Standardized catch rates of Spanish and king mackerel (*Scomberomorus maculatus* and *S. cavalla*) from the North Carolina Commercial fisheries.

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SUMMARY

Standardized indices of abundances were estimated for the Atlantic stock of Spanish and king mackerel from the commercial fisheries of the North Carolina State. The data analyzed included single trip catch information for all commercial vessels from 1994 to 2002 collected by the Trip Ticket Program. Analyses took into account not only trips targeting mackerels, but also other coastal pelagic species likely associated with the catch of mackerels. Standardization procedures used Generalized Linear Models (GLMs) with a delta lognormal approach taking into account the high percent of trips without catch of either Spanish or king mackerel.

Introduction

Information on relative abundance of Atlantic mackerel stocks is required to tune stock assessment models. Data collected from several commercial and recreational fisheries, as well fisheries independent surveys have been previously used to develop standardized catch per unit of effort (CPUE) indices of abundance. The last full stock assessment for Atlantic king mackerel used an index of abundance from the commercial fishery in North Carolina (MSAP 1998). However, in 1994 the North Carolina Department of Environment and Natural Resources (NCDENR) adopted a new program for collection of commercial fisheries data, the trip ticket program. Under this program, single trip catch and effort was collected with greater detailed of fishery and vessel information compare to prior data collection (Ref). This report documents the analytical methods applied to the available data, and presents standardized catch rates for Spanish and king mackerel. These indices included estimates of variance which better account for sampling error and correlation between observations in the catch rate analyzed through the application of random effects modeling methods (Cooke, 1997).

Materials and Methods

Commercial fisheries data were kindly provided by the NCDENR Division of Marine Fisheries. The data were part of the Trip Ticket Program, which summarized all fishery commercial selling activity in the North Carolina State, for both offshore and inshore fisheries. Each observation represented the catch/sell of a single trip by species. In order to account for potential trips that targeted Spanish or king mackerel, but were unsuccessful, the subset data included trips for those species most likely associated with catches of Spanish and king mackerel. Table 1 and figure 1 showed the set of species considered likely associated with catch of either Spanish or king mackerel. The main catch species were croakers, dogfish, bluefish and gray trout. King mackerel represents about 3% of the total catch reported from 1994 to 2002, while Spanish mackerel represented about 2%. About 51% of the trips reported catch of a single species (Table 2, fig 2), while 33% reported 2 or 3 species, and trips with more than 5 species were much less common (< 5%). For king mackerel, most of the catch came from trips where king was the only species caught (54%), however catch was also reported from multi-species trips (table 2, Fig 3). In the case of Spanish mackerel, most of the catch came from multi-species trips, between 2 to 6 different species (Fig 3).

The trip ticket program also collected information on the gear used for the catch. Figure 4 shows the percent of catch by gear, reported for king and Spanish mackerel. Data for catch rate analyses were restricted to trips where the following gears were used: trolling, gill net set and rod-reel for king mackerel, and gill net sink, gill net float and pound net for Spanish mackerel. The NCDENR also had an area classification that reflected the main bays, rivers and offshore areas for commercial fishery activities (NCDENR Trip Ticket User Manual). About 36 different water codes were recognized, of these, king mackerel were caught almost exclusively in the offshore areas, north and south of Cape Hatteras (Fig 5), while Spanish mackerel was caught in the offshore areas as well in the Pamlico Sound, and to a minor extend in the Core sound, New river and the Pamlico river. For the catch rate analysis, data were restricted to those areas that represent 2% or more of the total catch of each mackerel species.

In analyses of catch rates for both commercial (Ortiz and Scott 2002) and recreational (Ortiz 2003) fisheries, it has been shown that vessel, or vessel/skipper configuration has a significant role as predictor variable. This is directly related to the fishing power and catchability characteristics of the fleet, and if the fleet is large and variable, it becomes important to recognized and incorporate this factors in the process of catch rate standardization. Reviewing the trip ticket data, between 1994 and 2002, at least 1,656 different vessels ID reported catch of king mackerel (Fig 6). However, by reviewing the annual catch of all these vessels, 375 (23%) reported catch of king mackerel for at least four or more years, and more importantly the catch of these 375 vessels constituted 79,2% of the total catch of king between 1994 and 2002 (Fig 6). In a similar way, for Spanish mackerel, there were at least 1,319 vessels ID with reported catch, but 237 (18%) caught Spanish mackerel for 4 or more years, and they accounted for 84% of the total catch. Therefore, for the catch rate analyses, the data were restricted to those vessel ID's with a history of 4 or more years of catch reported, either for king or Spanish mackerel (Fig 7). Figure 8 shows the log-transformed frequency distribution of the nominal CPUE for king and Spanish mackerel for the positive trips, of the selected input data.

Index Development

Catch was reported in total pounds landed by species and trip. Although fishing effort data are currently collected as number of days per trip in the Trip Ticket Program, this information was only available since 1999. Thus nominal catch rates were estimated as total pounds per trip. The explanatory variables considered for the king and Spanish mackerel indices analyses included: year, month, gear, and area (i.e. water code). Relative indices of abundance were estimated by Generalized Linear Mixed Modeling (GLMM) approach using a delta lognormal model error distribution. The selection of a delta model responded to the high proportion of trips with zero catch. The analysis used a delta model with a binomial error distribution for modeling the proportion of positive trips, and a lognormal assumed error distribution for modeling the mean density or catch rate of successful trips. Parameterization of the model used the Generalized Linear Model structures. Thus, the proportion of successful trips per stratum was assumed to follow a binomial distribution where the estimated probability was a linear function of a set of fixed factors and interactions. The logit function was used as a link between the linear factor component and the binomial error assumed. For the successful trips, estimated catch rates were assumed to follow a lognormal distribution, also as a linear function of a set of fixed factors and interactions. In the later case, the identity was the link function in this model.

A step-wise regression procedure was used to determine the set of systematic or fixed factors and interactions that significantly explained the observed variability. The deviance difference between two consecutive modes formulations followed a Chi-square distribution. This statistic was used to test for the significance of an additional factor in the model, where the number of additional parameters minus one corresponded to the number of degrees of freedom in the Chi-square test (McCullagh and Nelder 1989). Deviance tables are presented for the two components of the delta model: the binomial proportion of positives, and the mean catch rate of positive trips. Final selection of explanatory factors was conditional on: a) the relative percent of deviance explained by the added factor in the model, normally factors that explained 5% or more of deviance were retained, b) the Chi-square significant test, and c) the type III test within the final specified model. Once a set of fixed factors was specified, all possible first level interactions were evaluated, in particular interactions that included the year factor. Analyses were done using the GLIMMIX and MIXED procedures for the SAS® statistical computer software (SAS Institute Inc. 1997). Once a set of fixed factors and interactions was selected for each species, all interactions that included the factor *year* were assumed as random interactions. This assumption allowed estimating annual indices, which was the main objective of the standardization process, but also recognized the variability associated with the year-factors interactions that were significant. This process converted the base models into the generalized linear mixed model category. The significance of random interactions was evaluated between nested models by using three criteria: the likelihood ratio test (Pinheiro and Bates 2000), the Akaike's information criteria (AIC), and the Schwarz Bayesian information criteria (BIC) (Little et al 1996). For the AIC and BIC smaller values indicated best model fit.

