below).

Abundance Indices

To reduce unexplained variability in catch rates unrelated to changes in abundance, catch-rates are standardized using methods described below. A delta lognormal approach (Lo *et al.* 1992; Ingram *et al.* 2010) is used to standardize catch-rates in each year as:

$$I_y = c_y p_y$$

where c_y are estimated annual mean CPUEs of non-zero catches modeled as lognormal distributions and p_y are estimated annual mean probabilities of capture modeled as binomial distributions. The lognormal model considers only the positive samples; the binomial model considers all samples. The lognormal and binomial means and their standard errors are estimated with generalized linear mixed models as least square means and back transformed. Each IOA is then computed from the equation above using the estimated least-squares means with variances calculated from:

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

where Cov(c,p)≈ $\rho_{c,p}\left[SE(c_y)SE(p_y)\right]$ and $\rho_{c,p}$ represents the correlation of c and p among years.

Because of the designed nature of LDWF fishery-independent surveys, model development was rather straightforward. Variables considered in model inclusion were year, CSA, and sampling location. Time of year was not considered in model inclusion. To determine the most appropriate models, we began the model selection process with fully-reduced models that included only year as a fixed effect. More complex models were then developed including interactions and random effects and compared using AIC and log-likelihood values. All sub-models were estimated with the SAS generalized linear mixed modeling procedure (PROC GLIMMIX; SAS 2009). In the final sub-models, year was considered a fixed effect, CSA was considered a random block effect, and sampling locations within CSAs were considered random subsampling block effects. Fits of lognormal submodels were evaluated with conditional residual plots. Binomial submodels were evaluated for overdispersion via Pearson's chi-square per degree of freedom statistic (Stroup 2013).

16-foot Trawl

Juvenile gulf menhaden IOAs of the "old" and "new" time-series are developed from the LDWF 16' inshore trawl survey. Catch per unit effort is defined as the number of gulf menhaden caught per trawl tow.

Annual sample sizes, observed percent positive samples, nominal CPUEs of positive samples, standardized IOAs, and corresponding coefficients of variation of the "old" and "new" time-series are presented (Table 1). Standardized IOAs and 95% confidence intervals of the "old" and "new" time-series are also presented graphically (Figure 4). Conditional residual plots of the lognormal sub-models indicate reasonable fits (Figure 5). Pearson's chi-square per degree of freedom statistics indicate no overdispersion in the binomial sub-models (all submodels$\leq$1.0).

Bag Seine

Juvenile gulf menhaden IOAs of the "old" and "new" time-series are also developed from the LDWF bag seine survey. Catch per unit effort is defined as the number of gulf menhaden caught per seine haul. Samples from the months of October through December are excluded from IOA development. For IOA development, we assume that sampling the mid-point of each quarter accurately represents the entire quarter.

Annual sample sizes, observed percent positive samples, nominal CPUEs of positive samples, standardized IOAs, and corresponding coefficients of variation of the "old" and "new" time-series are presented (Table 2). Standardized IOAs and 95% confidence intervals of the "old" and "new" time-series are also presented graphically (Figure 6). Conditional residual plots of the lognormal sub-models indicate reasonable fits (Figure 7). Pearson's chi-square per degree of freedom statistics indicate no overdispersion in the binomial sub-models (all submodels$<$1.0).

Experimental Gillnet

Adult gulf menhaden IOAs of the "old" and "new" time-series are also developed from the LDWF experimental survey. Catch per unit effort is defined as the number of gulf menhaden caught per net sample. Only samples from April through September are included in IOA development.

Annual sample sizes, observed percent positive samples, nominal CPUEs of positive samples, standardized IOAs, and corresponding coefficients of variation of the "old" and "new" time-series are presented (Table 3). Standardized IOAs and 95% confidence intervals of the "old" and "new" time-series are also presented graphically (Figure 8). Conditional residual plots of the lognormal sub-models indicate reasonable fits (Figure 9). Pearson's chi-square per degree of freedom statistics indicate no overdispersion in the binomial sub-models (all submodels<1.0).

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Tables

Table 1: Annual sample sizes, observed percent positive samples, nominal CPUEs of positive samples, indices of abundance, and corresponding coefficients of variation of the "old" and "new" time-series derived from the LDWF marine inshore trawl survey.

