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INDICES OF BLUE, MAKO AND THRESHER SHARK ABUNDANCE DERIVED FROM U.S. ATLANTIC RECREATIONAL FISHERY DATA

Elizabeth A. Babcock[1], Gregory Skomal[2]

SUMMARY

Standardized indices of abundance were derived for blue, Prionace glauca*, shortfin mako,* Isurus oxyrinchus, *and thresher,* Alopias vulpinus*, sharks using data from recreational shark tournaments in the state of Massachusetts for the years 1991 through 2006, and for blue and shortfin mako sharks using data from the private and charter boat recreational anglers covered by the National Marine Fisheries Service Marine Recreational Fishery Statistics Survey (MRFSS), for the years 1981 through 2005. For both the MRFSS and Massachusetts tournament data, the catch per unit effort (CPUE) data were standardized using a general linear model (GLM) with year, region and tournament included as explanatory variables in the tournament data, and year, season, fishing mode (private versus charter boat) and region included as explanatory variables in the MFRFSS data. The best fit model was chosen using the Akaike information criterion (AIC). For the tournament data, blue shark CPUE increased through the late 1990s and then declined, while shortfin mako sharks showed the opposite pattern. Thresher shark CPUEs were low and variable, but appeared to increase in recent years. For the MRFSS data, significant interactions between year, area, season and fishing mode complicate interpretation of annual trends.*

RÉSUMÉ

*Les indices d'abondance standardisée ont été obtenus pour le requin peau bleue (*Prionace glauca*), le requin taupe bleue (*Isurus oxyrinchus*) et le requin renard, (*Alopias vulpinus*) en utilisant les données des championnats de pêche récréative consacrés aux requins menés dans l'état du Massachusetts entre 1991 et 2006, et pour le requin peau bleue et le requin taupe bleue, en utilisant les données des pêcheurs à la ligne de la pêche récréative opérant sur des navires privés et affrétés, lesquels ont fait l'objet de l'enquête sur les statistiques de la pêche récréative maritime du Service National des Pêches Maritimes (MRFSS), au titre des années 1981-2005. Pour les données des championnats du MRFSS et du Massachusetts, les données de capture par unité d'effort (CPUE) ont été standardisées à l'aide d'un modèle linéaire généralisé (GLM), l'année, la région et le championnat ayant été inclus comme variables explicatives dans les données de championnat, et l'année, la saison, le mode de pêche (navire privé par opposition à navire affrété) et la région ayant été inclus comme variables explicatives dans les données du MFRFSS. Le meilleur ajustement de modèle a été sélectionné à l'aide du critère d'information d'Akaike (AIC). Pour les données du championnat, la CPUE du requin peau bleue au augmenté jusqu'à la fin des années 1990, pour ensuite chuter, tandis que celle du requin taupe bleue a dégagé un schéma opposé. Les CPUE du requin renard étaient faibles et variables, mais elles semblent avoir augmenté ces dernières années. Pour les données du MRFSS, d'importantes interactions entre année, zone, saison et mode de pêche compliquent l'interprétation des tendances annuelles.*

RESUMEN

*Se derivaron los índices de abundancia estandarizados para la tintorera (*Prionace glauca*), marrajo dientuso (*Isurus oxyrinchus*) y tiburón zorro* (Alopias vulpinus) *utilizando los datos de los torneos de pesca de recreo de tiburones del estado de Massachusetts dede 1991 hasta 2006 incluido, y para la tintorera y el marrajo dientuso utilizando los datos de los pescadores de caña de recreo de barcos privados y fletados cubiertos por la Prospección estadística de las pesquerías de recreo del Servicio Nacional de Pesquerías Marinas (National Marine Fisheries Service Marine Recreational Fishery Statistics Survey, MRFSS), desde 1981 hasta 2005 incluido. Tanto para los datos de torneos de Massachusetts como para los de la MRFSS, los datos de captura por unidad de esfuerzo (CPUE) fueron estandarizados utilizando un modelo lineal generalizado (GLM), incluyendo como variables explicativas año, región y torneo, en los datos de los torneos; y año, temporada, modo de pesca (buque*

[1] Pew Institute for Ocean Science, Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Cswy., Miami, FL 33149. USA. ebabcock@rsmas.miami.edu
[2] Massachusetts Division of Marine Fisheries, Massachusetts Shark Research Program, Martha's Vineyard Research Station, P.O. Box 68, Vineyard Haven, MA 02568-0068 USA.

privado vs buque fletado) y región, en los datos MRFSS. Se seleccionó el mejor ajuste del modelo utilizando el criterio de información Akaike (AIC). En los datos de los torneos, la CPUE de tintorera se incrementó desde finales de los noventa y después descendió, mientras que los datos del marrajo dientuso mostraban un patrón opuesto. Las CPUE del tiburón zorro fueron bajas y variables, pero parecen incrementarse en los últimos años. Para los datos de la MRFSS, las interacciones significativas entre año, zona, temporada y modo de pesca complican la interpretación de las tendencias anuales.

KEYWORDS

Catch/effort, abundance, angling, game fishing, Isurus oxyrinchus, Prionace glauca, Alopias vulpinus, *recreational fishing, shark tournaments*

1. Introduction

The blue shark, *Prionace glauca*, and the shortfin mako shark, *Isurus oxyrinchus*, are subjected to offshore recreational fisheries along the east coast of the United States. From May through September each year, both species are sought by charter and private vessels, primarily from Virginia to Maine. Moreover, several big game fishing tournaments that target these species are held annually in this region. Common thresher sharks, *Alopias vulpinus*, are also caught in these tournaments.