Relative indices of abundance were estimated for each species as the product of the year effect least square means (LSmeans) from the binomial and the lognormal model components. In the positive observations component, the LSmeans estimates were weighted proportional to the observed margins in the input data, taking into account the characteristic unbalanced distribution of the input data. For the lognormal LSmeans, a log back-transformation bias correction was also applied (Lo et al 1992).

Results and Discussion

Deviance analysis tables indicated that gear was a main explanatory variable for proportion of successful trips of king mackerel (Table 3). For king catch rate of successful trips, again gear and month were the main factors, as well the interaction year*month. The final model for the proportion of positives included the year gear area month and year*gear random interaction, while the mean catch rate of positive trips included the year gear area month and year*month interaction (Table 4). Diagnostic plots of the model fit of king mackerel are shown in figure 9. The distribution of residuals and cumulative normalized residual plot (qq-plots) illustrated the expected patterns for the positive trips model component. Figure 10 shows the observed and predicted distribution of proportions of positives trips. Finally, table 5 and figure 11 show the estimated standardized index for king mackerel from the commercial fisheries off North Carolina waters. For king mackerel there was not a definitive trend in the standard index, coefficient of variation of estimates were about 40%, and the highest catch rates were registered in 1997, since then catch rates were around the all years average.

For Spanish mackerel, the deviance table showed that gear, area and month were the main explanatory factors for both the proportion of positive trips and the mean catch rate for successful trips (Table 6). The interactions of year*area and year*month were significant in the case of mean catch rates

(Table 7). Diagnostic plots of model fit are shown in figure 12, as well the observed and predicted frequency distribution of the proportion of positive trips (Fig 10). Table 8 and figure 13 show the nominal and standard index for Spanish mackerel from the North Carolina commercial fisheries data. For Spanish mackerel the results suggest an increasing trend, particularly in the last three years where estimated catch rates are above the average of the time series. However, the coefficients of variation were also large.

Overall, the present analyses indicated that commercial fisheries for king and Spanish mackerel off North Carolina waters were an important component primarily of the offshore fleet. King mackerel appeared mainly as single targeted species, however there was a portion of fishing effort shared with other species. In contrast, Spanish mackerel was most commonly caught in multi-species trips. This reinforces the importance of considering fishing effort that, although targeted to these species is not included in traditional standardization process because only successful trips are included. The approach of considering species associated with the catch of king or Spanish mackerel was an alternative to taking into account such fishing effort. Evaluation of Areas and gear allowed selecting trips that potentially could target these species. In addition, the evaluation of vessel ID and their catch history indicated that there was a selective set of the fleet that commonly targeted these species. Further information on vessel characteristics, crew number, type of gear, etc, would allow for a better characterization of potential factors that affect catch rates of mackerels in the commercial fishery of North Carolina.

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Table 1. Species associated with catch of king and Spanish mackerel from the commercial North Carolina fisheries. Data from the Trip Ticket Program 1994-2002.

Species	Total lbs	Percent Catch
Croaker	84,587,480	30.5%
Dogfish, mixed	55,461,272	20.0%
Bluefish	27,527,526	9.9%
Gray Trout	26,767,772	9.7%
Spot	23,624,447	8.5%
Mullets, Jumping	19,642,720	7.1%
Sharks, mixed	16,374,175	5.9%
Mackerel, King	9,096,741	3.3%
Sea Mullet (whiting, king)	5,747,878	2.1%
Mackerel, Spanish	4,944,909	1.8%
Little Tunny (Albacore)	1,487,681	0.5%
Amberjack	1,178,751	0.4%
Bonito	220,698	0.1%
Wahoo	220,275	0.1%
Tuna, Blackfin	75,946	0.0%
Jack Almaco	50,171	0.0%
Banded Rudderfish	14,509	0.0%

Table 2. Distribution of fishing trips by number of different fish species caught and reported per trip from the North Carolina trip ticket program. King and Spanish mackerel number of trips that reported catch of these species classified according to the total number of species reported by trip.

Number of species reported by trip	Num trips	Percent	King mackerel	Percent King	Spanish	Percent Spanish
1	215411	51.5%	19897	54%	3575	9%
2	89700	21.4%	9575	26%	6145	16%
3	52977	12.7%	3190	9%	7169	19%
4	32981	7.9%	1353	4%	7629	20%
5	18377	4.4%	964	3%	7259	19%
6	6879	1.6%	827	2%	5015	13%
7	1416	0.3%	593	2%	1166	3%
8	377	0.1%	282	1%	326	1%
9	88	0.0%	77	0%	83	0%
10	6	0.0%	5	0%	6	0%
Total	**418,212**		**36,763**		**38,373**	

Table 3. Deviance analysis table for the mean catch rate of successful trips and the proportion of positive trips for king mackerel from the North Carolina commercial fisheries Trip ticket program. *p* value refers to the Chi-square test between two consecutive models.

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Model factors positive catch rates values	d.f.	Residual deviance	Change in deviance	% of total deviance	*p*
1	1	72413.0			
Year	8	71555.9	857.1	3.3%	< 0.001
Year Gear	2	62529.3	9026.6	35.3%	< 0.001
Year Gear Water	7	61443.1	1086.2	4.2%	< 0.001
Year Gear Water Month	11	47967.0	13476.1	52.6%	< 0.001
Year Gear Water Month Year*Gear	16	47754.8	212.3	0.8%	< 0.001
Year Gear Water Month Year*Water	38	47544.1	423.0	1.7%	< 0.001
Year Gear Water Month Year*Month	88	46815.9	1151.1	4.5%	< 0.001

Model factors proportion positives	d.f.	Residual deviance	Change in deviance	% of total deviance	*p*
1	1	78577.0			
Year	8	77956.0	621.04	0.9%	< 0.001
Year Gear	2	11945.3	66010.63	90.8%	< 0.001
Year Gear Water	7	9270.5	2674.88	3.7%	< 0.001
Year Gear Water Month	11	6885.6	2384.83	3.3%	< 0.001
Year Gear Water Month Year*Water	47	6536.8	348.89	0.5%	< 0.001
Year Gear Water Month Year*Month	88	6192.6	693.09	1.0%	< 0.001
Year Gear Water Month Year*Gear	16	5866.1	1019.56	1.4%	< 0.001

Table 4. Analysis of delta lognormal mixed model formulation for king mackerel catch rates from the NC Trip Ticket program. Likelihood ratio tests the difference of –2 REM log likelihood values between two nested models.