	Old IOA					New IOA				
Year	n	%Pos	CPUE	IOA	CV	n	%Pos	CPUE	IOA	CV
1967	170	26%	40.7	1.24	0.59	--	--	--	--	--
1968	157	39%	122.9	4.43	0.51	--	--	--	--	--
1969	166	19%	40.8	0.92	0.67	--	--	--	--	--
1970	298	7%	7.0	0.25	0.76	--	--	--	--	--
1971	354	26%	43.3	0.70	0.54	--	--	--	--	--
1972	382	32%	13.4	0.50	0.51	--	--	--	--	--
1973	551	34%	14.1	0.74	0.48	--	--	--	--	--
1974	591	40%	35.2	1.16	0.46	--	--	--	--	--
1975	539	35%	97.2	1.87	0.48	--	--	--	--	--
1976	507	35%	171.2	1.87	0.47	--	--	--	--	--
1977	430	34%	131.7	1.85	0.48	--	--	--	--	--
1978	449	31%	37.2	0.83	0.49	--	--	--	--	--
1979	561	23%	12.3	0.48	0.52	--	--	--	--	--
1980	678	25%	188.8	0.99	0.50	--	--	--	--	--
1981	748	23%	42.3	0.68	0.50	--	--	--	--	--
1982	783	29%	67.8	1.16	0.47	--	--	--	--	--
1983	742	34%	145.6	2.12	0.45	--	--	--	--	--
1984	713	47%	111.4	3.69	0.41	--	--	--	--	--
1985	833	35%	27.6	0.86	0.45	--	--	--	--	--
1986	697	33%	191.7	2.21	0.47	--	--	--	--	--
1987	794	32%	39.1	0.86	0.47	--	--	--	--	--
1988	798	34%	61.1	1.33	0.46	--	--	--	--	--
1989	812	30%	57.7	1.01	0.47	--	--	--	--	--
1990	900	34%	62.1	1.65	0.45	--	--	--	--	--
1991	872	31%	73.0	0.89	0.47	--	--	--	--	--
1992	700	39%	39.5	1.27	0.46	--	--	--	--	--
1993	855	42%	71.5	2.21	0.44	--	--	--	--	--
1994	882	34%	58.8	1.38	0.46	--	--	--	--	--
1995	869	36%	32.1	1.09	0.45	--	--	--	--	--
1996	950	40%	77.9	2.52	0.43	--	--	--	--	--
1997	1027	29%	43.9	1.05	0.47	--	--	--	--	--
1998	1054	41%	149.0	2.00	0.43	--	--	--	--	--
1999	1072	35%	105.6	1.91	0.45	--	--	--	--	--
2000	1048	29%	18.5	0.80	0.47	--	--	--	--	--
2001	1051	33%	71.9	1.50	0.46	--	--	--	--	--
2002	1025	36%	65.9	1.47	0.44	--	--	--	--	--
2003	1062	32%	47.7	1.18	0.46	--	--	--	--	--
2004	1058	35%	63.7	1.22	0.45	--	--	--	--	--
2005	996	34%	137.1	1.41	0.45	--	--	--	--	--
2006	1045	28%	20.3	0.73	0.47	--	--	--	--	--
2007	1041	35%	124.3	1.92	0.45	--	--	--	--	--
2008	1096	31%	28.7	1.02	0.46	--	--	--	--	--
2009	1064	37%	201.9	2.17	0.44	--	--	--	--	--
2010	945	54%	267.5	6.84	0.38	--	--	--	--	--
2011	869	47%	130.8	3.06	0.40	2444	36%	95.8	1.93	0.32
2012	883	39%	36.6	1.77	0.43	2516	30%	39.6	1.09	0.34
2013	755	36%	48.9	1.76	0.44	2118	29%	71.4	1.12	0.35
2014	481	44%	267.9	4.14	0.42	1364	38%	222.4	3.09	0.32
2015	468	38%	71.7	1.78	0.45	1332	32%	72.9	1.19	0.35
2016	470	40%	31.1	1.88	0.44	1346	29%	42.6	1.09	0.36
2017	482	37%	37.7	1.66	0.45	1388	28%	35.5	0.84	0.36

Table 2: Annual sample sizes, observed percent positive samples, nominal CPUEs of positive samples, indices of abundance, and corresponding coefficients of variation of the "old" and "new" time-series derived from the LDWF marine bag seine survey.

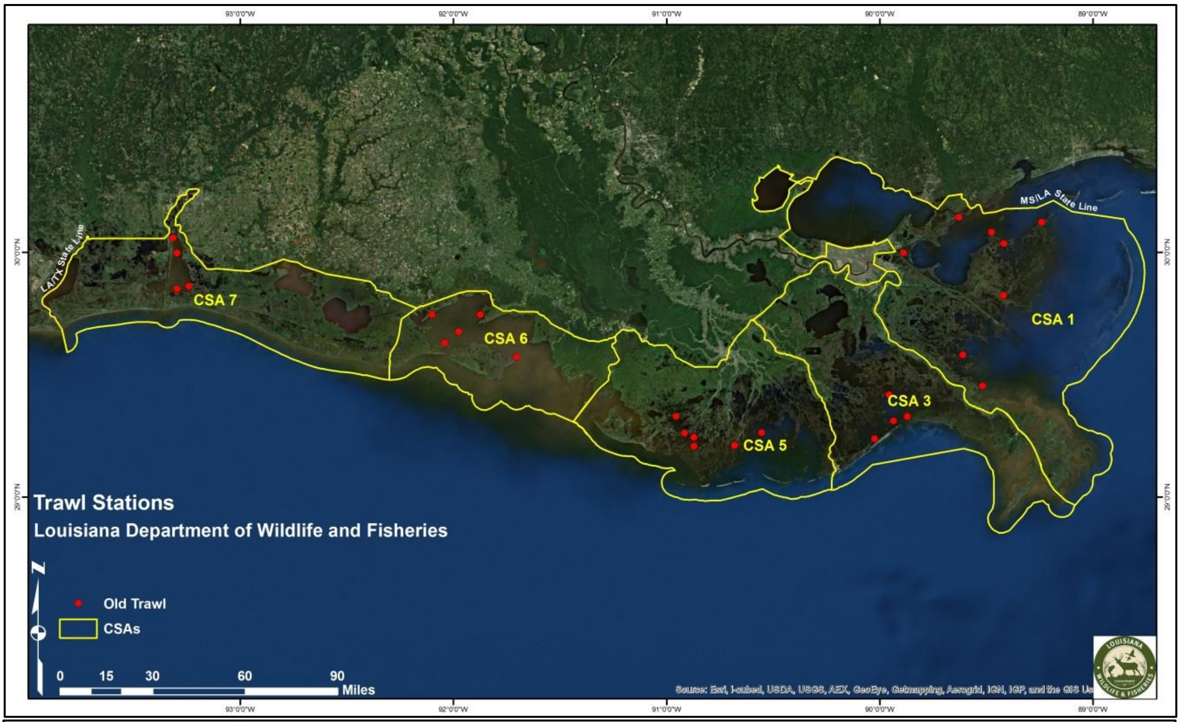
	Old IOA					New IOA				
Year	n	%Pos	CPUE	IOA	CV	n	%Pos	CPUE	IOA	CV
1988	314	40%	352.1	7.21	0.58	--	--	--	--	--
1989	332	44%	160.3	5.29	0.55	--	--	--	--	--
1990	334	50%	242.8	7.84	0.52	--	--	--	--	--
1991	315	46%	207.8	6.48	0.56	--	--	--	--	--
1992	327	45%	195.7	6.82	0.55	--	--	--	--	--
1993	324	53%	391.1	14.46	0.52	--	--	--	--	--
1994	363	41%	208.6	7.69	0.56	--	--	--	--	--
1995	386	38%	108.8	5.55	0.58	--	--	--	--	--
1996	387	52%	320.6	9.32	0.50	--	--	--	--	--
1997	391	43%	86.2	4.65	0.55	--	--	--	--	--
1998	396	52%	288.4	10.92	0.50	--	--	--	--	--
1999	404	43%	222.9	5.20	0.55	--	--	--	--	--
2000	411	32%	180.1	3.01	0.62	--	--	--	--	--
2001	406	38%	178.3	3.58	0.58	--	--	--	--	--
2002	393	39%	217.1	3.46	0.57	--	--	--	--	--
2003	403	41%	182.6	6.21	0.56	--	--	--	--	--
2004	408	40%	183.4	4.64	0.57	--	--	--	--	--
2005	369	41%	446.8	6.53	0.57	--	--	--	--	--
2006	392	40%	278.9	6.83	0.57	--	--	--	--	--
2007	399	50%	255.2	5.68	0.51	--	--	--	--	--
2008	385	42%	152.1	4.13	0.55	--	--	--	--	--
2009	407	46%	282.6	8.27	0.53	--	--	--	--	--
2010	384	60%	765.5	18.31	0.47	--	--	--	--	--
2011	170	66%	923.1	17.83	0.50	393	61%	787.0	21.16	0.47
2012	158	64%	501.9	10.40	0.52	342	60%	333.1	13.44	0.48
2013	123	57%	266.8	11.57	0.55	303	55%	215.2	13.41	0.49
2014	157	52%	612.8	12.83	0.55	391	55%	650.3	19.00	0.48
2015	362	51%	502.9	9.93	0.51	907	50%	470.6	12.10	0.48
2016	364	51%	463.1	12.08	0.51	915	53%	518.5	17.78	0.47
2017	368	45%	398.9	5.68	0.54	919	46%	420.8	8.88	0.50