The primary source of information about recreational fishing effort and catch is the National Marine Fisheries Service (NMFS) Marine Recreational Fishery Statistics Survey (MRFSS, MRFSS 2007). Total catch and effort data are also collected at shark tournaments by the Massachusetts Division of Marine Fisheries. Skomal *et al.* (2005) evaluated the data from these two sources to determine whether it is possible to derive unbiased indices of abundance for blue and shortfin mako sharks. We update this analysis, and also add an analysis of catch rates of common thresher sharks in the Massachusetts tournaments.

2. Methods

For both the MRFSS and Massachusetts tournament data, the raw catch per unit effort (CPUE) data were standardized using a general linear model (GLM) to account for the effects of different fishing areas and other factors that could affect catch rates. Once the effects of these explanatory variables were removed, the remaining year effect was assumed to be proportional to abundance (Babcock *et al.* 2000, Skomal *et al.* 2005, Ortiz *et al.* 2000).

From the MRFSS intercept survey data, only trips that fished more than 4.8km from shore were included in the analysis, as these trips were the most likely to catch blue and shortfin mako sharks. Blue shark catch rates (per angler-trip) were standardized using a delta lognormal GLM (Babcock *et al.* 2000, Lo *et al.* 1992, Ortiz *et al.* 2000), in which the number of positive trips in each stratum is assumed to be binomial, and the catch per trip of trips with a positive catch is assumed to be lognormally distributed. The index of abundance of blue sharks is the product of the year effects of the binomial and lognormal models. For shortfin mako sharks, only presence or absence in an angler-trip was standardized using a binomial GLM because there were few trips reporting more than one shark caught (only 8% of trips reporting the catch of a shortfin mako shark caught more than one). The MRFSS survey is stratified by year, fishing mode, sampling wave (two-month period), and state. For both species, we considered only strata for which there were substantial catches of blue or shortfin mako sharks. The explanatory variables considered were year (1981-2005), sampling wave (May-June, July-August, September-October), fishing mode (private versus charter boats), and region (North Atlantic: Maine through Connecticut; Mid Atlantic: New York through Virginia; and for shortfin mako sharks only, South Atlantic: North Carolina through Florida), and all second and third order interactions between them. The best models were chosen using the Akaike information criterion (Venables and Ripley 1997), which weighs the number of parameters against the fit of the model to find the most parsimonious model. A more detailed description of the methods applied to the MRFSS data may be found in Babcock *et al.* (2000).

For the tournament data for blue, shortfin mako and thresher sharks, CPUE was measured as total catch divided by total boat hours for each day of each tournament. Information on the number of anglers fishing in each boat was not available. It was not necessary to use a delta lognormal model because there were few zero observations; CPUE was modeled with a log-link GLM appropriate for lognormal data (Venables and Ripley 1997). The explanatory variables considered were year (1991-2006), region (Massachusetts: south of Cape Cod versus north of Cape Cod), and event (i.e. tournament) nested within region (Skomal *et al.* 2005). The test for significance of each effect was an *F* test appropriate for a log-link GLM (Venables and Ripley 1997). Since the sample design is unbalanced, the order in which the explanatory variables are entered into the model affects their significance (Venables and Ripley 1997). The explanatory variables were all categorical. We also entered year as a continuous variable to test whether there was a significant linear increase or decrease in the year effect over time, which might indicate a trend in biomass.

3. Results

Between 1981and 2005, the MRFSS intercept survey recorded 2627 blue sharks and 515 shortfin mako sharks in the strata defined for this analysis (**Table 1**). For blue shark catch rates derived from MRFSS data, year, wave, mode, region, and many of the interactions between these variables were significant for both the presence/absence (**Table 2a**) and positive trip CPUE (**Table 2b**). Thus, the trend over the time series is different for each year, wave, mode, and region, and it is not likely that the model year effect tracks the abundance of blue sharks throughout the region. The normal q/q plots of the residuals show a lack of fit, particularly for the CPUE in positive trips (**Figure 1, Figure 2**).

For shortfin mako shark presence/absence in the MRFSS data (**Table 2c**), year, wave, mode, and region were significant, as well as wave × region and mode × region interactions. The AIC best fit model did not include any interactions with year. The index appears fairly flat with a possible decrease in recent years (**Figure 3**). The q/q normal plot also showed a lack of fit (**Figure 4**).

Massachusetts tournaments between 1991 and 2002 recorded 17163 blue sharks, 693 shortfin mako sharks and 182 common thresher sharks (**Table 3**). In the GLM of blue shark catch rates derived from Massachusetts tournament data, only year and region were included in the AIC best model (**Table 4a**). The CPUE index appears to increase through about 1998 followed by a decrease through 2006 (**Figure 5**). The residual and q/q normal plots show a good fit of the model to the data (**Figure 6**).

In the GLM for shortfin mako shark CPUE from the tournament data, only year is included in the AIC best model (**Table 4b**). The CPUE year effect appears to decline until around 2000, followed by an increase through the present. (**Figure 7**). The q/q normal plot shows some lack of normality in the residuals (**Figure 8**).

For thresher sharks, year was not significant unless region or event was included in the model **(Table 4c-d)**, and the best model according to the AIC was the null model (i.e. no explanatory variables). The model including both year and region appeared to show a slight increase in recent years (**Figure 9, Figure 10**).

4. Discussion

For the recreational fishery, the MRFSS data is the most wide-ranging fishery-dependent data set and covers a relatively long time series. However, the survey does not capture a large fraction of the recreational fishing effort for pelagic sharks. The fact that the yearly trend in catch rates for blue sharks is influenced by fishing mode, time of year, and region, implies that the year effect is probably not tracking blue shark abundance throughout the region. For shortfin mako sharks, the MRFSS index is quite variable, but does not appear to show a trend over time in either fishing mode.

