Standardized Catch Rates of King Mackerel from the Southeast Shark Drift Gillnet Fishery: 1993-2007

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Introduction

The shark drift gillnet fishery developed off the east coast of Florida and Georgia in the late 1980's. Initially, vessels in this fishery strike netted and drift netted for king mackerel, *Scomberomorus cavalla*, Spanish mackerel, *S. maculatus*, bluefish, *Pomotomus saltatrix*, and occasionally for sharks November through March. As the fishery developed, some fishers drift gillnetted for sharks October through April before and after the mackerel seasons (Schaefer et al., 1989). By 1987, many fishers were drift gillnetting for king mackerel April through September to compensate for the reduction in quotas in the winter fisheries. However, as the king mackerel drift gillnet fishery was further restricted in 1990, more fishers began drift gillnetting for sharks during all times of the year (Trent et al., 1997). In 1999, some vessels involved in this fishery also began strike netting for sharks during winter months. While sharks are generally the target for vessels drift netting for sharks, king mackerel are captured as bycatch.

Observations of the catch and bycatch from the east Florida-Georgia shark drift and strike gillnet fishery are required by law, and reports are prepared annually (i.e., Carlson and Bethea 2007, Baremore et al. 2007 and references therein). Historically, the shark driftnet observer program was structured to cover 100% of the drift and strike gillnetting effort in the southeast U.S. restricted area from November 15 to March 31. This was in response to The Atlantic Large Whale Take Reduction Plan and the Biological Opinion issued under Section 7 of the Endangered Species Act, focusing on the predominant fishing activity occurring in this area (drift gillnetting for sharks) and the risks this gear posed to the northern right whale, *Eubalaena glacialis*, during the calving season and sea turtle species year-round. Outside the right whale calving season (April 1 to November 14), an interim final rule (March 30, 2001; 66 FR 17370) to the Fishery Management Plan for Highly Migratory Species (i.e. tunas, billfish, sharks; NMFS, 1999) established a level of observer coverage for these vessels equal to that which would attain a sample size needed to provide estimates of marine mammal or sea turtle interactions with an expected coefficient of variation of 0.3. In 2005, the observer program was expanded to include all vessels that have an active directed shark permit and fish with sink gillnet gear. These vessels were selected for observer coverage in an effort to determine their impact on shark resources when the fishing method is not drift or strike gillnet or not targeting sharks and to assess any potential risks to northern right whales and other protected species. These vessels were not previously subject to observer coverage because they were either targeting non-highly migratory species or were not fishing gillnets in a drift or strike fashion.

In 2006, the National Marine Fisheries Service (NMFS) Southeast Regional Office requested further expansion of the scope of the shark gillnet observer program to include all vessels fishing gillnets regardless of target, and for coverage to be extended to cover the full geographic range of gillnet fishing effort in the southeast United States. This was requested because of the need to monitor (at statistically adequate levels) all gillnet fishing effort to assess risks to right whales and other protected species. Further, in 2007 the regulations implementing the Atlantic Large Whale Take Reduction Plan were amended to include the removal of the mandatory 100% observer coverage for drift gillnet vessels during the right whale calving season and to prohibit all gillnets in an expanded southeast U.S. restricted area from Cape Canaveral, Florida to the North Carolina/South Carolina border during November 15 - April 15. The rule does possess limited exemptions, only in waters south of 29 degrees N latitude, for shark strikenet fishing during this same period and for Spanish mackerel, *Scomberomorus maculatus*, gillnet fishing in the months of December and March. Based on these regulations and on current funding levels, the shark gillnet observer program now covers all anchored (sink, stab, set), strike, or drift gillnet fishing by vessels that fish from Florida to North Carolina year-round.

Herein, we develop a catch rate series for king mackerel based on data collected by on-board observers from 1993-1995 and 1998-2007.

I. Fishery description

Vessels, fishing gear, and fishing techniques have been previously described in Trent et al. (1997). Generally, shark driftnet vessels operate between 4.8 and 14.4 km from shore in areas north of Key West, FL (~24° 37-24° 58' N) and between West Palm Beach, FL (~26° 46'N) and Altamaha Sound, GA (~31° 45' N) (Figure 1). Vessels fish gillnets (both multi and monofilament) ranging in length from 547.2-2,736 m; depths from 9.1-13.7 m and stretched mesh sizes from 12.7-25.4 cm (Trent et al. 1997; Baremore et al. 2007 and references therein). Nets are normally set in a straight line off the stern at night, allowed to drift at the surface for a period of time and then hauled onto the vessel when the catch is adequate. The number of drift gillnet vessels has decreased from about 12 in 1990 to about 6, depending on the market value of sharks and the level of activity in other fisheries.