Table 3: Annual sample sizes, observed percent positive samples, nominal CPUEs of positive samples, indices of abundance, and corresponding coefficients of variation of the "old" and "new" time-series derived from the LDWF marine experimental gillnet survey.

	Old IOA					***New IOA***				
Year	*n*	*%Pos*	*CPUE*	*IOA*	*CV*	*n*	*%Pos*	*CPUE*	*IOA*	*CV*
1988	*417*	*21%*	*10.2*	*0.58*	*0.28*	--	--	--	--	--
1989	*473*	*14%*	*8.2*	*0.33*	*0.29*	--	--	--	--	--
1990	*489*	*15%*	*34.5*	*0.40*	*0.29*	--	--	--	--	--
1991	*469*	*14%*	*11.6*	*0.32*	*0.30*	--	--	--	--	--
1992	*472*	*13%*	*8.0*	*0.27*	*0.30*	--	--	--	--	--
1993	*457*	*13%*	*8.8*	*0.26*	*0.30*	--	--	--	--	--
1994	*486*	*14%*	*19.2*	*0.35*	*0.29*	--	--	--	--	--
1995	*520*	*13%*	*16.2*	*0.32*	*0.30*	--	--	--	--	--
1996	*520*	*15%*	*8.6*	*0.31*	*0.29*	--	--	--	--	--
1997	*520*	*18%*	*11.9*	*0.45*	*0.28*	--	--	--	--	--
1998	*509*	*17%*	*13.7*	*0.47*	*0.28*	--	--	--	--	--
1999	*520*	*17%*	*13.5*	*0.42*	*0.29*	--	--	--	--	--
2000	*528*	*20%*	*13.5*	*0.66*	*0.27*	--	--	--	--	--
2001	*528*	*18%*	*13.3*	*0.47*	*0.28*	--	--	--	--	--
2002	*520*	*18%*	*11.3*	*0.43*	*0.28*	--	--	--	--	--
2003	*526*	*17%*	*10.6*	*0.46*	*0.28*	--	--	--	--	--
2004	*527*	*15%*	*12.1*	*0.39*	*0.29*	--	--	--	--	--
2005	*478*	*19%*	*13.3*	*0.57*	*0.28*	--	--	--	--	--
2006	*519*	*22%*	*14.9*	*0.75*	*0.27*	--	--	--	--	--
2007	*528*	*18%*	*13.2*	*0.47*	*0.28*	--	--	--	--	--
2008	*514*	*24%*	*19.5*	*0.89*	*0.27*	--	--	--	--	--
2009	*528*	*26%*	*15.7*	*0.91*	*0.26*	--	--	--	--	--
2010	*463*	*16%*	*8.5*	*0.39*	*0.29*	--	--	--	--	--
2011	*486*	*24%*	*17.7*	*0.74*	*0.27*	*1202*	*21%*	*15.3*	*0.63*	*0.17*
2012	*498*	*25%*	*15.2*	*0.89*	*0.26*	*1269*	*25%*	*14.3*	*0.89*	*0.16*
2013	--	--	--	--	--	*624*	*20%*	*21.9*	*0.74*	*0.17*
2014	--	--	--	--	--	*625*	*20%*	*14.6*	*0.77*	*0.17*
2015	--	--	--	--	--	*626*	*18%*	*16.4*	*0.57*	*0.18*
2016	--	--	--	--	--	*626*	*17%*	*22.3*	*0.63*	*0.18*
2017	--	--	--	--	--	*620*	*18%*	*18.6*	*0.67*	*0.18*

Figures

Figure 1: Long-term station locations of the LDWF marine inshore trawl, bag seine, and experimental gillnet surveys used in the "old" time-series. Yellow lines delineate LDWF Coastal Study Areas.