The Massachusetts tournament catch data for blue sharks appeared to show different trends North and South of Cape Cod when these data were analyzed through 2004 (Skomal *et al.* 2005). Skomal *et al*. (2005) speculated that a regional shift in blue shark distribution might account for this, possibly related to a decline in male blue shark abundance South of Cape Cod, documented by a fishery independent survey from 1977 through 1994 (Simpfendorfer *et al*. 2002). However, the current analysis through 2006 does not include year x region interaction in the best fit model. There were no significant interactions with year in the shortfin mako tournament CPUE, implying that the yearly changes in mako CPUE may be the result of actual changes in mako shark abundance in this region.

Interestingly, the shortfin mako shark index was at its lowest in the late 1990s through 2002, and has since increased, out of phase with the blue shark index in the same region, which increased until 1998 and then declined.

Acknowledgements

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Table 1. Number of sharks reported in the MRFSS intercept data, for the strata used in the analysis. Sampling effort varies over time.

	Blue sharks		*Shortfin mako sharks*	
	Charter boat	*Private boat*	*Charter boat*	*Private boat*
1981	1	2	2	3
1982	1	3	3	3
1983	0	34	0	4
1984	14	5	2	2
1985	0	8	2	11
1986	53	62	15	16
1987	38	17	4	33
1988	11	77	11	8
1989	66	52	10	16
1990	13	46	17	10
1991	24	92	13	8
1992	148	116	39	27
1993	82	161	16	22
1994	76	42	5	12
1995	32	238	11	19
1996	154	161	6	12
1997	119	91	7	6
1998	150	53	15	10
1999	31	93	3	12
2000	38	38	5	12
2001	8	52	10	12
2002	11	3	7	9
2003	21	18	4	5
2004	12	21	11	9
2005	30	9	13	3

Table 2. Analysis of deviance for GLMs for the MRFSS data, showing the best fit models according to the AIC.

(a) blue shark presence/absence.

	Df	*Deviance*	*Resid. Df*	*Resid. Dev*	*Pr(Chi)*
NULL			299	1635.403	
year	24	649.7289	275	985.675	0.0000
wave	2	2.1214	273	983.553	0.3462
mode	1	43.4323	272	940.121	0.0000
region	1	100.0418	271	840.079	0.0000
year×wave	48	162.5806	223	677.498	0.0000
year×mode	24	126.5968	199	550.902	0.0000
year×region	24	53.8971	175	497.004	0.0004
wave×mode	2	8.3754	173	488.629	0.0152
wave×region	2	45.077	171	443.552	0.0000

(b) blue shark CPUE.

	Df	Deviance	Resid. Df	Resid. Dev	F Value	Pr(F)
NULL			1069	3165.355		
year	1	111.2143	1068	3054.140	26.80049	0.000000
wave	1	41.8097	1067	3012.331	10.07533	0.001546
mode	1	49.0920	1066	2963.239	11.83023	0.000606
region	1	72.1257	1065	2891.113	17.3809	0.000031
year×wave	1	0.0115	1064	2891.101	0.00278	0.957942
year×mode	1	1.2017	1063	2889.900	0.28958	0.590604
year×region	1	0.0290	1062	2889.871	0.00699	0.933401
wave×mode	1	23.4651	1061	2866.405	5.65465	0.017586
wave×region	1	0.4064	1060	2865.999	0.09794	0.754379
mode×region	1	16.3516	1059	2849.647	3.94043	0.047397
year×wave×mode	1	4.1983	1058	2845.449	1.01172	0.314722
year×wave×region	1	3.3943	1057	2842.055	0.81797	0.365981
year×mode×region	1	12.2874	1056	2829.767	2.96102	0.085587

(c) mako sharks presence/absence

	Df	Deviance	Resid. Df	Resid. Dev	Pr(Chi)
NULL			449	1240.370	
year	24	107.3444	425	1133.026	0.0000
wave	2	18.2601	423	1114.766	0.0001
mode	1	42.3138	422	1072.452	0.0000
region	2	564.7852	420	507.667	0.0000
wave×region	4	30.1949	416	477.472	0.0000
mode×region	2	24.0738	414	453.398	0.0000

Table 3. Number of blue, shortfin mako and common thresher sharks caught in Massachusetts tournaments (NA means no tournament).

	Blue		*Mako*		*Thresher*	
	South	*North*	*South*	*North*	*South*	*North*
1991	291	21	35	0	1	1
1992	288	NA	32	NA	3	NA
1993	456	119	45	0	1	0
1994	632	NA	47	NA	6	NA
1995	572	345	29	1	14	1
1996	876	142	5	0	0	0
1997	679	85	3	2	2	0
1998	1578	258	9	0	2	5
1999	1781	177	22	0	0	1
2000	1561	111	7	0	7	0
2001	1197	NA	15	NA	3	NA
2002	1014	NA	55	NA	8	NA
2003	923	NA	57	NA	16	NA
2004	1709	NA	95	NA	35	NA
2005	1440	15	75	1	49	0
2006	893	NA	158	NA	27	NA

Table 4. Analysis of deviance for the best fit models (AIC) for the Massachusetts tournament data (a) blue sharks.

	Df	*Deviance Resid.*	*Df*	*Resid. Dev*	*F Value*	*Pr(F)*
NULL			80	46.05127		
year	15	22.10776	65	23.94351	4.60734	0.000008
region	1	5.65881	64	18.2847	17.68977	0.000083

(b) shortfin mako sharks

	Df	*Deviance Resid.*	*Df*	*Resid. Dev*	*F Value*	*Pr(F)*
NULL			80	3.05822		
year	15	1.502339	65	1.555881	3.991354	0.000046

(c) common thresher sharks model with year effect only.

	Df	*Deviance Resid.*	*Df*	*Resid. Dev*	*F Value*	*Pr(F)*
NULL			80	0.654468		
year	15	0.247438	65	0.40703	2.30572	0.010718

(d) common thresher sharks model with year and region.