King mackerel Atlantic Model	-2 REM Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	
Proportion Positives					
Year Gear Water Month	5511	5513	5518.3		
Year Gear Water Month *Year*Gear*	5390.2	5394.2	5396.8	120.8	0.0000
Positive Catch					
Year Gear Water Month	97092.6	97094.6	97102.9		
Year Gear Water Month *Year*Month*	96662.9	96666.9	96672.2	429.7	0.0000

Table 5. Nominal and standard CPUE for king mackerel, 95% confidence intervals and coefficient of variation from the NC Trip ticket program commercial fishery data.

Year	Num Obs	Nominal	Standard	Coeff Var	Index	95% confidence intervals	
1994	3966	187.809	8.436	39.6%	0.688	1.475	0.321
1995	3247	243.160	8.917	39.6%	0.728	1.560	0.339
1996	2465	276.174	7.765	39.8%	0.634	1.365	0.294
1997	4287	327.767	12.257	38.8%	1.000	2.113	0.473
1998	3311	314.072	9.449	39.4%	0.771	1.648	0.361
1999	3401	304.358	6.884	40.0%	0.562	1.214	0.260
2000	3223	268.830	7.065	39.9%	0.576	1.243	0.267
2001	2840	233.028	6.246	40.1%	0.510	1.103	0.235
2002	2325	247.517	5.521	40.4%	0.450	0.980	0.207

Table 6. Deviance analysis table for the mean catch rate of successful trips and the proportion of positive trips for Spanish mackerel from the North Carolina commercial fisheries Trip ticket program. *p* value refers to the Chi-square test between two consecutive models.

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Model factors positive catch rates values	Degrees of freedom	Residual deviance	Change in deviance	% of total deviance	*p*
1	1	88641.3			
Year	8	86484.4	2156.9	8.3%	< 0.001
Year Gear	2	81801.4	4683.0	18.0%	< 0.001
Year Gear Water	9	75169.4	6632.0	25.5%	< 0.001
Year Gear Water Month	11	64360.6	10808.8	41.5%	< 0.001
Year Gear Water Month Year*Gear	16	63798.2	562.4	2.2%	< 0.001
Year Gear Water Month Year*Water	61	63146.9	1213.7	4.7%	< 0.001
Year Gear Water Month Year*Month	82	62619.1	1741.5	6.7%	< 0.001

Model factors proportion positives	Degrees of freedom	Residual deviance	Change in deviance	% of total deviance	*p*
1	1	32294.5			
Year	8	31918.9	375.67	1.3%	< 0.001
Year Gear	2	29086.9	2831.99	10.0%	< 0.001
Year Gear Water	9	26548.8	2538.13	9.0%	< 0.001
Year Gear Water Month	11	4822.0	21726.80	76.6%	< 0.001
Year Gear Water Month Year*Gear	16	4511.3	310.61	1.1%	< 0.001
Year Gear Water Month Year*Water	64	4366.8	455.17	1.6%	< 0.001
Year Gear Water Month Year*Month	88	3939.8	882.19	3.1%	< 0.001

Table 7. Analysis of delta lognormal mixed model formulation for king mackerel catch rates from the NC Trip Ticket program. Likelihood ratio tests the difference of –2 REM log likelihood values between two nested models.

Spanish mackerel Atlantic Model	-2 REM Log likelihood	Akaike's Information Criterion	Schwartz's Bayesian Criterion	Likelihood Ratio Test	
Proportion Positives					
Year Month Gear Water	6924.8	6926.8	6932.1		
Year Month Gear Water *Year*Month*	6844.2	6848.2	6853.6	80.6	0.0000
Year Month Gear Water *Year*Month Year*Gear*	6814.4	6820.4	6828.4	29.8	0.0000
Positive Catch					
Year Gear Water Month	86733.7	86735.7	86743.8		
Year Gear Water Month *Year*Month*	86345.8	86349.8	86355.1	387.9	0.0000
Year Gear Water Month *Year*Month Year*Water*	86095.8	86101.8	86109.6	250	0.0000

Table 8. Nominal and standard CPUE for Spanish mackerel, 95% confidence intervals and coefficient of variation from the NC Trip ticket program commercial fishery data

Year	Num Obs	Nominal	Standard	Coeff Var	Index	95% confidence intervals	
1994	2398	154.072	1.036	32.9%	0.644	1.224	0.339
1995	2233	126.353	0.760	32.7%	0.473	0.895	0.250
1996	2128	145.765	0.664	33.4%	0.413	0.791	0.216
1997	3382	183.511	1.029	27.8%	0.640	1.104	0.371
1998	2349	125.866	0.686	32.0%	0.427	0.797	0.228
1999	2341	176.991	0.816	31.6%	0.508	0.940	0.274
2000	2913	189.143	1.304	28.9%	0.811	1.429	0.461
2001	2454	208.505	1.089	31.1%	0.677	1.243	0.369
2002	2025	274.445	1.608	32.5%	1.000	1.885	0.531

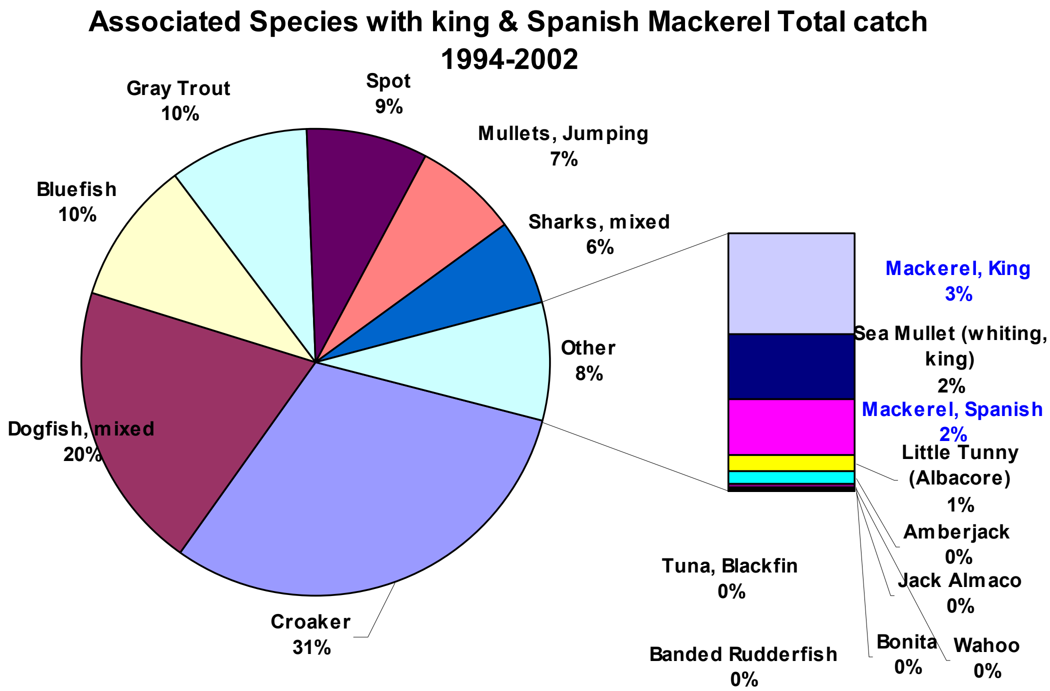


Figure 1. Distribution of total catch for associated species with king and Spanish mackerel from the commercial fisheries of North Carolina. Data from the North Carolina Trip Ticket Program 1994-2002.