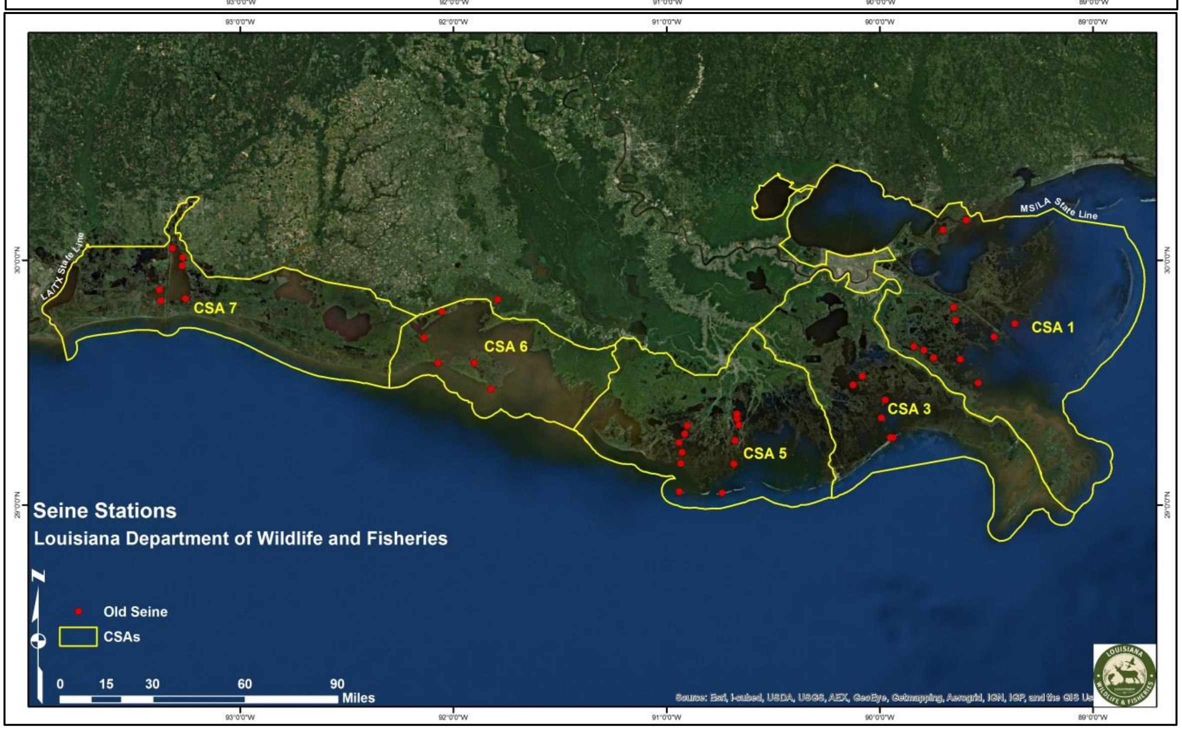


Figure 1 (continued):

