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UPDATED INDEX OF ABUNDANCE FOR SHORTFIN MAKO SHARKS FROM THE U.S. MARINE RECREATIONAL FISHERIES STATISTICS SURVEY

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SUMMARY

The standardized index of abundance for shortfin mako sharks from the National Marine Fisheries Service Marine Recreational Fishery Statistics Survey (MRFSS) was updated with data from 1981 through 2010. The catch per unit effort (CPUE) data were standardized using a general linear mixed model (GLMM) with year, season, fishing mode (private versus charter boat) and region included as explanatory variables. Because of the large number of zero observations, the CPUE was standardized using a delta-lognormal approach. Both the fraction of trips with a positive observation, and the delta-lognormal abundance index were highly variable, and showed a high in the mid 1990s, followed by a decline, then a stable trend over the last 10 years.

RÉSUMÉ

L'indice d'abondance standardisé du requin-taupe bleu élaboré sur la base de l'enquête statistique des pêcheries récréatives marines (MFRSS) du National Marine Fisheries Service des États-Unis a été mis à jour avec des données couvrant la période 1981-2010. Les données de capture par unité d'effort (CPUE) ont été standardisées en utilisant un modèle mixte linéaire généralisé (GLMM) dont les variables explicatives étaient l'année, la saison, le mode de pêche (navire privé par opposition à navire affrété) et la région. En raison de la quantité élevée d'observations nulles, la CPUE a été standardisée au moyen d'une approche delta-lognormale. La proportion des sorties présentant une observation positive tout comme l'indice d'abondance delta-lognormal étaient extrêmement variables et présentaient un pic au milieu des années 1990, suivi d'une baisse et d'une tendance stable au cours des dix dernières années.

RESUMEN

Se actualizó el índice de abundancia estandarizado para el marrajo dientuso del National Marine Fisheries Service Marine Recreational Fishery Statistics Survey (MRFSS) con datos desde 1981 hasta 2010. Se estandarizaron los datos de captura por unidad de esfuerzo utilizando un modelo lineal mixto generalizado (GLMM) con año, temporada, modo de pesca (privado frente a fletado) y región como variables explicativas. Debido al gran número de observaciones cero, la CPUE se estandarizó utilizando un enfoque delta-lognormal. Tanto la proporción de mareas con una observación positiva como el índice de abundancia delta-lognormal fueron muy variables y mostraron un punto máximo a mediados de los 90, seguido de un descenso y posteriormente una tendencia estable durante los últimos diez años.

KEYWORDS

Catch/effort, mathematical models, population dynamics, abundance trends

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1. Introduction

The shortfin mako shark, *Isurus oxyrinchus* is caught in small numbers by recreational fishermen on the East Coast of the United States. Mako sharks are occasionally observed in dock-side angler interviews conducted by the National Marine Fisheries Service (NMFS) Marine Recreational Fishery Statistics Survey (MRFSS 2012). Skomal *et al.* (2005) and Babcock and Skomal (2008) developed a standardized index of abundance for mako sharks from the MRFSS data set. This paper updates the analysis in Babcock and Skomal (2008).

2. Methods

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 shortfin mako sharks. Mako shark catch rates (per angler-trip) were standardized using a delta-lognormal generalized linear mixed model (GLMM, Lo *et al.* 1992, Ortiz and Arocha 2004, Babcock and Skomal 2008), in which the number of positive trips in each stratum is assumed to be binomial, and the CPUE in trips with a positive catch is assumed to be lognormally distributed. The delta-lognormal index of abundance of mako sharks is the product of the year effects of the binomial and lognormal models, with the standard errors calculated by the method of Lo *et al.* (1992).

The MRFSS survey is stratified by year, fishing mode, sampling wave (two-month period), and sub-region. Only strata for which there were substantial catches of shortfin mako sharks were included in the analysis. The explanatory variables considered were year (1981-2010), 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 South Atlantic: North Carolina through Florida), and all second order interactions between them. The best models were chosen using the Akaike information criterion (AIC) and the Bayesian information criterion (BIC). Variables could also be excluded if they explained less than 5% of the deviance explained by the full model (Ortiz and Arocha 2004). In the case that there were significant interactions between factors, the interaction was treated as a random effect; all main effects were treated as fixed. All analyses were conducted in R (R Core Development Team 2012, Bates 2012, Mazerolle 2012).

