SCRS/2004/108 Col.Vol.Sci.Pap.ICCAT, 58(3): 1034-1043 (2005)

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

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SUMMARY

Generalized linear models were used to derive indices of abundance for blue, Prionace glauca*, and shortfin mako,* Isurus oxyrinchus*, sharks based on two components of the U.S. Atlantic recreational fishery: (1) the private and charter boat recreational anglers covered by the National Marine Fisheries Service Marine Recreational Fishery Statistics Survey (MRFSS, 1981-2002), and (2) Massachusetts shark tournaments (1991-2002). From the MRFSS data, blue shark CPUE showed different trends for different regions, seasons and fishing modes, implying that CPUE is not tracking blue shark abundance. Mako shark CPUE differed by mode for private versus charter boats, and showed no trend in either boat type. In the Massachusetts tournaments, blue shark CPUE showed different trends north and south of Cape Cod. Mako shark CPUE declined in the 1990s in Massachusetts tournaments, then increased again in 2002.*

RÉSUMÉ

*Des modèles linéaires généralisés ont été utilisés pour dériver les indices d'abondance du requin peau bleue (*Prionace glauca*) et du requin taupe bleue (*Isurus oxyrinchus*) sur la base de deux éléments de la pêcherie récréative nord-américaine dans l'Atlantique: (1) les pêcheurs récréatifs à la ligne opérant à bord de bateaux privés ou en location couverts par l'enquête statistique sur la pêcherie récréative du National Marine Fisheries Service (MRFSS, 1981-2002), et (2) les championnats de requins du Massachussetts (1991-2002). A partir des données du MRFSS, la CPUE du requin peau bleue a dégagé diverses tendances en fonction des différents modes de pêche, régions et saisons, ce qui implique que la CPUE ne suit pas l'abondance du requin peau bleue. La CPUE du requin taupe bleue a varié en fonction du bateau, privé ou en location, et n'a dégagé aucune tendance en matière de type de bateau. Dans les tournois du Massachussets, la CPUE du requin peau bleue a montré des tendances différentes au Nord et au Sud de Cap Cod. La CPUE du requin taupe bleue a diminué dans les années 1990 dans les tournois du Massachussets, puis a amorcé une reprise en 2002.*

RESUMEN

Se utilizaron modelos lineales generalizados para obtener índices de abundancia para la tintorera (Prionace glauca) *y el marrajo dientuso* (Isurus oxyrinchus), *basándose en los componentes de la pesquería de recreo atlántica estadounidense: (1) los pescadores con caña de buques de recreo privados y fletados cubiertos por la National Marine Fisheries Service Marine Recreational Fishery Statistics Survey (Encuesta sobre Estadísticas de las Pesquerías de Recreo del Servicio Nacional de Pesquerías Marinas, MRFSS, 1981-2002), y (2) los torneos de pesca de tiburones de Massachussets (1991-2002). En los datos del MRFSS, la CPUE de tintorera exhibía tendencias diferentes en las diversas regiones, temporadas y modas de pesca, lo que implica que la CPUE no sigue la abundancia de tintorera. La CPUE de marrajo dientuso difería en la moda en los buques privados y fletados, y no mostraba ninguna tendencia en ambos tipos de buque. En los torneos de Massachussets, la CPUE de tintorera mostraba tendencias diferentes en el Norte y el Sur de Cabo Cod. La CPUE de marrajo dientuso descendió en los noventa en los torneos de Massachussets y, posteriormente, volvió a incrementarse en 2002.*

KEYWORDS

Catch/effort, angling, game fishing, Isurus oxyrinchus, Prionace glauca, recreational fishing, shark tournaments

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1. Introduction

The blue shark, *Prionace glauca*, and the shortfin mako shark, *Isurus oxyrinchus*, are subjected to extensive 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.

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 2002). Total catch and effort data are also collected at shark tournaments by the Massachusetts Division of Marine Fisheries. We evaluate the data from these two sources to determine whether it is possible to derive unbiased indices of abundance for blue and shortfin mako sharks.