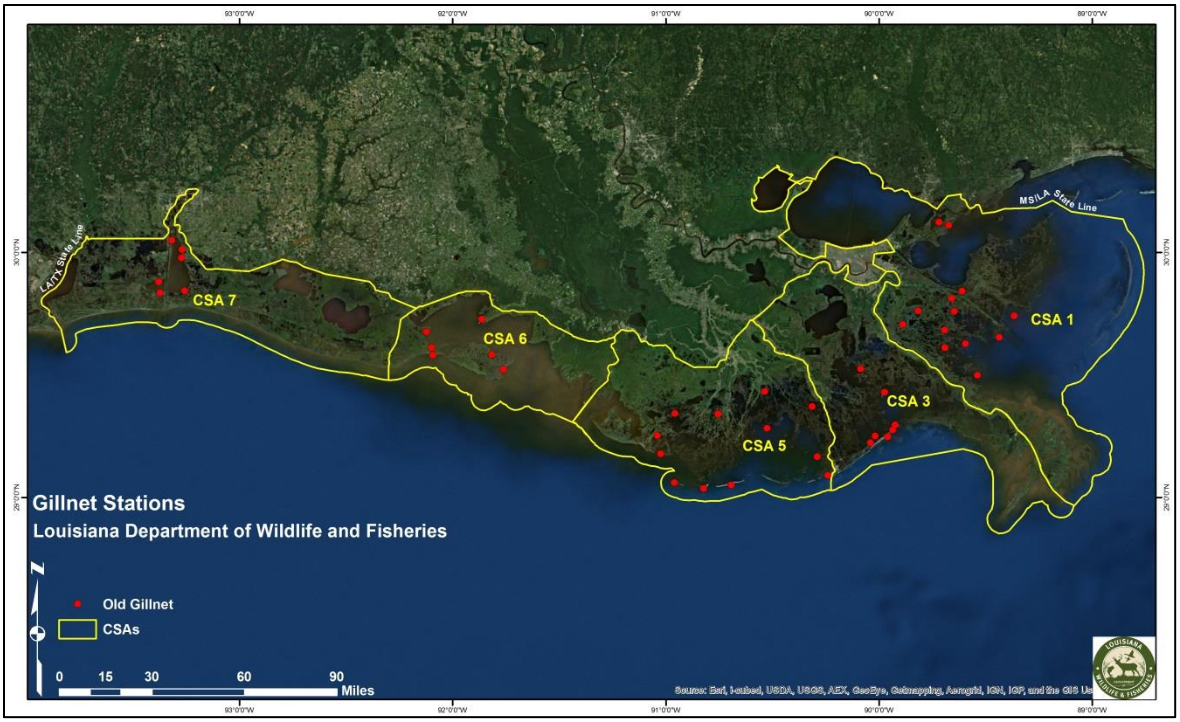
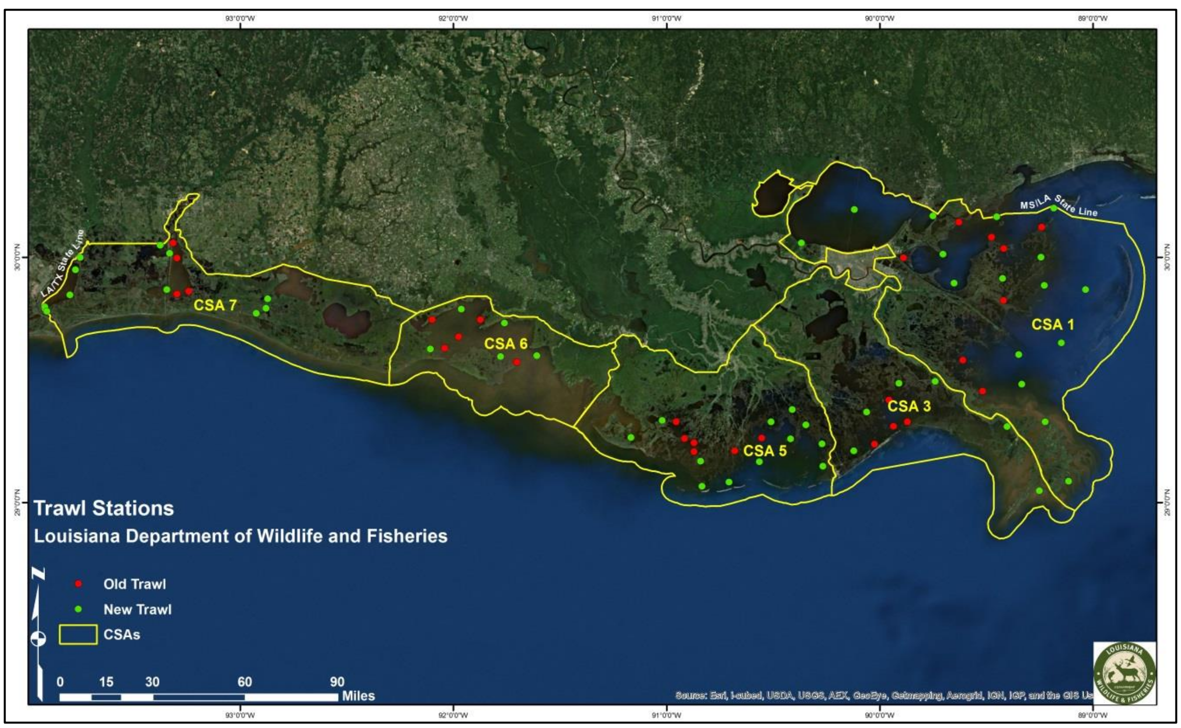


Figure 2: Current station locations of the LDWF marine inshore trawl, bag seine, and experimental gillnet surveys used in the "new" time-series. Yellow lines delineate LDWF Coastal Study Areas.



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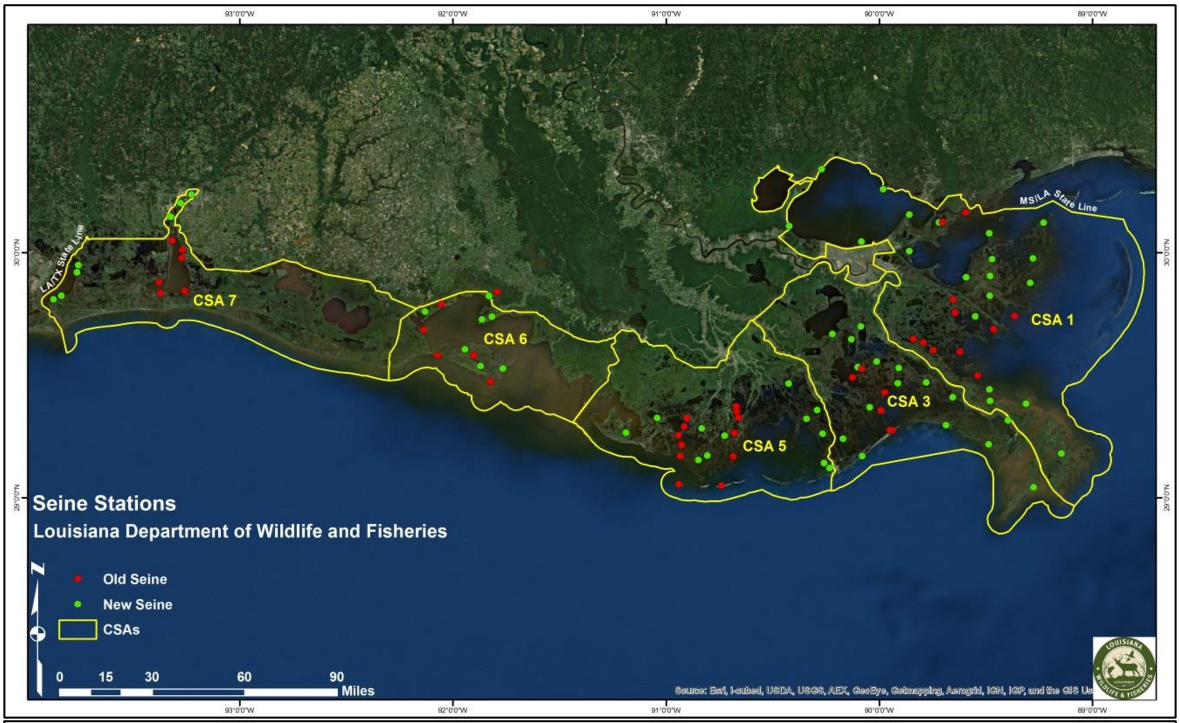