This analysis differs from that in Babcock and Skomal (2008) in the following. First, Babcock and Skomal (2008) only analyzed binomial presence/absence, not the full delta-lognormal model, due to the small number of trips that caught more than one shortfin mako shark. The current paper provides both the presence/absence index and the delta-lognormal index. Third, the analysis of Babcock and Skomal (2008) did not include any mixed effects. In the current analysis, there were significant interactions between year and other factors, so the mixed model approach was necessary.

3. Results and Discussion

A total of 711 shortfin mako shark have been reported between 1981 and 2010 in the MRFSS intercept survey (**Table 1**). The vast majority of the shortfin mako sharks observed were caught offshore, in the charter or private boat modes, in the North, Mid or South Atlantic sub-regions, between May and October. These strata include 84% of the shortfin mako sharks although they include only 9.8% of the sampled trips. The GLMM analysis was applied to these strata only.

For the 479 trips that caught at least one mako shark, the AIC and BIC best model of log-CPUE included year, mode, region, wave, and the interaction between mode and region (**Table 2a, 2b**). The positive log-CPUEs were approximately normally distributed (**Figure 1, Figure 2**), implying that the lognormal model was appropriate. However, the very small number of positive trips implied that many combinations of gear, mode, wave and year were not sampled.

There were 252,686 trips in the included strata, of which about 0.2% of the trips caught at least one mako shark. In the presence/absence GLMM (**Table 2c, 2d**) both the AIC and the BIC preferred the model that included all the main effects plus year × mode and region × wave. The diagnostics of this model indicate relatively good model fit (**Figure 3**).

The presence/absence index and the delta-lognormal index give very similar results for the trend in abundance over time (**Table 3, Figure 4**). Both are highly variable, and show a decline in the late 1990s, followed by a stable trend in the last 10 years.

The MRFS angler intercept program is designed to sample the entire U.S. recreational fishery, rather than focusing on offshore anglers who catch sharks. Although mako sharks are seen in this survey, they are seen in very small numbers. There has also been a tendency in the U.S. recreational fishery toward increased catch-and-release of sharks (**Babcock 2010**), including shortfin mako sharks (**Figure 4**). Thus, an increasing fraction of the sharks that are caught are released without ever being seen by dockside observers, which may lead to more sharks being misidentified, or not identified to species. For all these reasons, the MRFSS index of abundance for shortfin mako sharks should be treated with caution.

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Table 1. Number of mako sharks observed in the MRFSS angler interview survey.

(a) by area

Coastal	Inland	Offshore (>4.8km)
34	12	665

(b) by fishing mode

Charter/party	Private/Rental	Shore-based
358	348	5

(c) by subregion

North Atlantic	Mid-Atlantic	South Atlantic	Gulf of Mexico	Caribbean
82	496	104	26	3

(d) by wave

Jan-Feb	Mar-Apr	May-Jun	Jul-Aug	Sep-Oct	Nov-Dec
7	41	249	294	100	20

(e) by year

1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
7	9	5	8	24	35	41	21	32	34
1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
25	69	41	21	37	19	17	31	18	20
2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
28	16	14	25	24	25	19	12	17	17

Table 2. Analysis of deviance tables.

(a) Fixed effects model for log of CPUE if present, AIC best model with fixed effects

	Df	*Deviance*	*Resid Df*	*Resid Dev*	*F*	*Pr(>F)*	*% Deviance*
NULL			478	292.20			
year	29	28.35	449	263.85	1.98	0.0022	37.02
mode	1	9.68	448	254.17	19.57	0.0000	12.64
region	2	18.25	446	235.93	18.45	0.0000	23.83
wave	2	7.72	444	228.21	7.80	0.0005	10.08
mode×region	2	7.03	442	221.18	7.11	0.0009	9.18
mode×wave	2	1.15	440	220.03	1.16	0.3142	1.50
region×wave	4	4.41	436	215.62	2.23	0.0652	5.75

(b) Mixed effects models for log of CPUE if present

Model	*AIC*	*BIC*
year+mode+region+wave+mode×region	1131.11	1285.46
year+mode+region+wave+mode×wave	1137.77	1292.13
year+mode+region+wave+region×wave	1135.79	1290.15
year+mode+region+wave+mode×region+mode×wave	1133.03	1291.55
year+mode+region+wave+year×region+region×wave	1132.39	1290.92
year+mode+region+wave+mode×wave+region×wave	1137.41	1295.93
year+mode+region+wave+mode×region+mode×wave+region×wave	1133.89	1296.58