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 are removed, the remaining year effect was assumed to be proportional to abundance (Babcock *et al.* 2000, 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 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 cell of the design 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 effect for the binomial model and the year effect for the lognormal model. For mako sharks, only presence or absence in an angler-trip was standardized using a binomial GLM to derive an index of abundance because there were few trips reporting more than one shark caught. 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 and mako sharks. The explanatory variables considered were year (1981-2002), 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 blue 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. 2002.

For the tournament data for both blue and mako sharks, CPUE was measured as total catch divided by total boat hours for each day of each tournament, due to the lack of information on the number of anglers fishing in each boat (Browder and Prince 1988). 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 (1991-2002), region (Massachusetts: south of Cape Cod versus north of Cape Cod), and event (i.e. tournament) nested within region, so that the GLM model was:

$$U_{i,j,k,l} + 0.001 = \beta_0 + \beta_{yr,i} + \beta_{reg,j} + \beta_{ev,k} + \beta_{yr,i,reg,j} + \varepsilon_{i,j,k,l}$$

where $U_{i,j,k,l}$ is the CPUE in year *i*, region *j,* event *k,* and day *l,* with event being nested within region. β_0 is an intercept term, while $\beta_{yr,i,}$, $\beta_{reg,j}$, and $\beta_{ev,kl}$ are the parameters associated with the main effects of year *i*, region j, and event k. $\beta_{yr,i,reg,j}$ is the interaction effect between year *i* and region *j;* $\varepsilon_{i,j,k,l,}$ is an error term. 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 1981 and 2002, the MRFS intercept survey recorded 2500 blue sharks and 472 mako sharks in the strata defined for this analysis (**Table 1**). For blue shark catch rates from the 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 plot of the residuals also demonstrated a lack of fit (**Figure 1**, **Figure 2**).

For mako shark presence/absence from the MRFSS data (**Table 2c**), year, wave, mode, and region were significant, as well as the year × mode, wave × region and mode × region interactions. Since mode was the only variable with a significant interaction with year, the trend may be different in the two modes, but is the same in each region and wave (**Figure 3**). For both fishing modes, the index was highly variable and showed no trend. The q/q normal plot also showed a lack of fit (**Figure 4**).

Massachusetts tournaments between 1991 and 2002 recorded 12183 blue sharks and 307 mako sharks (**Table 3**). In the GLM of blue shark catch rates from Massachusetts tournament data, year, region, and the year × region interaction were significant (**Table 4a**). There were not enough data points to include both the year × region interaction and tournament events in the model simultaneously. Event was not significant if region was already included in the model. The significant interaction between region and year implies that there were different trends over time in the two regions (**Figure 5**). The linear increase in blue shark CPUE over the time series is 4% per year, and is significant (p=0.039 if year is the first variable in the model). The residual and q/q normal plots show a good fit of the model to the data (**Figure 6**).

In the GLM for mako shark CPUE from the tournament data, year and region are significant, but the year × region interaction is not significant (**Table 4b**). Tournament event was significant (p=0.018) even when year and region were already included in the model. The CPUE year effect appears to decline until 2002 when it increased again (**Figure 7**). The linear change in year effect was not significant, even when year was the first variable entered into the model. The q/q normal plot shows some lack of normality in the residuals (**Figure 8**).

4. Discussion

Assessments of the status of pelagic sharks in the North Atlantic have been largely limited to the analysis of fishery-dependent CPUE data. Simpfendorfer et al. (2002) reported an 80% decline in standardized catch rates of male blue sharks from a fishery-independent longline survey in the western North Atlantic, but the catch data were restricted to the period of 1977 to 1994. 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 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 mako sharks, each region and time of year has a similar trend, so that it is more likely that the year effect actually reflects changes in abundance over time. The index is quite variable, but does not appear to show a trend over time in either fishing mode. The fact that the MRFSS survey is not designed for rare-event species including pelagic sharks further complicates and argues against the utility of these data for assessing the status of blue and mako sharks.

The Massachusetts tournament catch data for blue sharks showed different trends in the two regions. If both trends are tracking abundance, then they may be indicative of a regional shift in blue shark distribution. In their analysis of catch data from a western North Atlantic fishery-independent catch survey, Simpfendorfer et al. (2002) observed the highest blue shark CPUE's in a core area south of Cape Cod, which coincides with the southern region of the Massachusetts tournament effort. These workers reported a decline in male blue shark abundance in this region from 1977 to 1994. Subsequent to this period, Massachusetts tournament data demonstrated an increase and decline in catch rates in this region from 1996 to 2002.