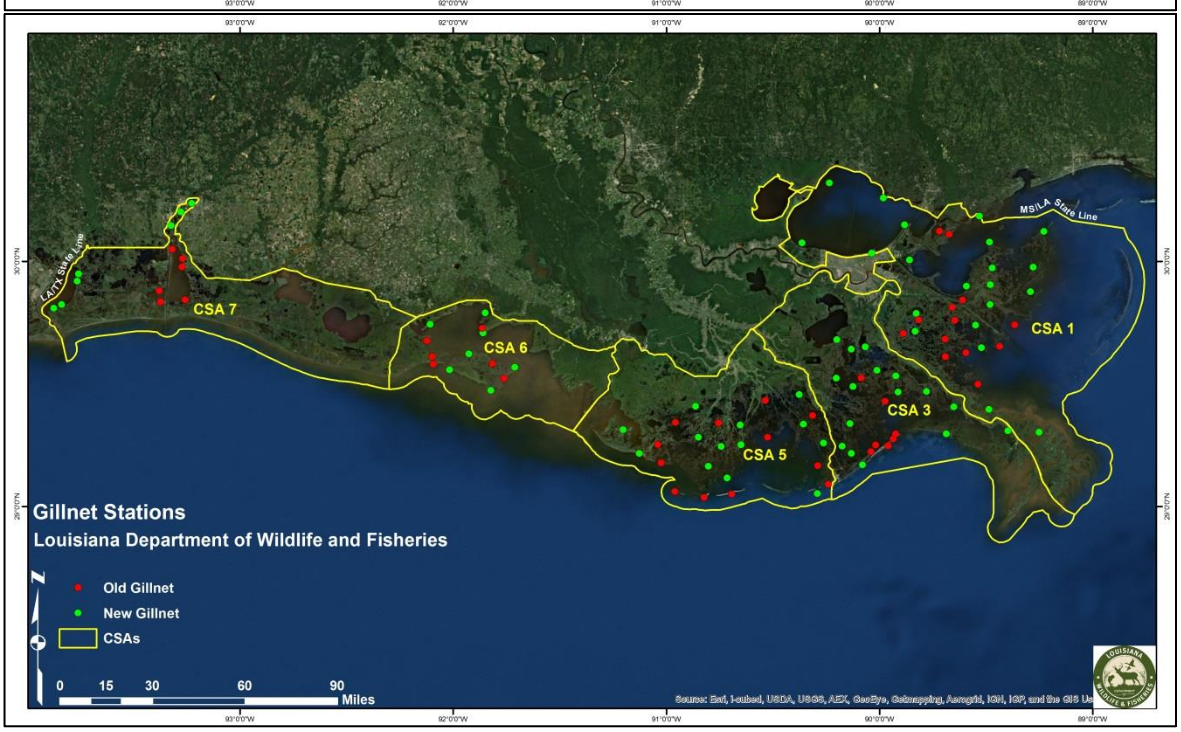

Figure 3: Size distributions of the "old" time-series inshore trawl (1967-2017; top), bag seine (1996-2017; middle), and experimental gillnet surveys (1996-2012; bottom).