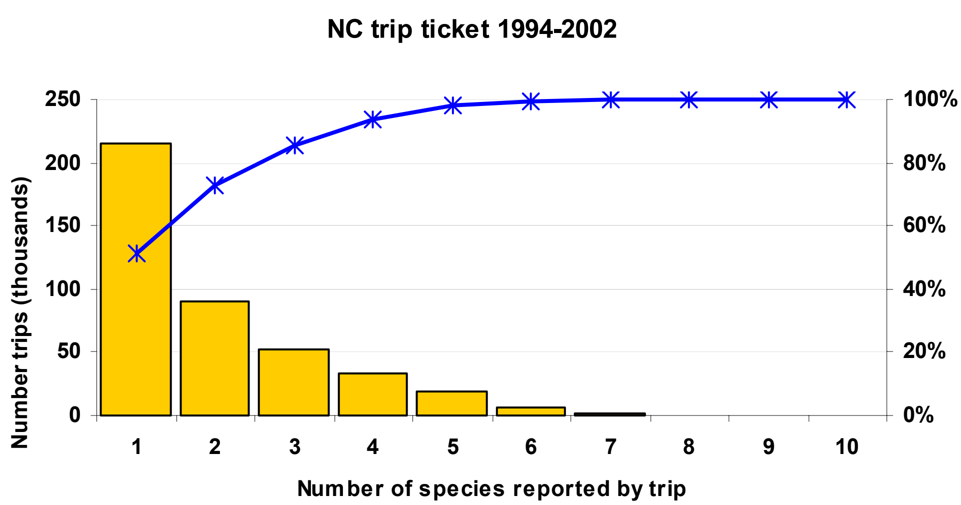


Figure 2. Distribution of trips that reported one, two or more species per trip from the Trip ticket data 1994-2002 North Carolina commercial fisheries.

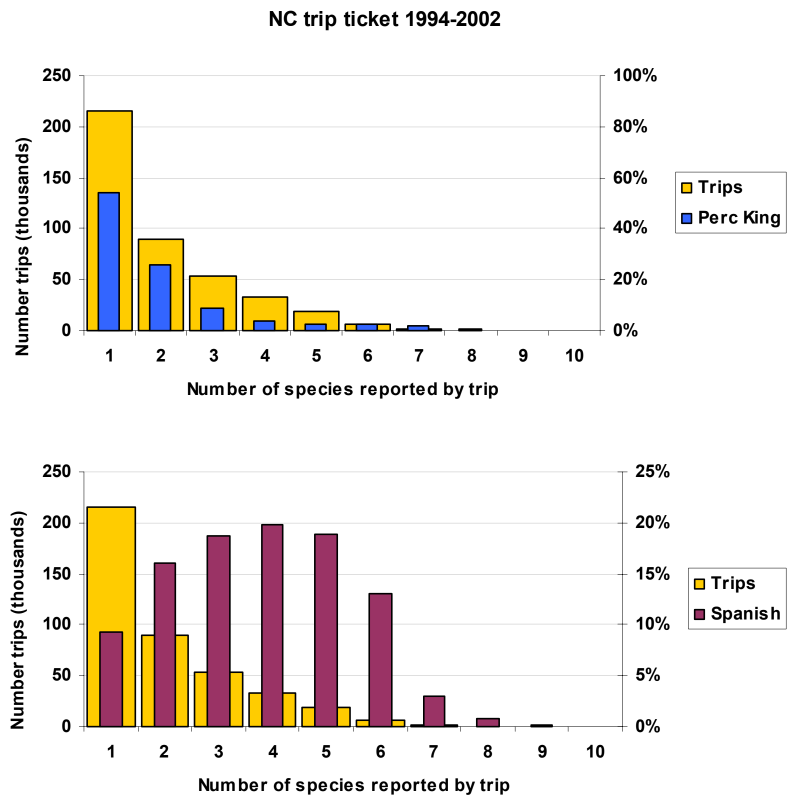


Figure 3. Percent of trips that reported king (top) or Spanish (bottom) mackerel catch in relation to the total number of species reported in each trip.

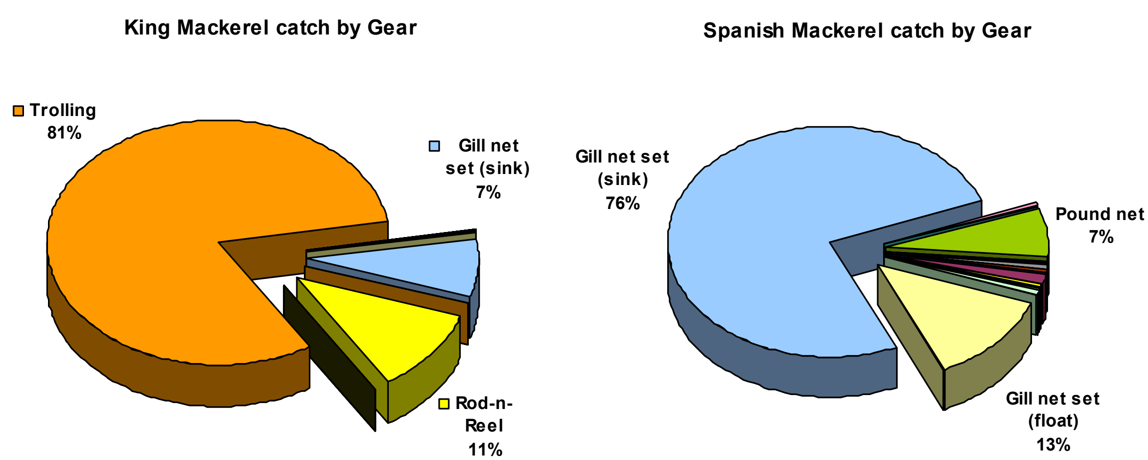


Figure 4. Percent distribution of king and Spanish mackerel catch [1994-2002] by gear type from the commercial fisheries Trip ticket program North Carolina.