There were no significant interactions with year in the 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. It would be worth continuing to monitor this series to determine whether the increase in CPUE in 2002 is an outlier, or indicative of an increase in mako shark abundance off Massachusetts.

5. Acknowledgements

E. Babcock's work was funded by the Constantine S. Niarchos fellowship in Marine Conservation, the David and Lucille Packard Foundation, the Pew Charitable Trusts and the Wildlife Conservation Society. The Massachusetts Sport Fishing Tournament Monitoring Program is funded, in part, by the Sportfish Restoration Act. This is Massachusetts Division of Marine Fisheries Contribution No. 12.

References

BABCOCK, E.A., E.K. Pikitch and M.K. McAllister. 1999. Catch rates of blue sharks (*Prionace glauca*) in the U. S. Atlantic recreational fishery. Col. Vol. Sci. Pap. ICCAT 51: 1850:1851.

BROWDER, J.A. and E.D. Prince. 1988. Exploration of the use of tournament and dock catch and effort data to obtain indices of annual relative abundance for blue and white marlin 1972 through 1986. Col. Vol. Sci. Pap. ICCAT 28: 287-299.

MARINE RECREATIONAL FISHERIES STATISTICS SURVEY. 2002. National Marine Fisheries Service, Office of Science & Technology, Fisheries Statistics & Economics Division.

LO, N.C., L.D. Jacobson and J.L. Squire. Indices of relative abundance from fish spotter data based on Delta-lognormal models. Canadian Journal of Fisheries and Aquatic Sciences 49: 2525-2525.

ORTIZ, M., J. Cramer, A. Bertolino, and G. Scott. 2000. Standardized catch rates by sex and age for swordfish (*Xiphias gladius*) from the U.S. longline fleet 1981-1998. Col. Vol. Sci. Pap. ICCAT 51**:** 1523 – 1551.

SIMPFENDORFER, C.A., R.E. Hueter, U. Bergman, and S.M.H. Connett. 2002. Results of a fishery-independent survey for pelagic sharks in the western North Atlantic, 1977-1994. Fisheries Research 55: 175-192.

VENABLES, W.N. and B.D. Ripley. 1997. Modern Applied Statistics with S-plus. 2nd Edition. Springer-Verlag, New York.

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

	Blue shark		*Mako shark*	
	Charterboat	*Private boat*	*Charterboat*	*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	60	10	7
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	39	232	12	22
1996	154	161	6	12
1997	119	91	7	6
1998	150	53	16	9
1999	31	93	3	12
2000	38	38	5	12
2001	8	52	10	12
2002	11	3	7	9

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			395	4298.21	
year	21	542.11	374	3756.09	<0.001
wave	2	7.86	372	3748.23	0.020
mode	1	175.09	371	3573.14	<0.001
region	2	2382.15	369	1190.99	<0.001
year × wave	42	175.84	327	1015.16	<0.001
year × mode	21	149.61	306	865.55	<0.001
year × region	42	83.26	264	782.29	<0.001
wave × mode	2	39.96	262	742.33	<0.001
wave × region	4	100.21	258	642.12	<0.001
mode × region	2	3.27	256	638.85	0.195
year × wave × mode	42	261.24	214	377.62	<0.001
year × wave × region	84	227.93	130	149.69	<0.001
wave × mode × region	4	17.10	126	132.59	0.002

(b) blue shark CPUE

	Df	*Deviance*	*Resid. Df*	*Resid. Dev*	*F Value*	*Pr(F)*
NULL			1248	1772.05		
year	21	104.32	1227	1667.73	3.89	<0.001
wave	2	39.91	1225	1627.82	15.62	<0.001
mode	1	0.36	1224	1627.46	0.28	0.596
region	1	69.53	1223	1557.92	54.43	<0.001
year × wave	37	214.10	1186	1343.83	4.53	<0.001
year × mode	19	87.22	1167	1256.61	3.59	<0.001
year × region	18	70.89	1149	1185.72	3.08	<0.001
wave × region	2	17.94	1147	1167.78	7.02	0.001
mode × region	1	0.69	1146	1167.09	0.54	0.464
year × wave × region	24	50.16	1122	1116.93	1.64	0.028
year × mode × region	13	33.45	1109	1083.48	2.01	0.017