(c) Fixed effects model for presence/absence, AIC best model

	Df	*Deviance*	*Resid Df*	*Resid dev*	*Pr(>Chi)*	*% Dev*
NULL			539	1449.92		
year	29	110.47	510	1339.45	0.0000	11.37
mode	1	22.51	509	1316.94	0.0000	2.32
region	2	663.35	507	653.59	0.0000	68.28
wave	2	24.4	505	629.19	0.0000	2.51
year×mode	29	58.82	476	570.37	0.0009	6.05
mode×region	2	44.05	474	526.31	0.0000	4.53
region×wave	4	47.92	470	478.39	0.0000	4.93

(d) Mixed effects model for presence/absence

Model	*AIC*	*BIC*
year+mode+region+wave+year×mode	701.19	855.68
year+mode+region+wave+mode×region	681.08	835.57
year+mode+region+wave+region×wave	683.18	837.68
year+mode+region+wave+year×mode+mode×region	683.04	841.82
year+mode+region+wave+year×mode+region×wave	658.18	816.96
year+mode+region+wave+mode×region+region×wave	685.18	843.97
year+mode+region+wave+year×mode+mode×region+region×wave	660.15	823.23

Table 3. Indexes of abundance, showing the mean of the raw data, the standardized index, and the CV of the standardized index, for both the delta-lognormal index, and the index derived by standardizing the fraction of trips with a positive observation of mako sharks.

	Lognormal Index			*Fraction positive*		
Year	Data	Index	CV	Data	Index	CV
1981	0.17	0.06	0.95	0.00148	0.00039	0.95
1982	0.25	0.13	1.25	0.00245	0.00085	1.25
1983	0.09	0.04	1.37	0.00077	0.00030	1.37
1984	0.16	0.06	1.31	0.00111	0.00039	1.31
1985	0.57	0.17	1.18	0.00402	0.00095	1.18
1986	0.95	0.34	1.15	0.00562	0.00162	1.15
1987	0.77	0.24	1.22	0.00114	0.00049	1.22
1988	0.30	0.17	1.18	0.00160	0.00069	1.18
1989	0.36	0.19	1.15	0.00248	0.00092	1.15
1990	0.46	0.25	1.15	0.00291	0.00117	1.15
1991	0.24	0.16	1.16	0.00217	0.00101	1.16
1992	0.73	0.44	1.15	0.00358	0.00199	1.15
1993	0.71	0.55	1.15	0.00393	0.00267	1.15
1994	0.27	0.21	1.17	0.00181	0.00135	1.17
1995	0.46	0.40	1.15	0.00289	0.00219	1.15
1996	0.25	0.22	1.17	0.00184	0.00133	1.17
1997	0.25	0.20	1.18	0.00149	0.00093	1.18
1998	0.36	0.34	1.15	0.00258	0.00174	1.15
1999	0.23	0.18	1.18	0.00158	0.00085	1.18
2000	0.31	0.36	1.17	0.00138	0.00112	1.17
2001	0.21	0.19	1.16	0.00173	0.00108	1.16
2002	0.19	0.12	1.18	0.00126	0.00072	1.18
2003	0.11	0.07	1.21	0.00074	0.00040	1.21
2004	0.23	0.14	1.17	0.00152	0.00085	1.17
2005	0.20	0.13	1.18	0.00118	0.00063	1.18
2006	0.25	0.19	1.17	0.00149	0.00098	1.17
2007	0.28	0.20	1.18	0.00166	0.00087	1.18
2008	0.05	0.03	1.23	0.00074	0.00041	1.23
2009	0.19	0.14	1.19	0.00136	0.00084	1.19
2010	0.26	0.23	1.19	0.00129	0.00086	1.19

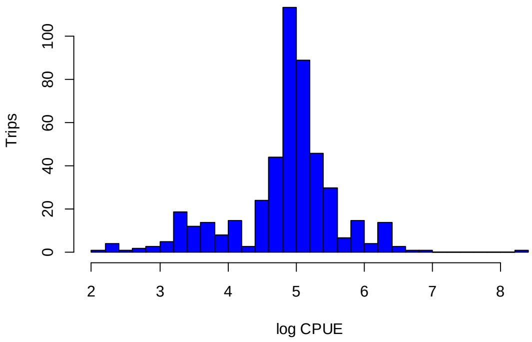

Figure 1. Histogram of log CPUE for trips that reported at least one mako shark.