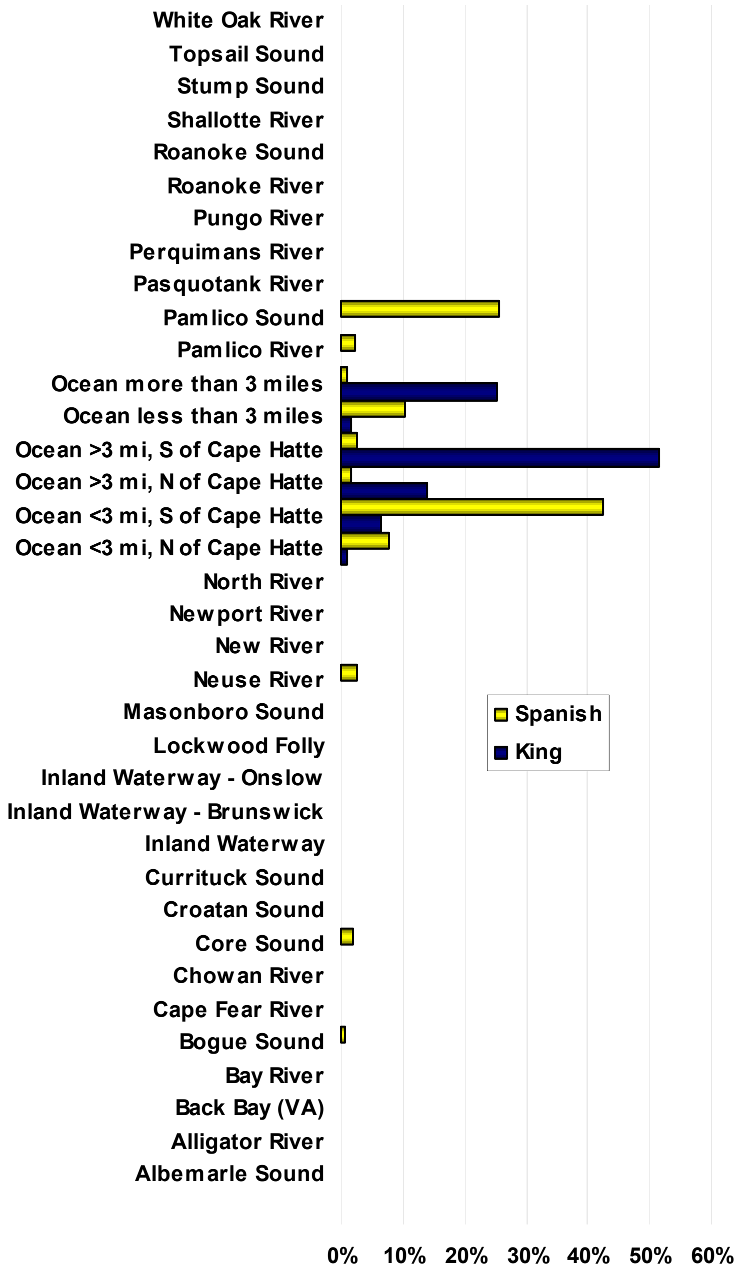


Figure 5. Catch distribution by area (water codes) from the commercial fisheries North Carolina. Data compiled from the Trip ticket program 1994-2002.

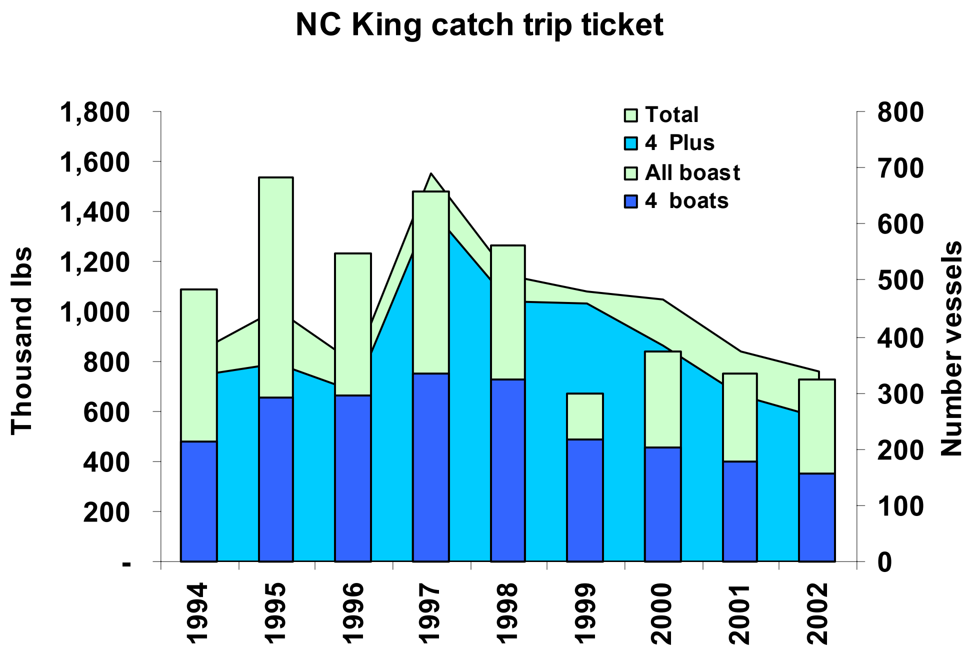


Figure 6. Annual king mackerel catch (area) and number of vessel ID that reported that catch from the North Carolina commercial fisheries 1994-2002. Darker areas and bars represent vessels that have at least 4 or more years of reported catch history.