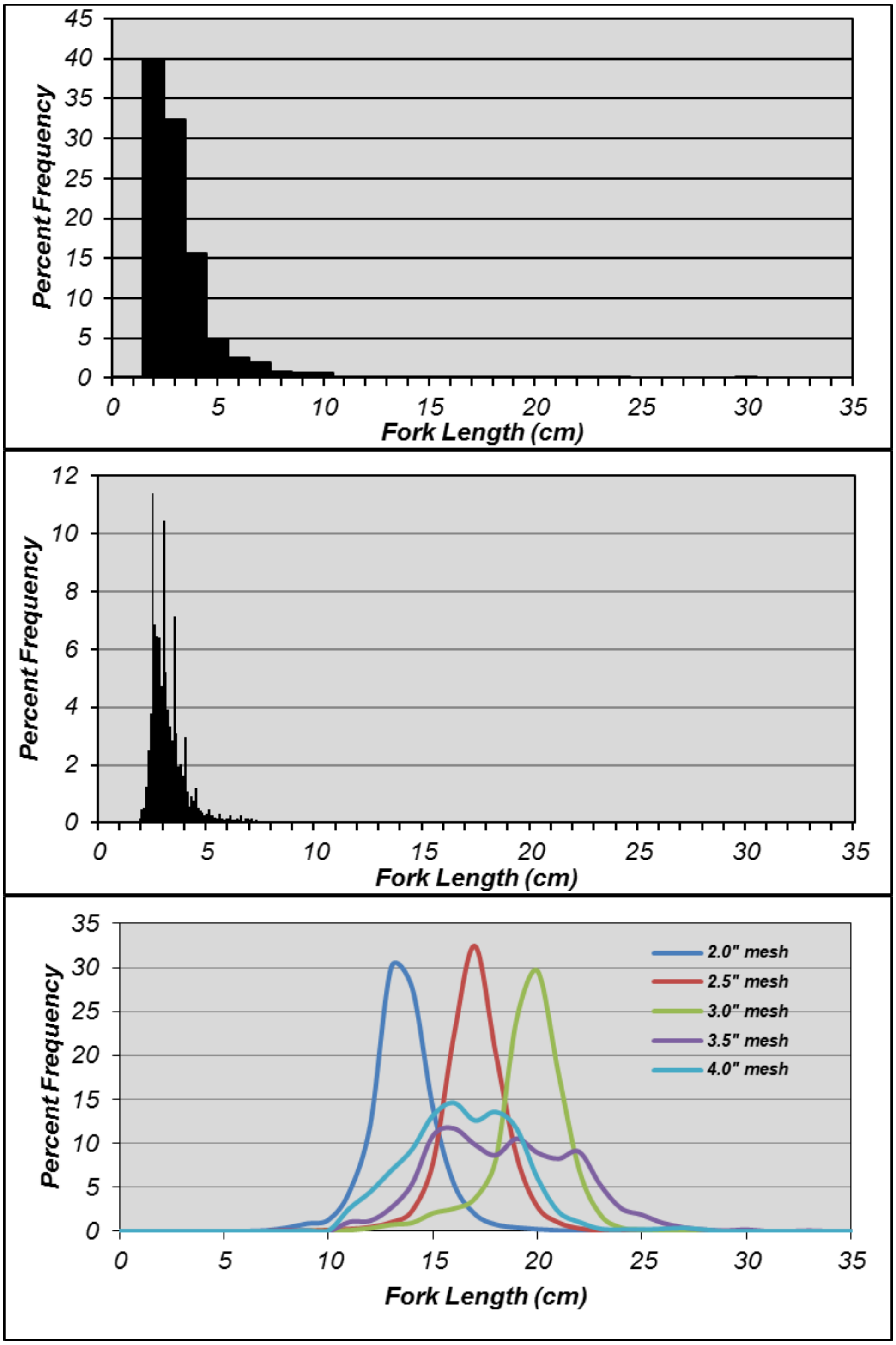

Figure 4: Standardized indices of abundance and 95% confidence intervals of the “old” and “new” time-series derived from the LDWF marine inshore trawl survey. Each time-series has been normalized to its individual long-term mean for comparison.

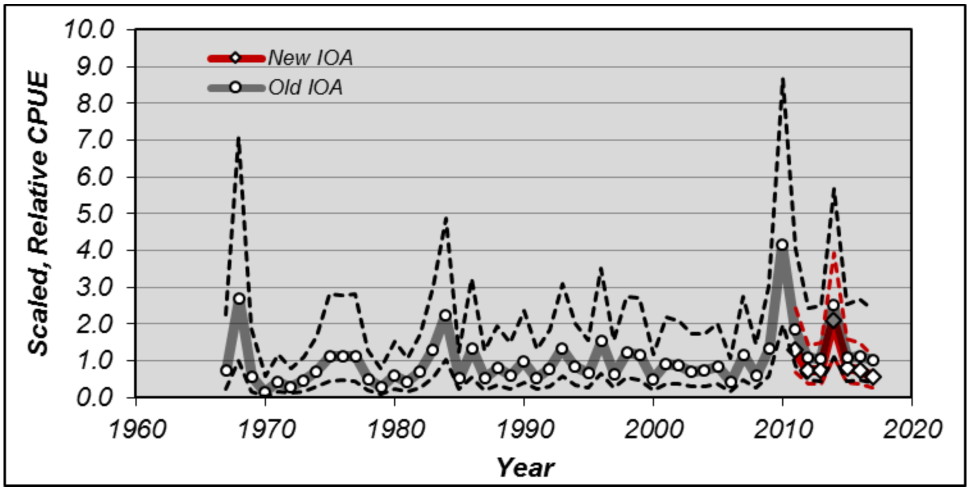

Figure 5: Conditional residual plots of the lognormal submodels of the “old” and “new” time-series derived from the LDWF marine inshore trawl survey. Graphics on the left represent the “old” time-series; graphics on the right represent the “new” time-series.

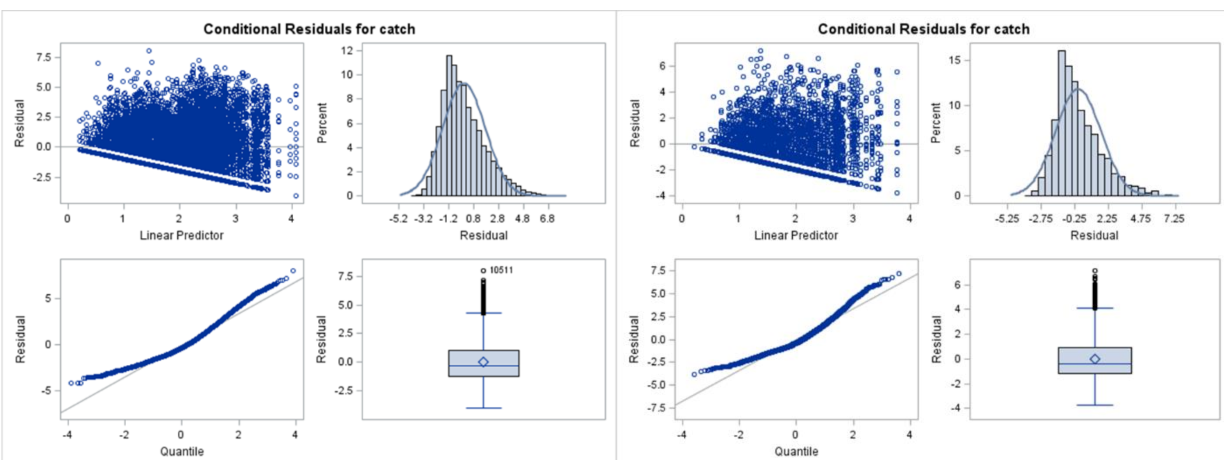

Figure 6: Standardized indices of abundance and 95% confidence intervals of the “old” and “new” time-series derived from the LDWF marine bag seine survey. Each time-series has been normalized to its individual long-term mean for comparison.