Information on this fishery was collected using on-board NMFS-approved contract observers. The observer normally left port with the vessel between 1500-1700 hrs; depending on distance to the fishing grounds. Trips are normally 1-3 days in duration. For each set and haul of the net observers recorded: beginning and ending times of setting and hauling; estimated length of net set; latitude and longitude coordinates; and water depth. During haul back, the observer remained about 3-8 m forward of the net reel in an unobstructed view and recorded species, numbers and estimated lengths (±30 cm) of sharks and other species caught as they were suspended in the net just after passing over the power roller.

Catch rates analysis

A combined data set was developed based on observer programs from Trent el al. (1997) and Baremore et al. (2007 and references therein). Catch rates were standardized in a two-part generalized linear model analysis using the PROC GENMOD procedure in SAS (SAS Inst., Inc.). For the purposes of analysis, several categorical variables were constructed:

-"Year" (13 levels)= 1993-1995, 1998-2007

- "Area" (3 levels)=location of net set (Figure 1).

South Florida=South of 27°51' N Latitude

Central Florida=27°51' N to 30°00' N Latitude

N. Florida/Georgia=North of 30°00' N Latitude

- "SetBegin" (4 levels)

Dawn=0401-1000 hrs

Day=1001-1600 hrs
Dusk=1601-2200 hrs
Night=2201-0400 hrs

-"Season" (4 levels): corresponds to the level of observer coverage as it pertains to the right whale calving season and the large coastal shark season.

Rightwhale1=Jan-Mar
Nonrightwhale1=Apr-Jun
Nonrightwhale2=Jul-Sep
Rightwhale2=Oct-Dec

-"Meshsize" (3 levels): corresponds to the principal mesh size used in the fishing gear. Small mesh=4"-6" stretched mesh Medium mesh=7"-9" stretched mesh Large mesh=>10" stretched mesh.

The proportion of sets that caught king mackerel (when at least one king mackerel was caught) was modeled assuming a binomial distribution with a logit link function. The positive catches were modeled assuming a lognormal distribution with a normal link function. Positive catches were modeled using a dependent variable of the natural logarithm of the number of king mackerel caught per 10^{-7} net area hours, i.e.:

CPUE=log [(king mackerel kept+king mackerel released)/(net length*net depth*soak time/10000000)]

Initially, a null model was run with no factors entered into the model. Models were then fit in a stepwise forward manner adding one independent variable. Each factor was ranked from greatest to least reduction in deviance per degree of freedom when compared to the null model. The factor with the greatest reduction in deviance was then incorporated into the model providing the effect was significant at $p<0.05$ based on a Chi-Square test, and the deviance per degree of freedom was reduced by at least 1% from the less complex model. The process was continued until no factors met the criterion for incorporation into the final model. Regardless of its level of significance, year was kept in all final models. After selecting the set of fixed factors and interactions for each error distribution, all interactions that included the factor year were treated as random interactions (Ortiz and Arocha, 2004). This process converted the basic models from generalized linear models into generalized linear mixed models. The final model determination was evaluated using the Akaike Information Criteria (AIC), and Schwarz's Bayesian Criterion (BIC). Models with smaller AIC and BIC values are preferred to those with larger values. These models were fit using a SAS macro, GLIMMIX (glmm800MaOB.sas: Russ Wolfinger, SAS Institute Inc.) and the MIXED procedure in SAS statistical computer software (PROC GLIMMIX). Relative indices of abundance were calculated as the product of the year effect least square means from the two independent models. The standard error of the combined index was estimated with the delta method (Appendix 1 in Lo et al., 1992).

Results and Discussion

The percentage of sets with zero catches was 58.3%. The stepwise construction of the models is summarized in Table 1.

The final binomial model was:

Proportion positive trips = YEAR+AREA+MESH.

The final lognormal model was:

ln(CPUE) = YEAR+SEASON+AREA.

The delta-lognormal abundance index is shown in Figure 2. To allow for visual comparison with the nominal values, both series were scaled to their respective means. The index statistics can be found in Table 3.