(c) mako sharks presence/absence

	Df	*Deviance*	*Resid. Df*	*Resid. Dev*	*Pr(Chi)*
NULL			395	1193.33	
year	21	82.07	374	1111.27	<0.001
wave	2	21.86	372	1089.41	<0.001
mode	1	51.03	371	1038.38	<0.001
region	2	569.78	369	468.60	<0.001
year × mode	21	48.74	348	419.86	0.001
wave × region	4	24.85	344	395.01	<0.001
mode × region	2	23.68	342	371.32	<0.001

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

	Blue shark		*Mako shark*	
	South	North	South	North
1991	291	21	35	0
1992	288	NA	32	NA
1993	456	119	45	0
1994	632	NA	47	NA
1995	572	345	29	1
1996	876	142	5	0
1997	679	85	3	2
1998	1578	258	9	0
1999	1781	177	22	0
2000	1561	111	7	0
2001	1197	NA	15	NA
2002	1014	NA	55	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			63	36.63		
year	11	13.93	52	22.70	7.84	<0.001
region	1	5.33	51	17.38	32.99	<0.001
year × region	7	7.60	44	9.78	6.72	<0.001

(b) mako sharks

	Df	*Deviance*	*Resid. Df*	*Resid. Dev*	*F Value*	*Pr(F)*
NULL			63	2.27		
region	1	0.68	62	1.59	38.08	<0.001
year	11	0.76	51	0.84	3.88	0.001
region × year	7	0.06	44	0.77	0.52	0.818

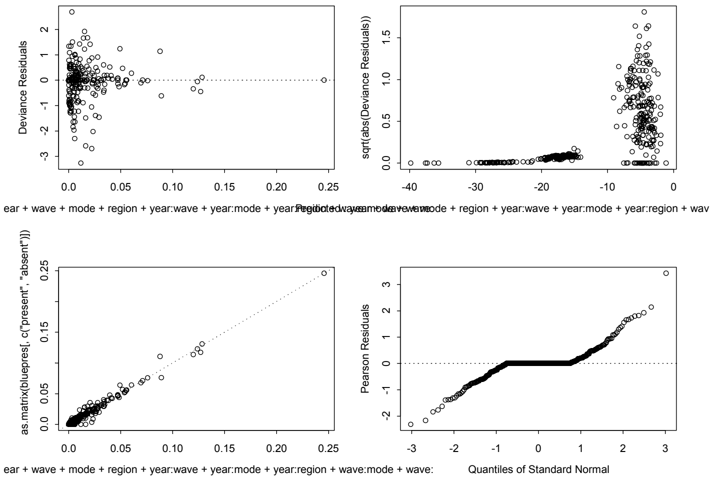

Figure 1. Diagnostics for the AIC best model for the blue shark MRFSS data presence/absence analysis.

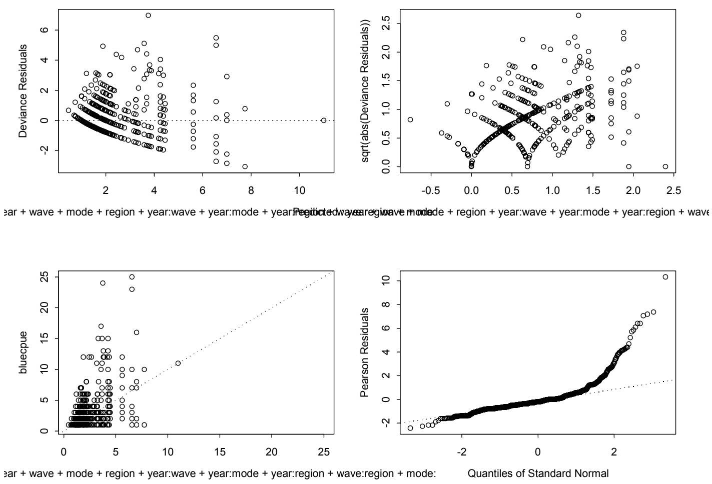

Figure 2. Diagnostics for the AIC best model for the blue shark MRFSS data CPUE analysis.