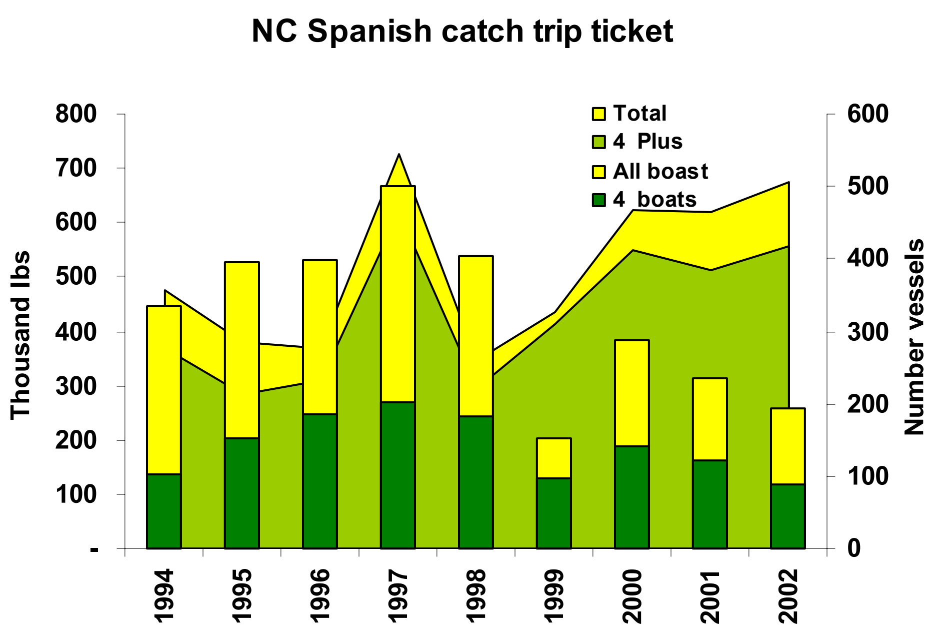
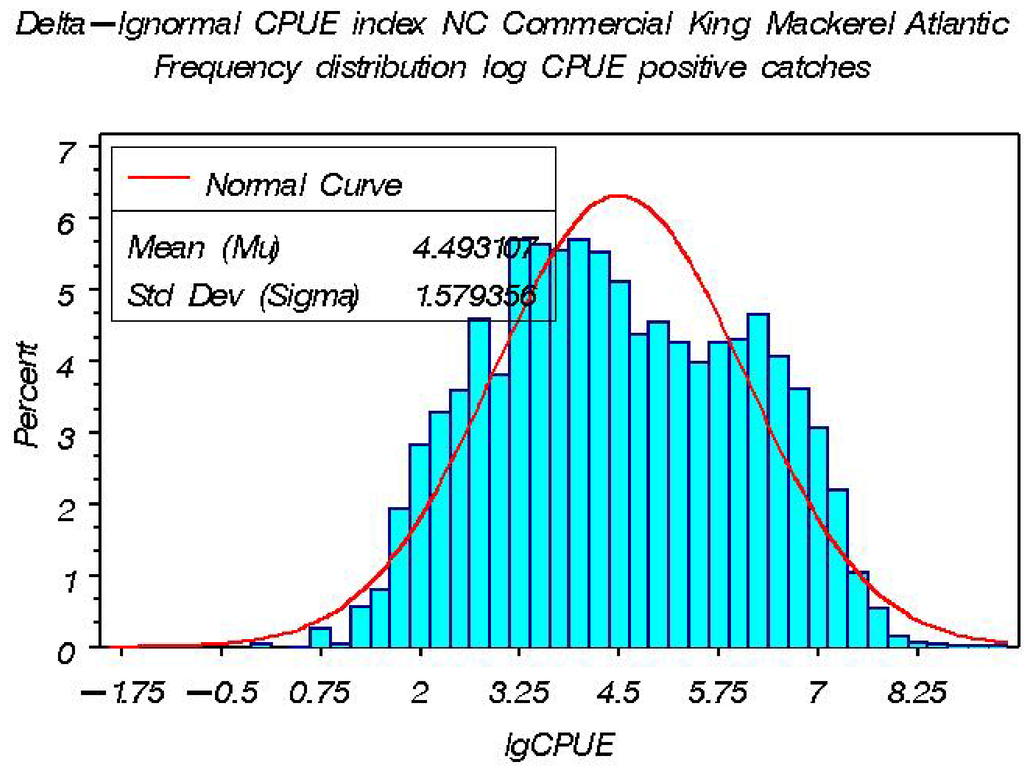


Figure 7. Annual Spanish mackerel catch (area) and number of vessel ID that reported that catch from the North Carolina commercial fisheries 1994-2002. Darker areas and bars represent vessels that have at least 4 or more years of reported catch history.



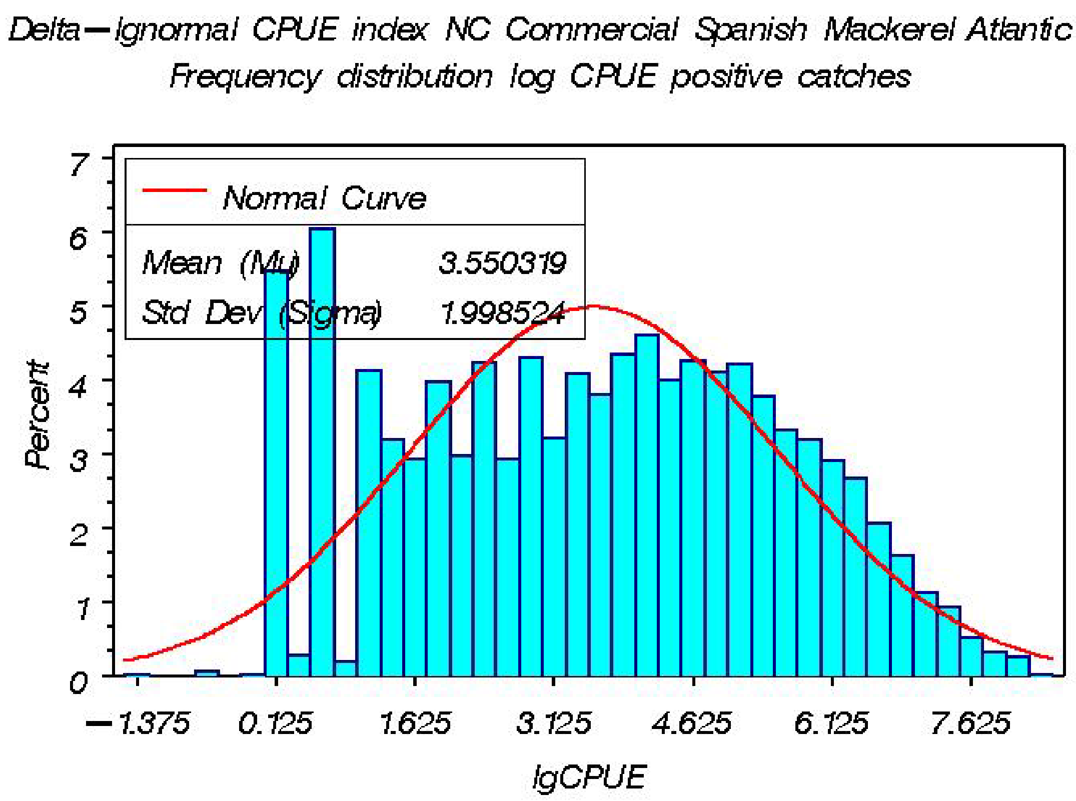
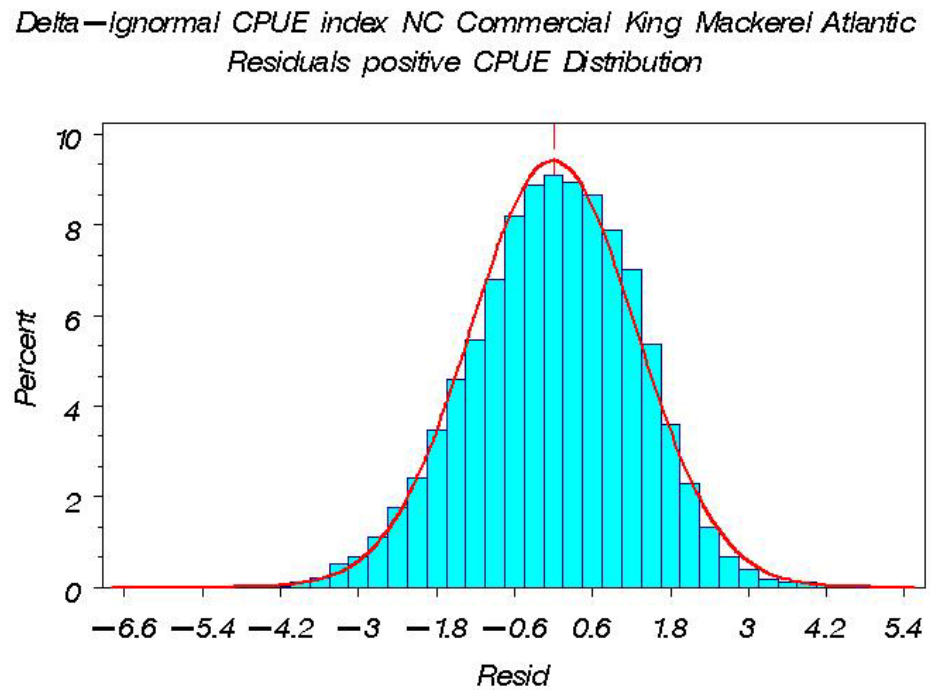