Diagnostic plots assessing the fit of the models were deemed acceptable (Figure 3-6). The frequency distribution of the natural logarithm of CPUE and residuals approximated a normal distribution. When plotted by year, the residuals were distributed evenly around zero. The quantile-quantile plot of the data from all models tended to fall along the reference line indicating the data are from a normal distribution. In summary, all diagnostic plots met assumptions, and supported an acceptable fit to the selected models.

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Acknowledgements

We thank all observers for collecting data from this fishery since the initiation of the program. This is National Marine Fisheries Service Panama City Laboratory-Contribution 08-03.

Table 1. Analysis of deviance of explanatory variables for the binomial and lognormal generalized linear formulations of the proportion of positive and positive catches for king mackerel.

Binomial

FACTOR	DF	DEVIANCE	DEVIANCE/DF	%DIFF	DELTA%	CHISQUARE	PR>CHI
NULL	446	617.24	1.38				
YEAR	434	475.97	1.10	20.76	20.76	141.27	<.0001
YEAR+							
AREA	432	342.61	0.79	42.69	21.94	133.36	<.0001
MESH	432	412.31	0.95	31.04		63.66	<.0001
SETBEGIN	431	461.72	1.07	22.59		14.24	0.003
SEASON	431	471.31	1.09	20.98		4.66	0.199
YEAR+AREA+							
MESH	430	326.28	0.76	45.17	2.48	16.34	0.000
SETBEGIN	429	337.97	0.79	43.07		4.64	0.2004

Lognormal

FACTOR	DF	DEVIANCE	DEVIANCE/DF	%DIFF	DELTA%	CHISQUARE	PR>CHI
NULL	206	539.25	2.618				
YEAR	195	388.83	1.994	23.83	23.83	67.70	<.0001
YEAR+							
SEASON	192	294.78	1.535	41.35	17.52	57.32	<.0001
MESH	193	321.35	1.665	36.39		39.45	<.0001
AREA	193	334.92	1.735	33.71		30.89	<.0001
SETBEGIN	192	379.64	1.977	24.47		4.95	0.176
YEAR+SEASON+							
AREA	190	270.72	1.425	45.57	4.22	17.62	0.0001
MESH	190	277.93	1.463	44.12		12.19	0.002
YEAR+SEASON+AREA+							
MESH	188	263.83	1.403	46.39	0.82	5.34	0.0694

Table 2. Analysis of mixed model formulations for king mackerel. Final model selected is in bold.

Binomial

Mixed Model	AIC	BIC	(-2) LOGLIKELIHOOD
YEAR+AREA+MESH	154.0	155.3	152.0
YEAR+AREA+MESH YEAR*AREA	162.0	164.8	158.0
YEAR+AREA+MESH YEAR*MESH	165.8	167.2	163.8

Lognormal

Mixed Model	AIC	BIC	(-2) LOGLIKELIHOOD
YEAR+SEASON+AREA	651.9	655.2	649.9
YEAR+SEASON+AREA YEAR*SEASON	651.9	653.2	649.9
YEAR+SEASON+AREA YEAR*AREA	652.0	654.6	648.0

Table 3. The absolute standardized index of abundance for king mackerel with the associated coefficients of variation (CV) and number of sets observed (N).

Year	Absolute index	CV	N
1993	266.20	0.63	5
1994	77.09	0.58	39
1995	215.12	0.49	7
1996	-		
1997	-		
1998	-		9
1999	8.53	0.40	49
2000	11.78	0.56	43
2001	48.28	0.28	77
2002	49.89	0.33	47
2003	49.61	0.49	24
2004	51.55	0.31	31
2005	77.83	0.35	31
2006	0.0	-	4
2007	32.70	0.96	81

Figure 1. Distribution of fishing effort in the directed shark gillnet fishery 1993-1995 and 1998-2007. Fishing areas defined for GLM analysis are; area 1: South Florida; area 2: Central Florida; area 3: North Florida/Georgia.