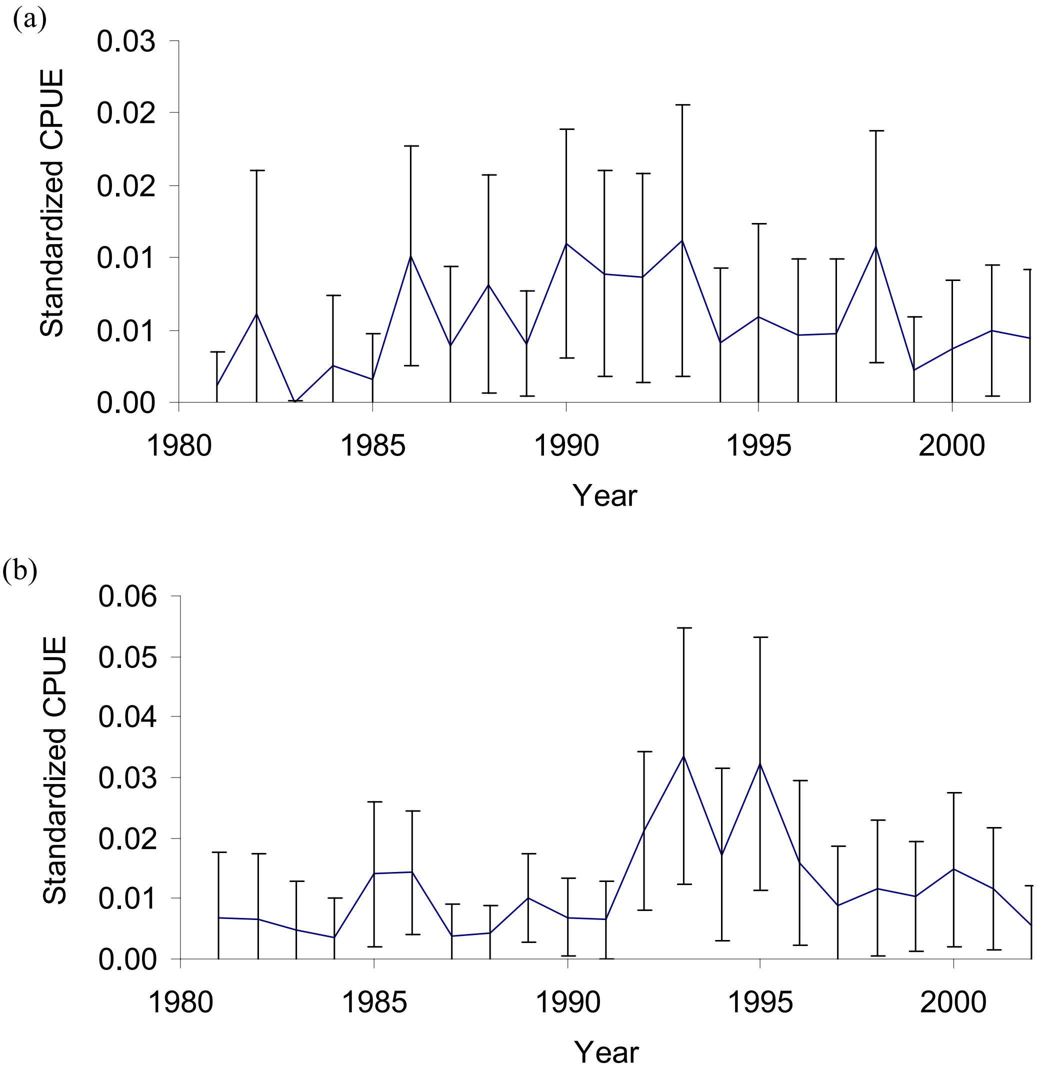

Figure 3. GLM standardized presence/absence (±2 SE) of mako sharks from MRFSS data, for the AIC best fit model which includes and interaction between year and fishing mode (a) charterboat, (b) private boat.