Figure 8. Frequency distribution of log-transformed nominal CPUE for king and Spanish mackerel successful trips from the North Carolina Trip ticket program 1994-2002.



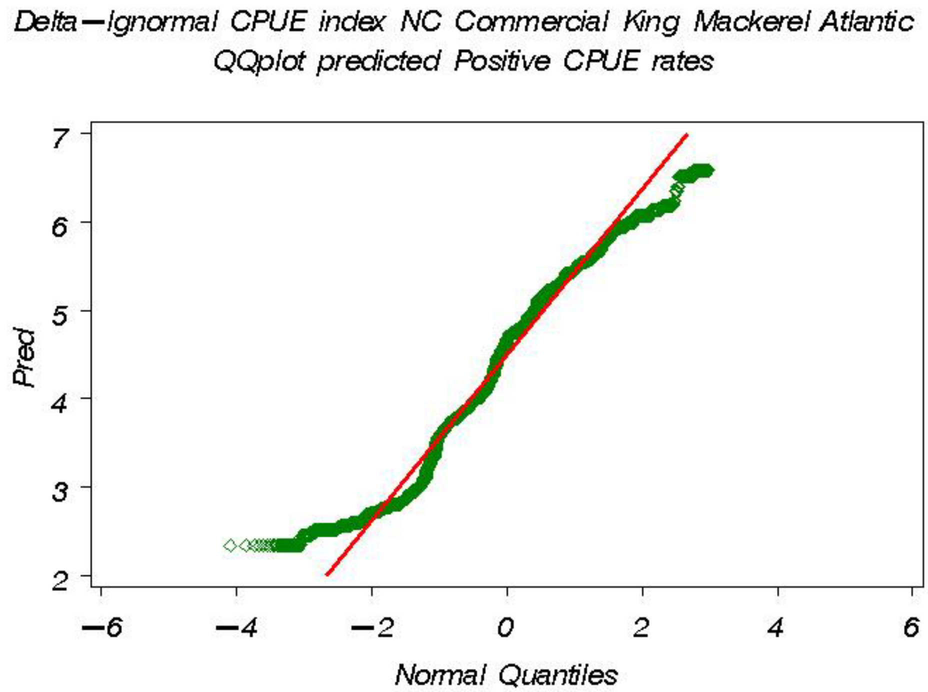


Figure 9. Model fit diagnostic plots for king mackerel positive trips component of the delta lognormal model. Top distribution of residuals, bottom normalized cumulative residual plot or qq-plots.

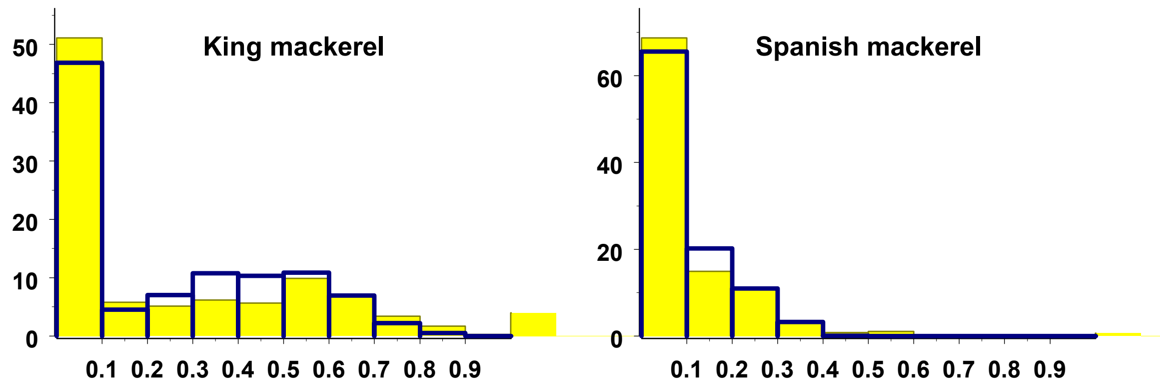


Figure 10. Observed (solid bars) and predicted (open bars) frequency distribution of proportion of positive trips for king and Spanish mackerel North Carolina commercial fisheries. Predicted values are from the delta model proportion of positives component, assuming a binomial error distribution.

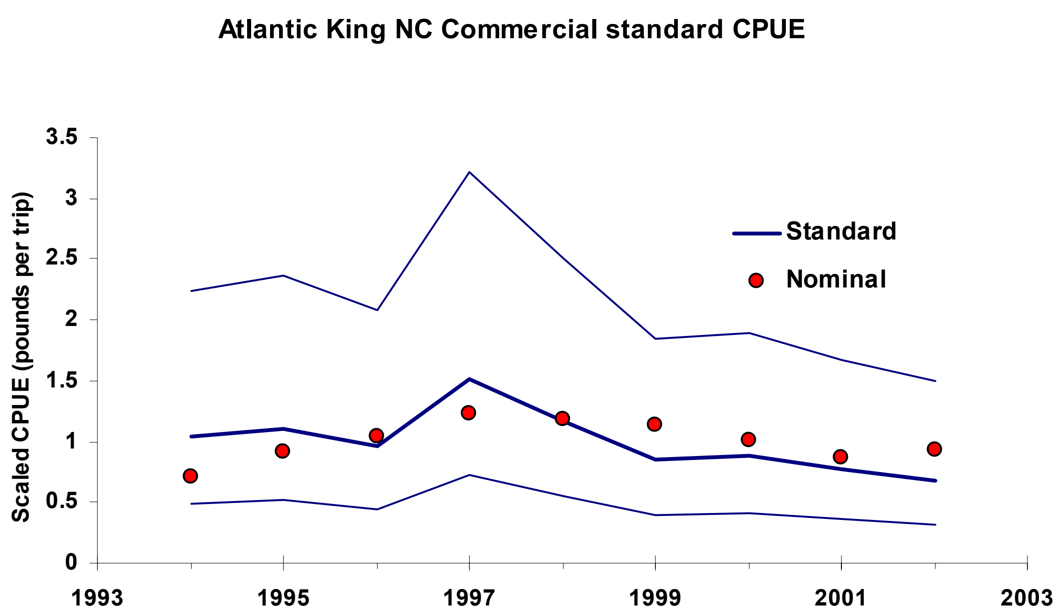


Figure 11. Nominal and standard index of abundance with 95% confidence intervals for Atlantic king mackerel from the North Carolina commercial fisheries 1994-2002.