	Df	*Deviance Resid.*	*Df*	*Resid. Dev*	*F Value*	*Pr(F)*
NULL			80	0.654468		
year	15	0.247438	65	0.40703	2.464102	0.006507
region	1	0.01465	64	0.39238	2.188405	0.143959

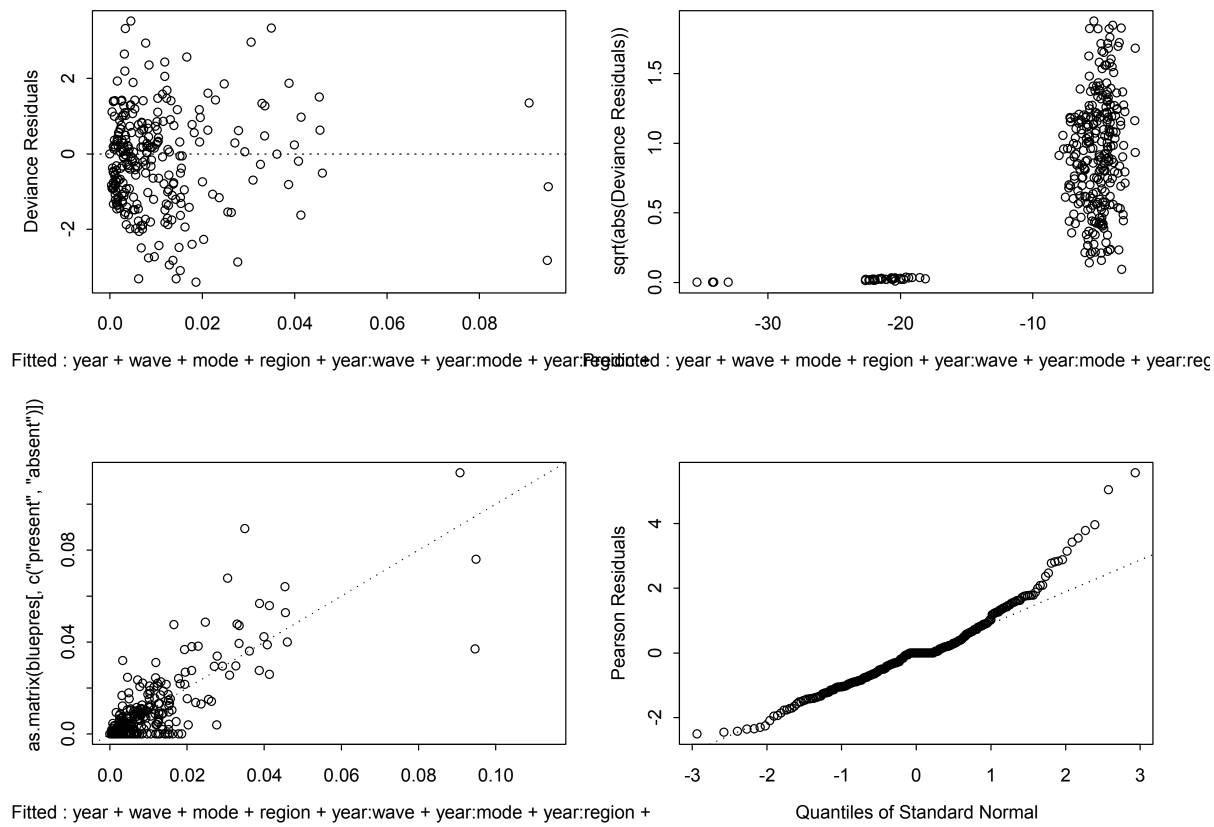

Figure 1. Diagnostics for the AIC best model for the blue shark MRFSS data presence/absence GLM.