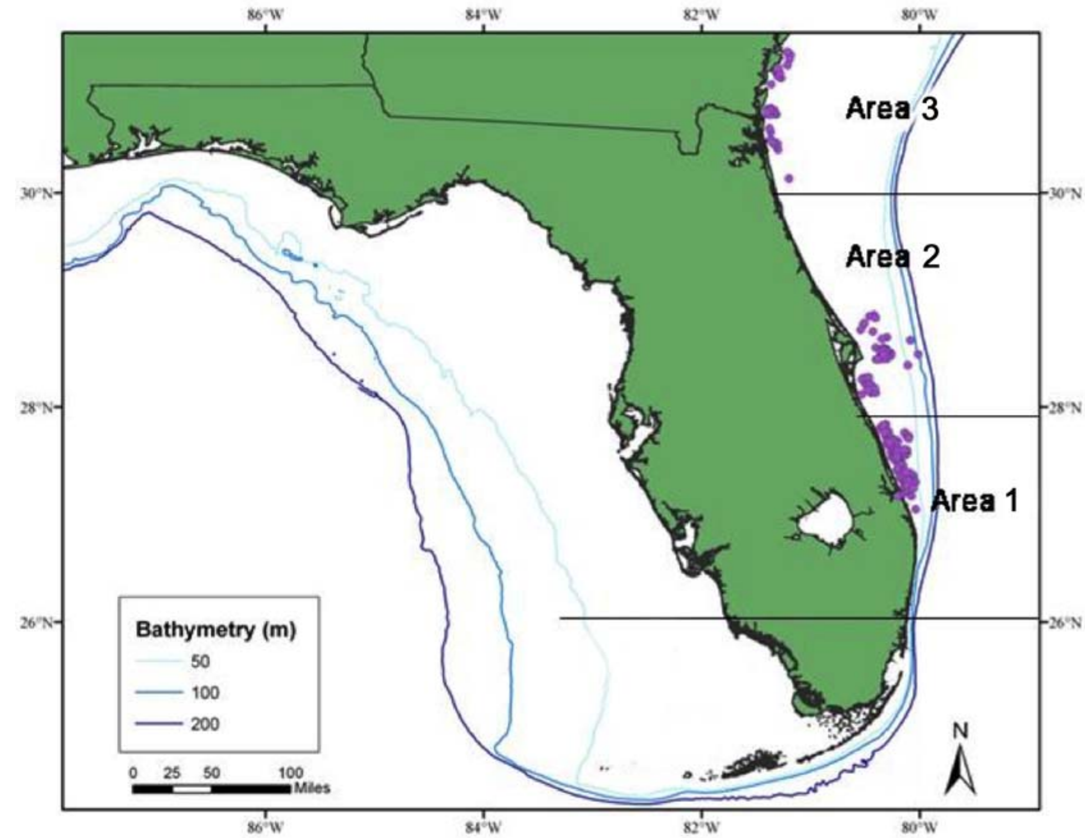

Figure 2. Relative (index/overall mean) standardized and nominal catch rates for king mackerel.