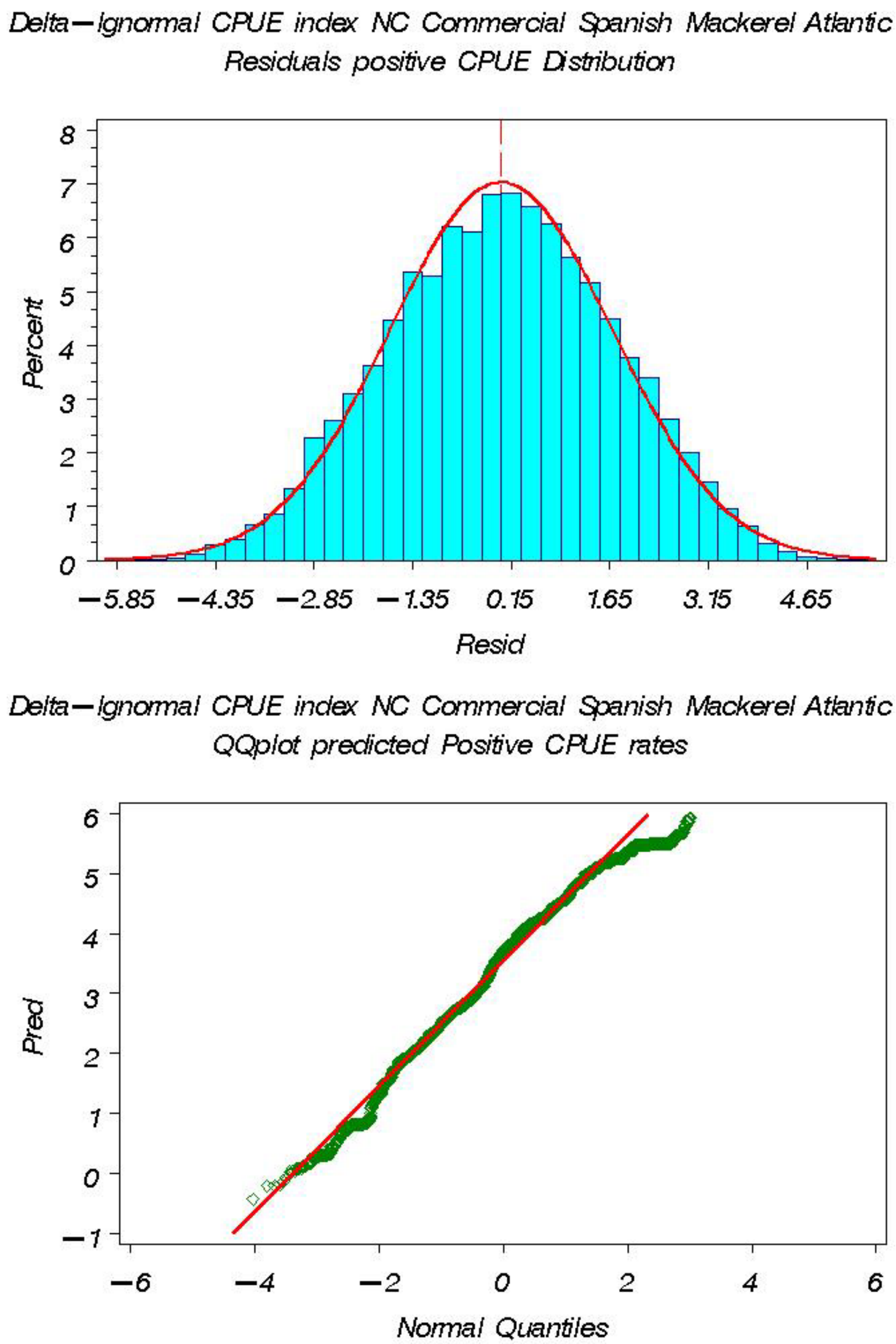


Figure 12. Model fit diagnostic plots for Spanish mackerel positive trips component of the delta lognormal model. Top distribution of residuals, bottom normalized cumulative residual plot or qq-plots.

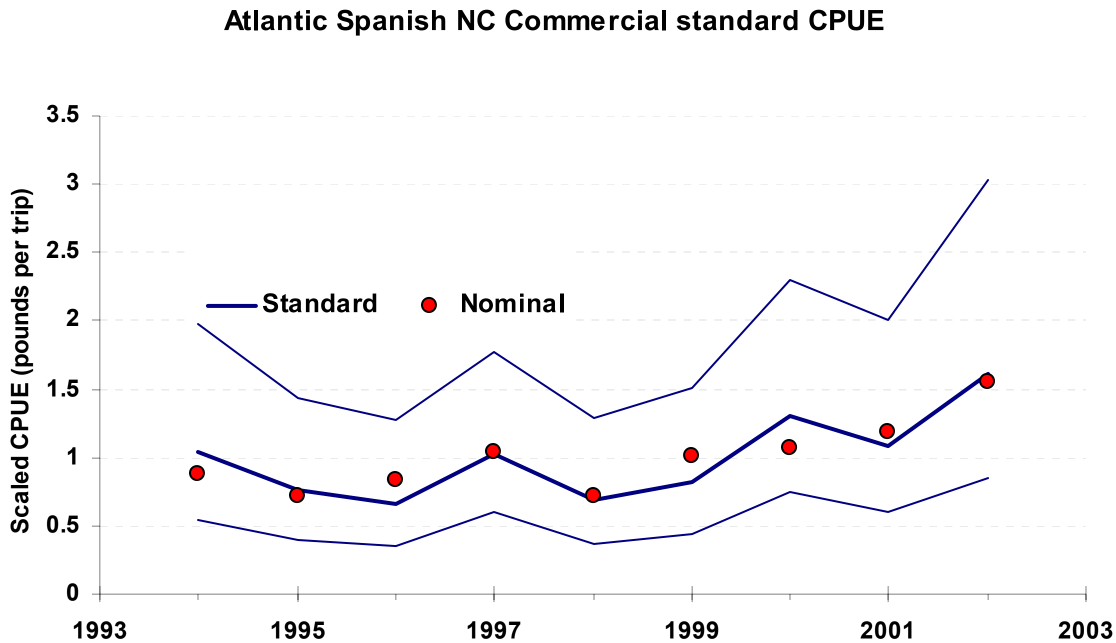


Figure 13. Nominal and standard index of abundance with 95% confidence intervals for Atlantic Spanish mackerel from the North Carolina commercial fisheries 1994-2002.