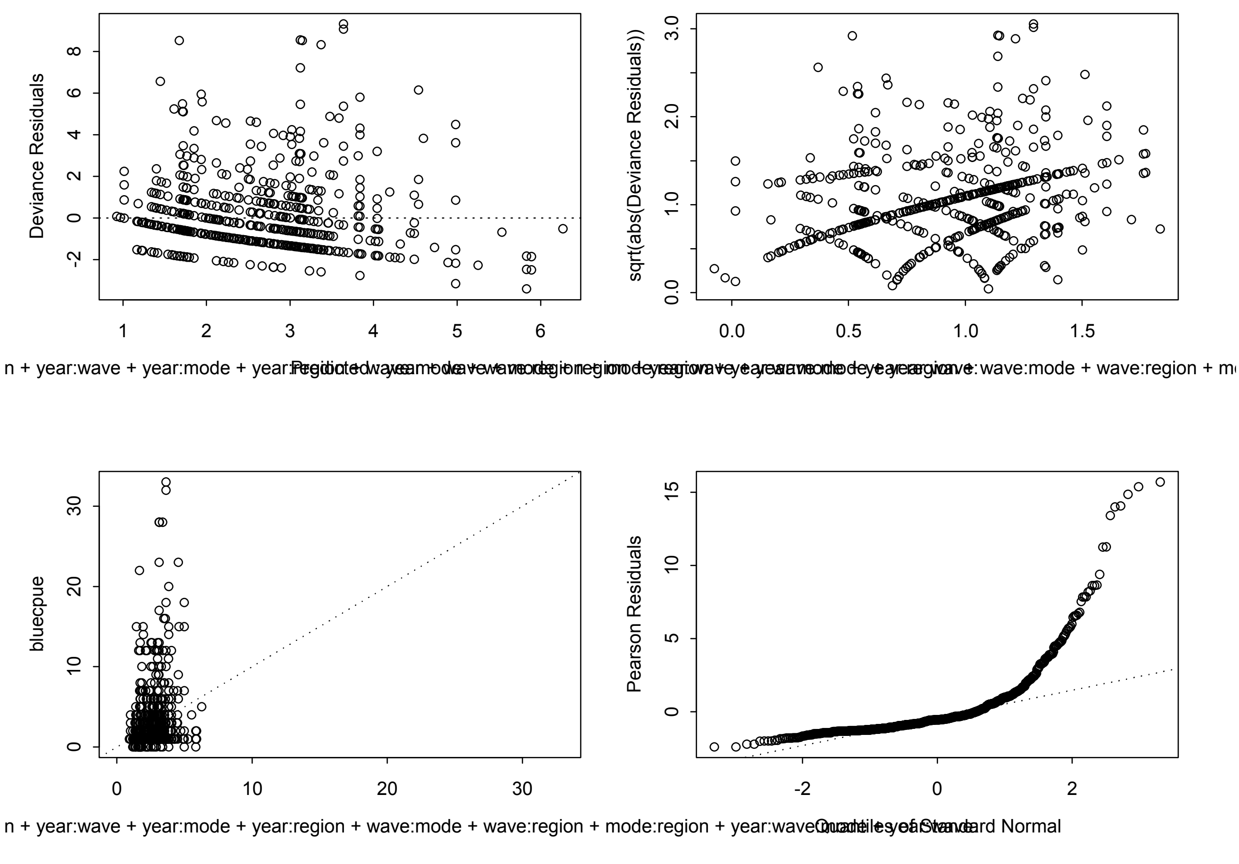

Figure 2. Diagnostics for the AIC best model for the blue shark MRFSS data CPUE GLM.

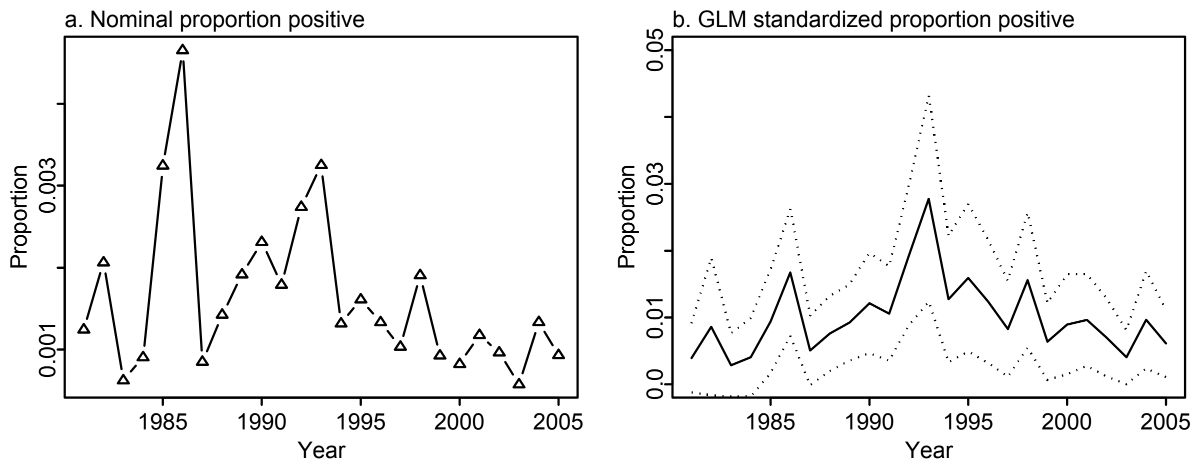

Figure 3. Nominal and GLM standardized presence/absence (±2 SE) of mako sharks from MRFSS data, for the AIC best fit model.