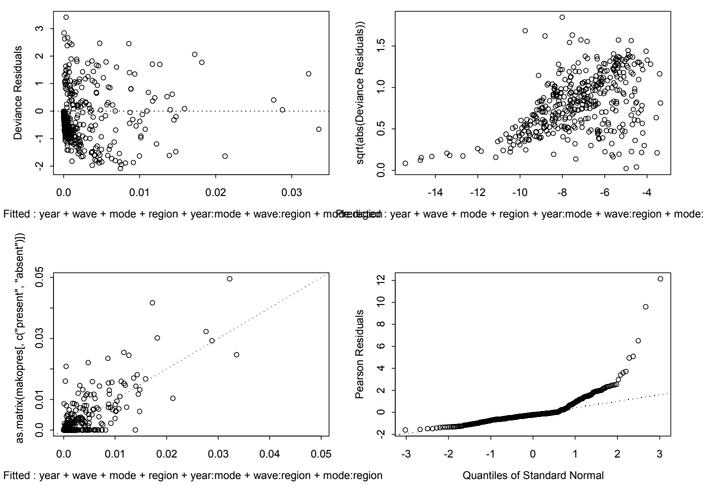

Figure 4. Diagnostics for mako presence/absence in the MRFSS data.

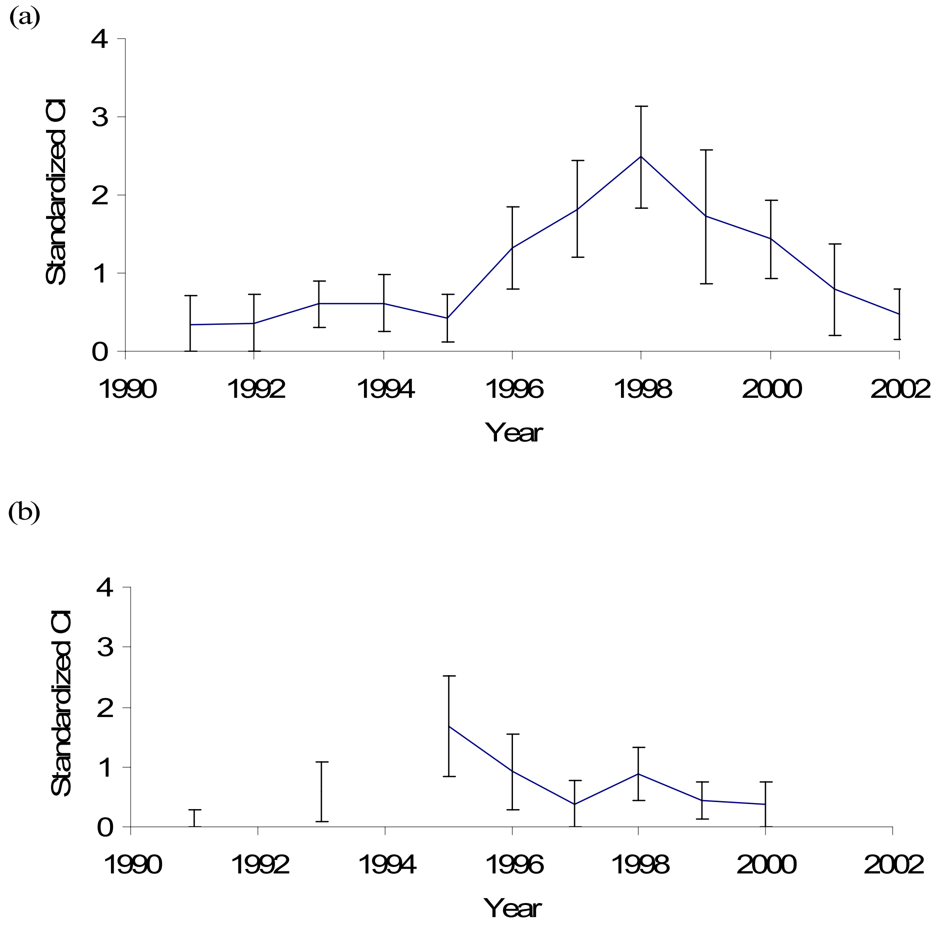

Figure 5. GLM standardized CPUE (±2 SE) of blue sharks from Massachusetts tournament data, from a model including year, region and year × region. (a) South of Cape Cod, (b) North of Cape Cod.