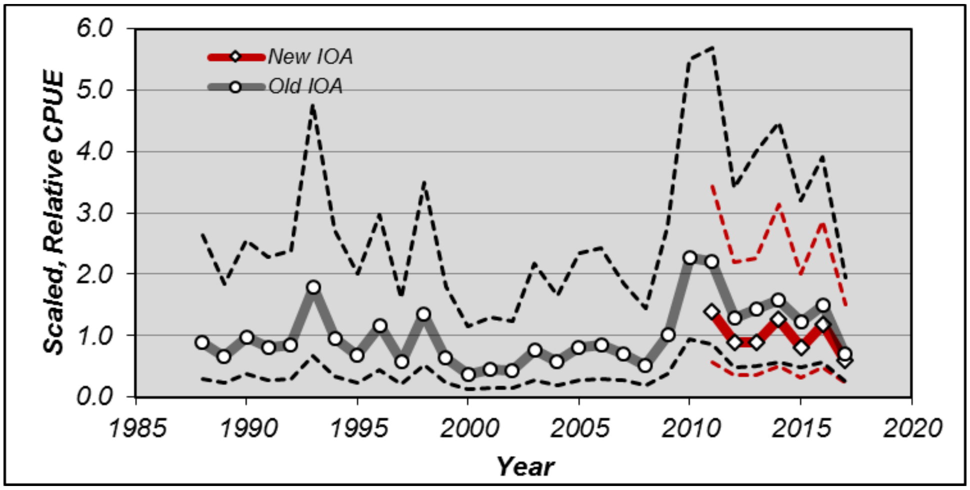

Figure 7: Conditional residual plots of the lognormal submodels of the “old” and “new” time-series derived from the LDWF marine bag seine survey. Graphics on the left represent the “old” time-series; graphics on the right represent the “new” time-series.

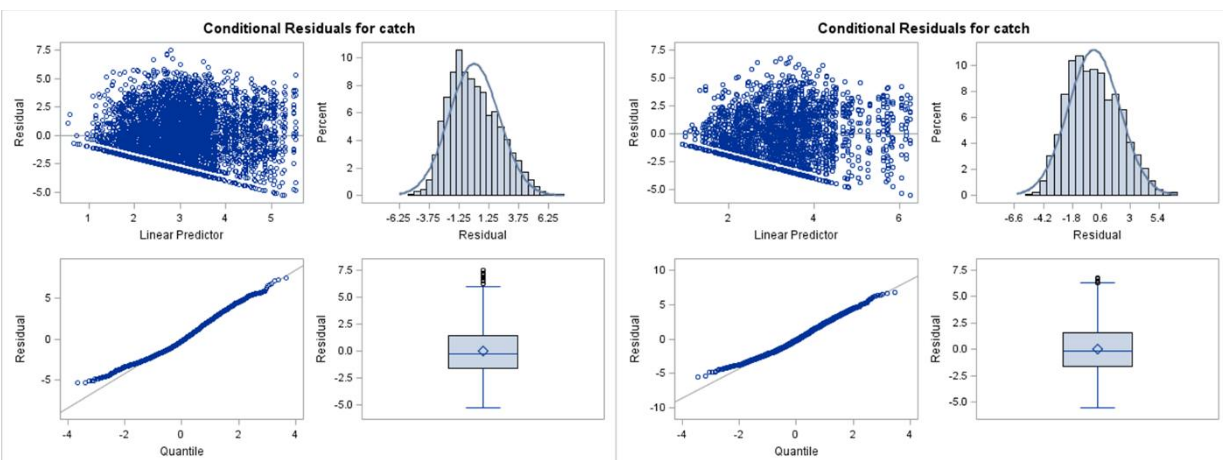

Figure 8: Standardized indices of abundance and 95% confidence intervals of the "old" and "new" time-series derived from the LDWF marine experimental gillnet survey. Each time-series has been normalized to its individual long-term mean for comparison.

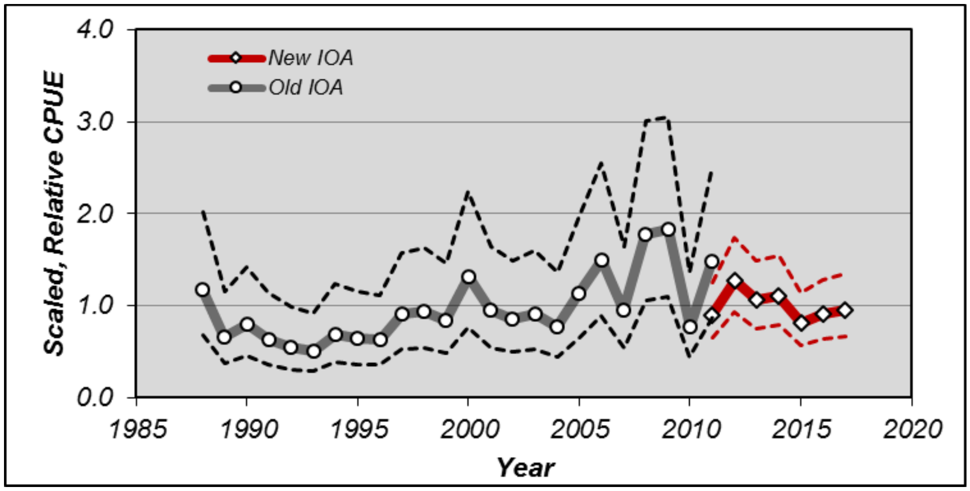

Figure 9: Conditional residual plots of the lognormal submodels of the "old" and "new" time-series derived from the LDWF marine experimental gillnet survey. Graphics on the left represent the "old" time-series; graphics on the right represent the "new" time-series.