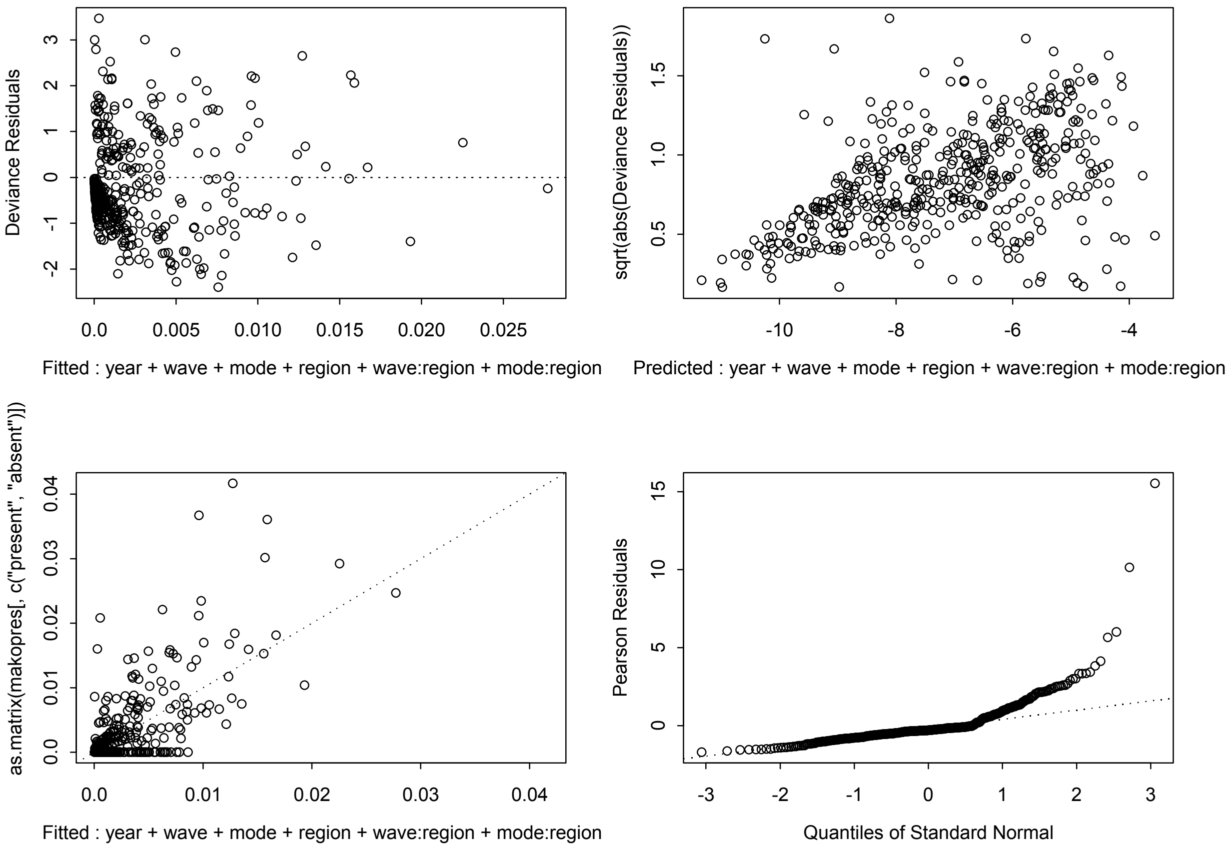

Figure 4. Diagnostics for the AIC best fit GLM model of mako presence/absence in the MRFSS data.

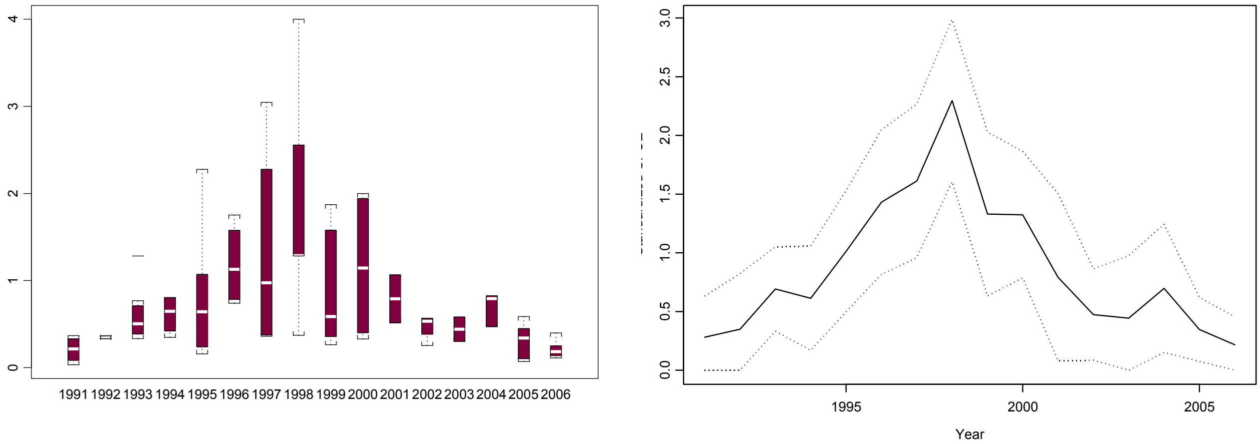

Figure 5. Nominal and GLM standardized CPUE (±2 SE) of blue sharks from Massachusetts tournament data.

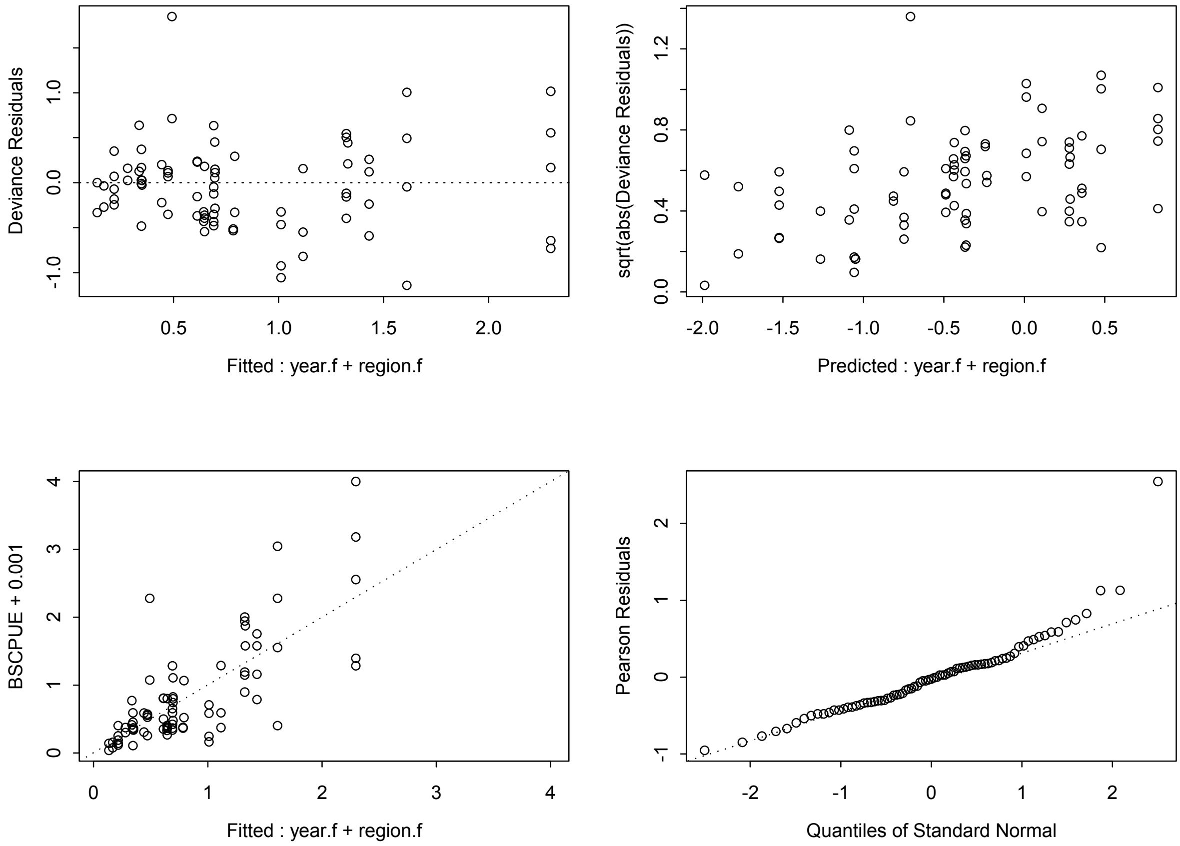

Figure 6. Diagnostics for the AIC best fit GLM model of blue shark CPUE in tournaments.