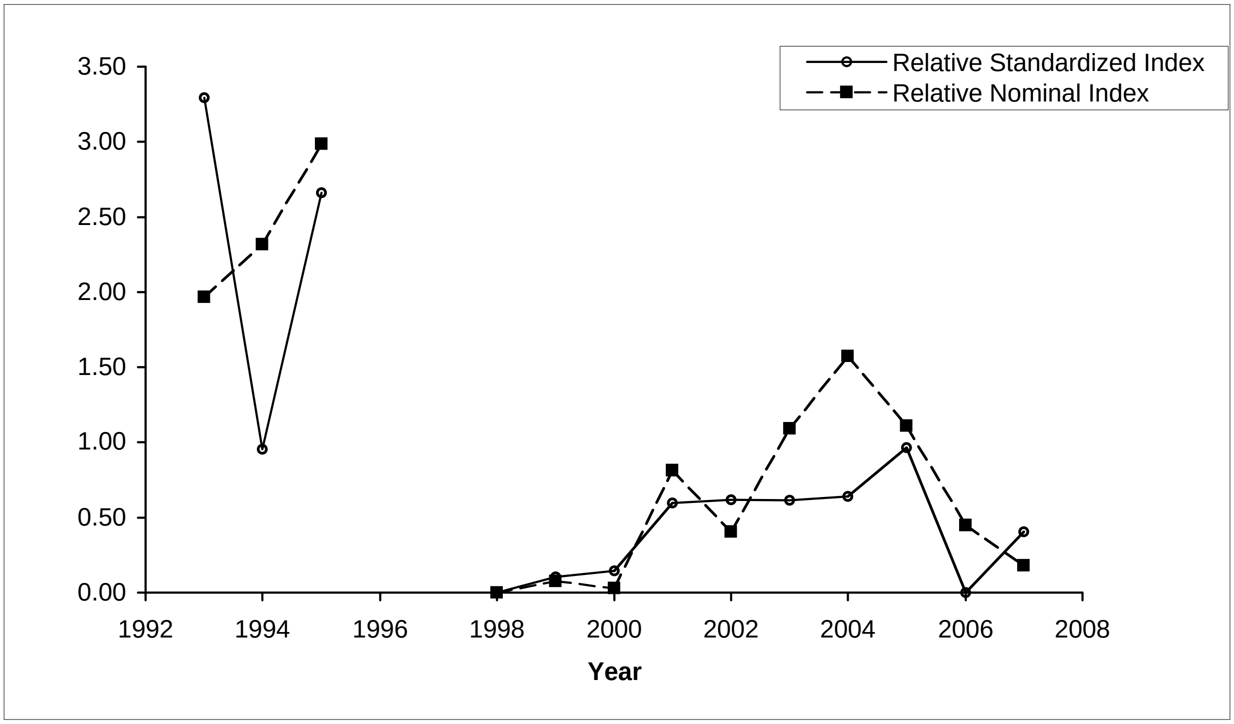

Figure 3. Residuals for the binomial model on the proportion positive catch rates.

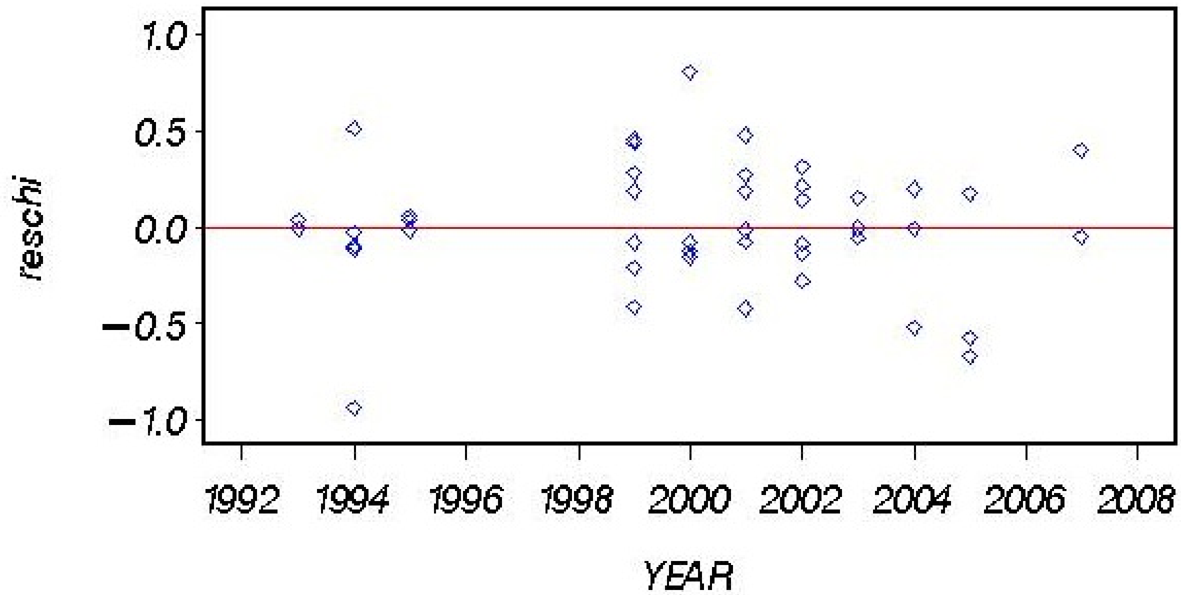

Figure 4. Residuals for the lognormal model on positive catch rates.