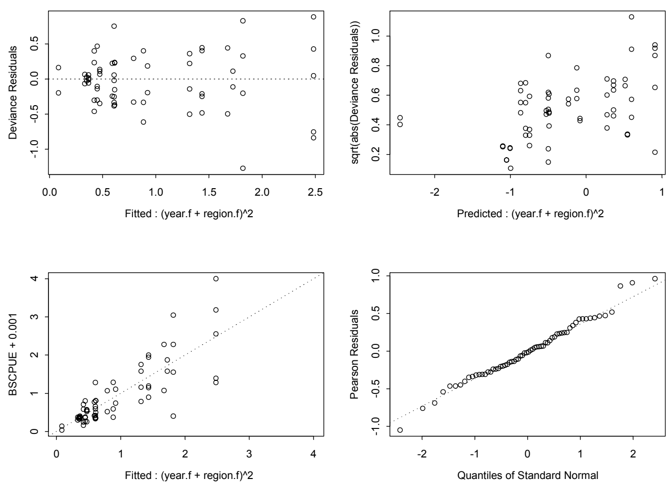

Figure 6. Diagnostics for blue sharks in tournaments.

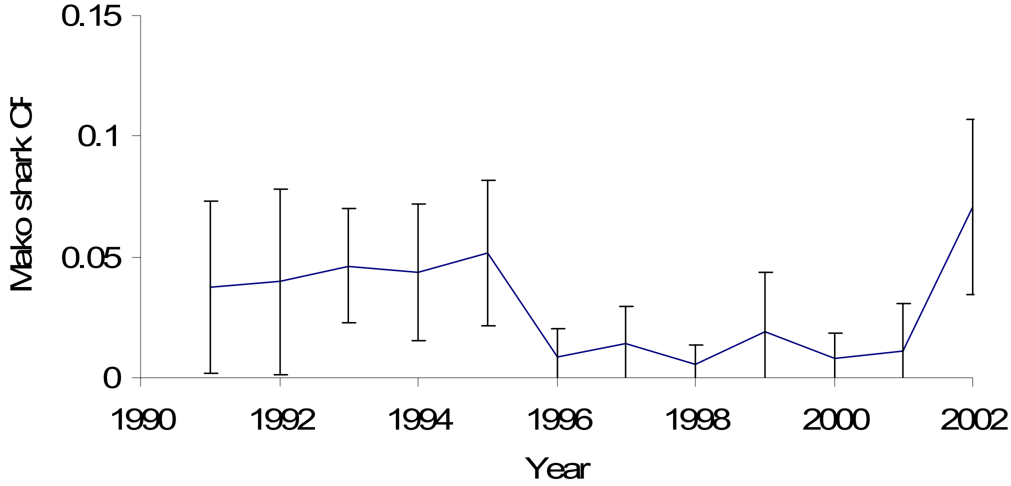

Figure 7. GLM standardized CPUE (±2 SE) of mako sharks from Massachusetts tournament data, for a model including year and region as explanatory variables (South of Cape Cod).

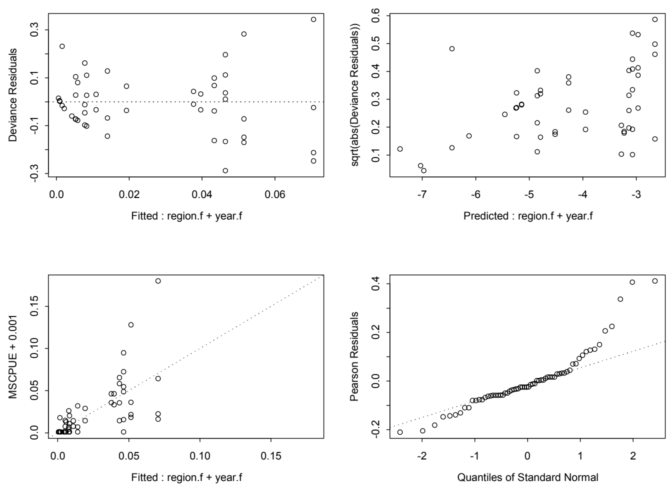

Figure 8. Diagnostics for mako sharks in tournaments.