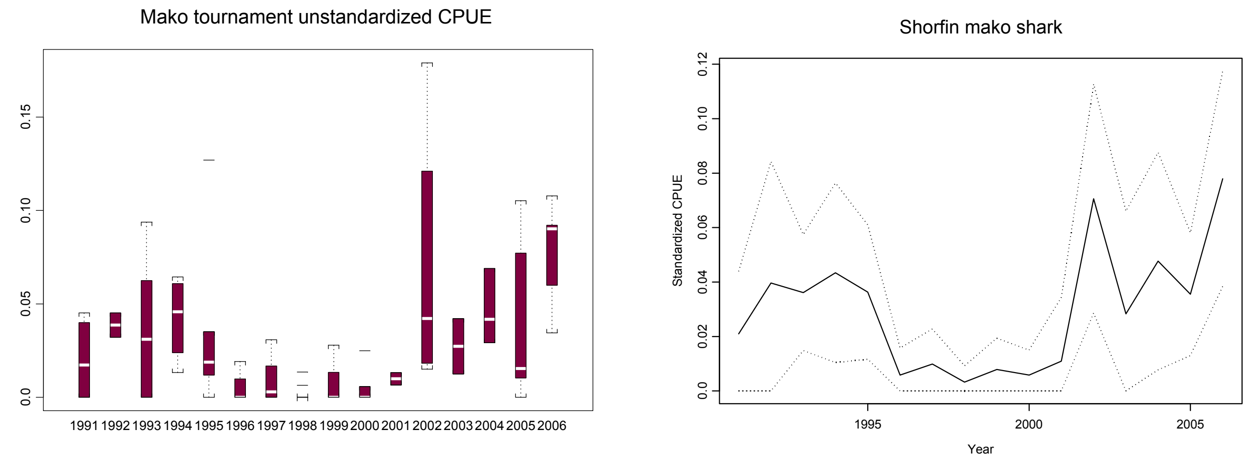

Figure 7. Nominal and GLM standardized CPUE (±2 SE) of mako sharks from Massachusetts tournament data.

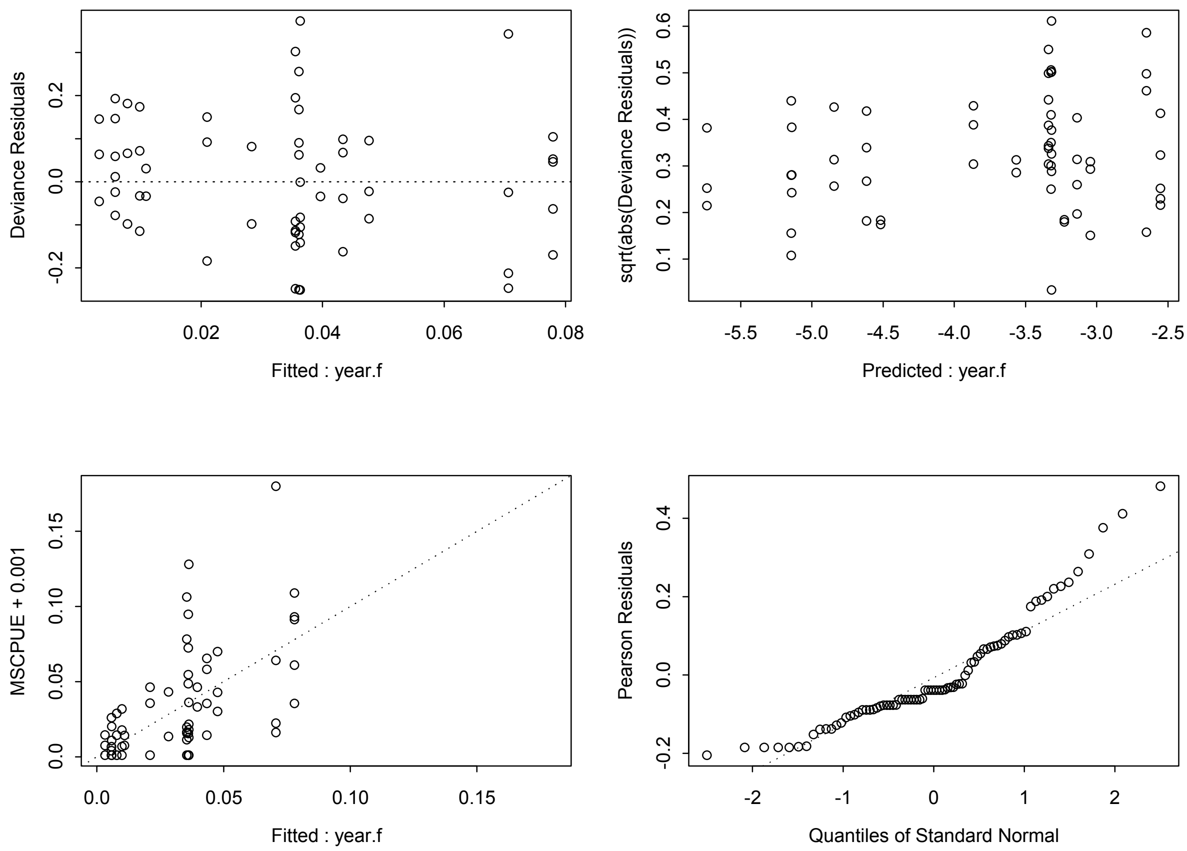

Figure 8. Diagnostics for the AIC best fit GLM model of mako shark CPUE in tournaments.