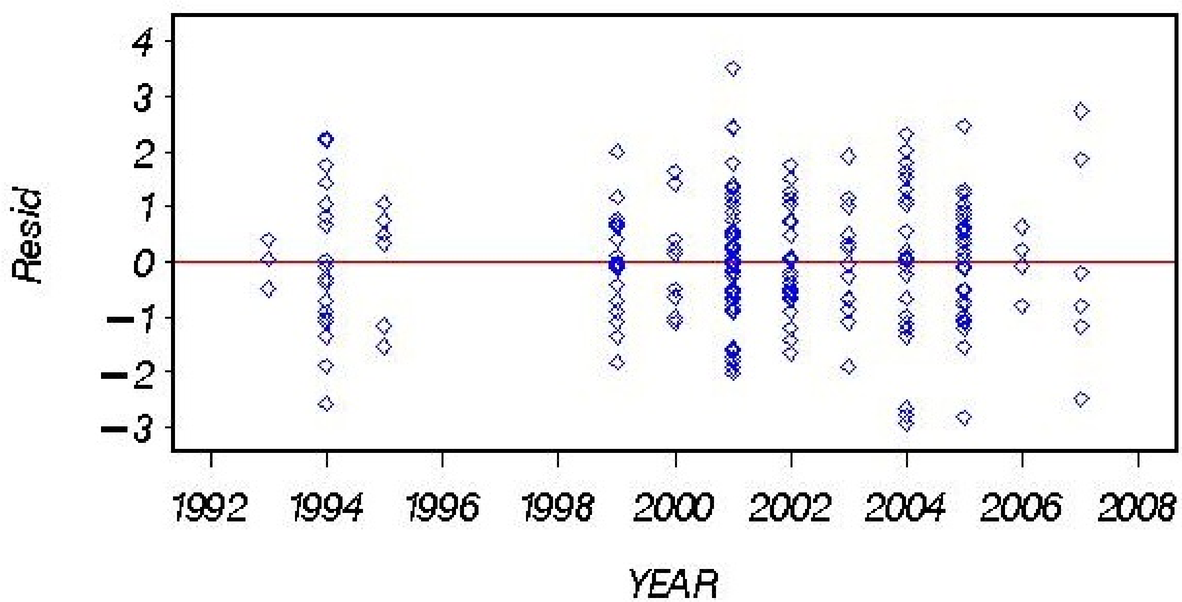

Figure 5. Frequency distribution of natural logarithm (CPUE). The solid line is the expected normal distribution.

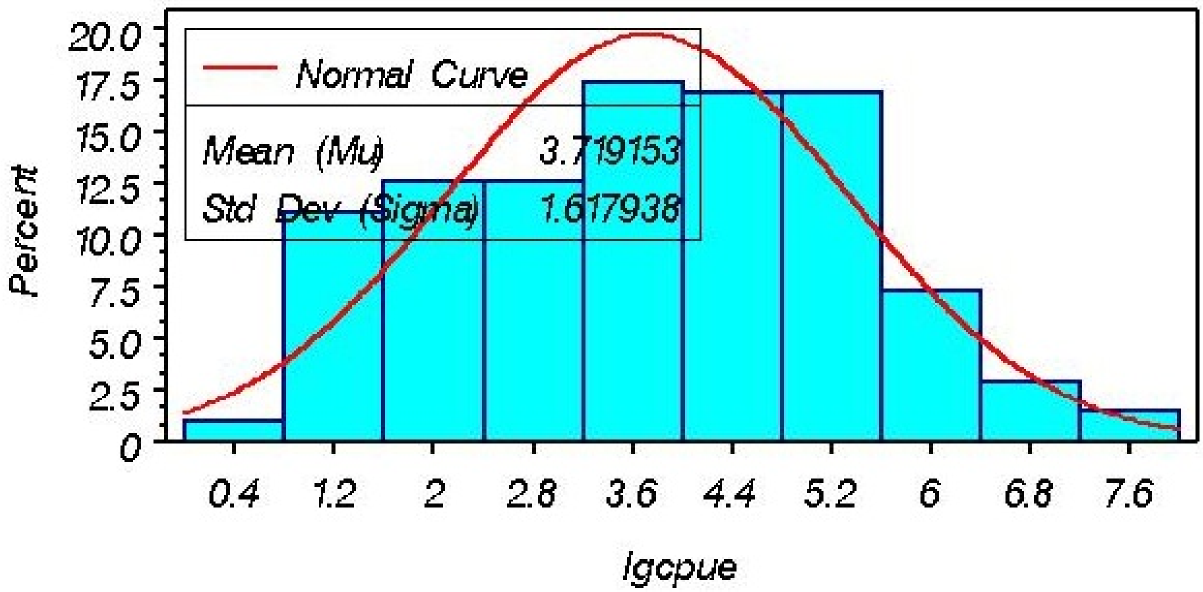

Figure 6. Quantile-quantile plots of natural logarithm (CPUE).