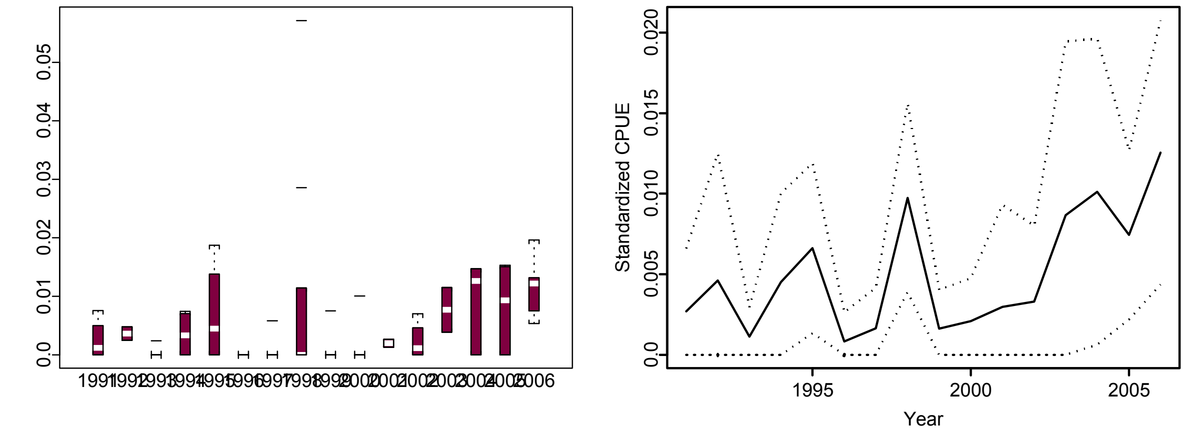

Figure 9. Nominal and GLM standardized CPUE (±2 SE) of thresher sharks, for the model including both year and region.

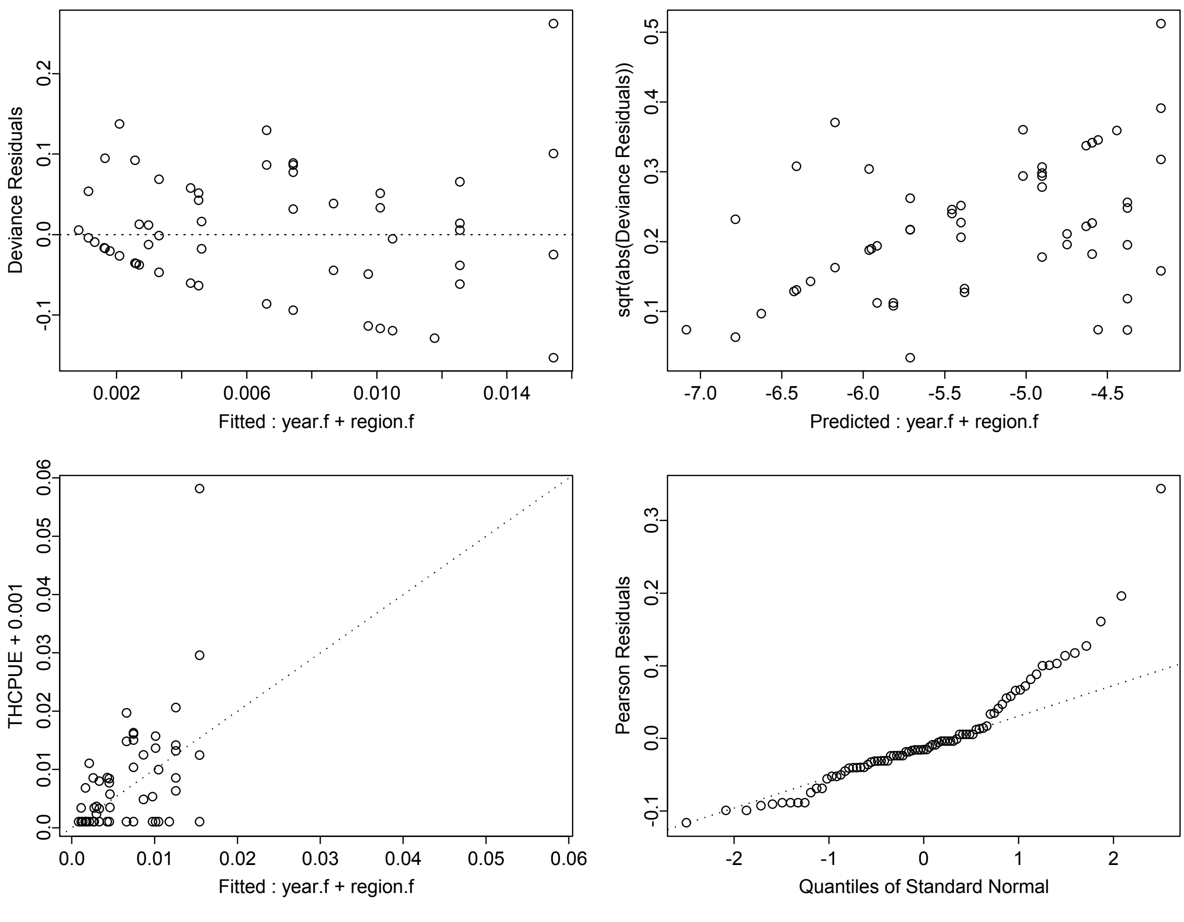

Figure 10. Diagnostics for thresher sharks in tournaments for the GLM model including both year and region.