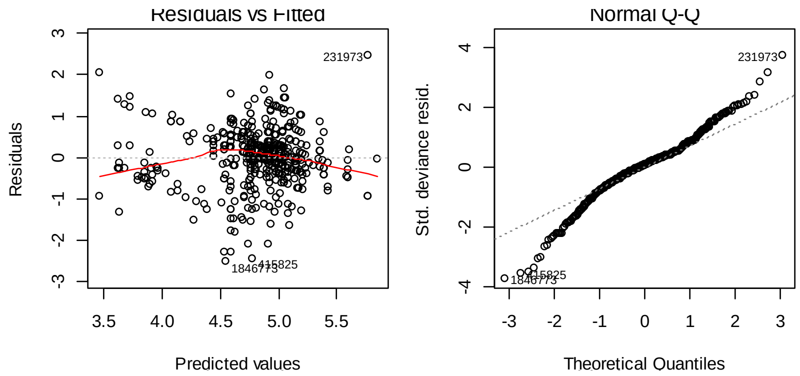

Figure 2. Diagnostics for the model of log CPUE if present.

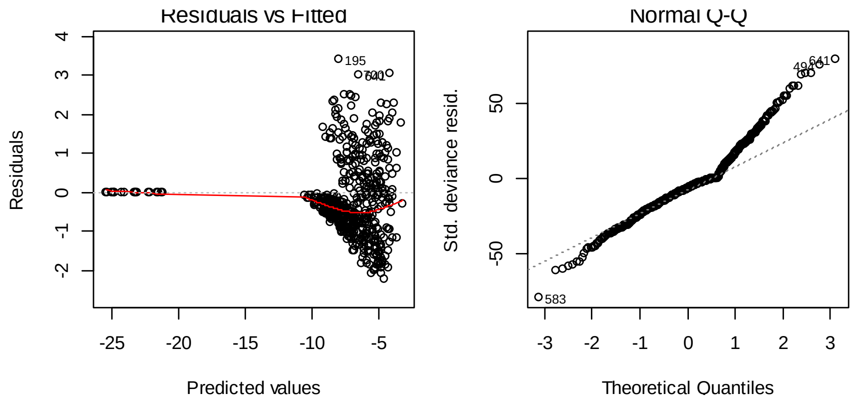

Figure 3. Diagnostics for the model of presence/absence.

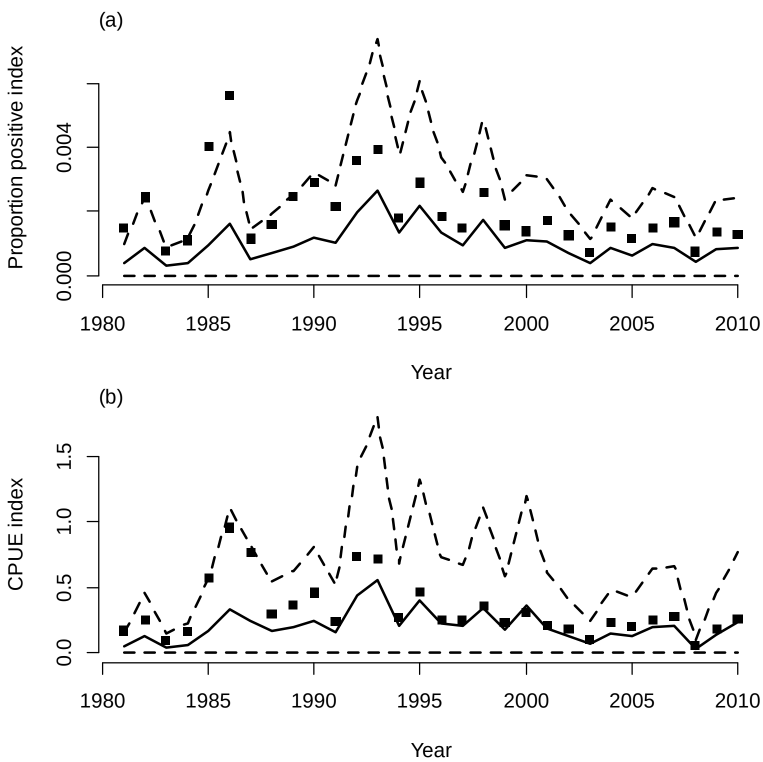

Figure 4. Indexes of abundance, (a) proportion of trips that observe mako sharks, (b) delta-lognormal CPUE index.

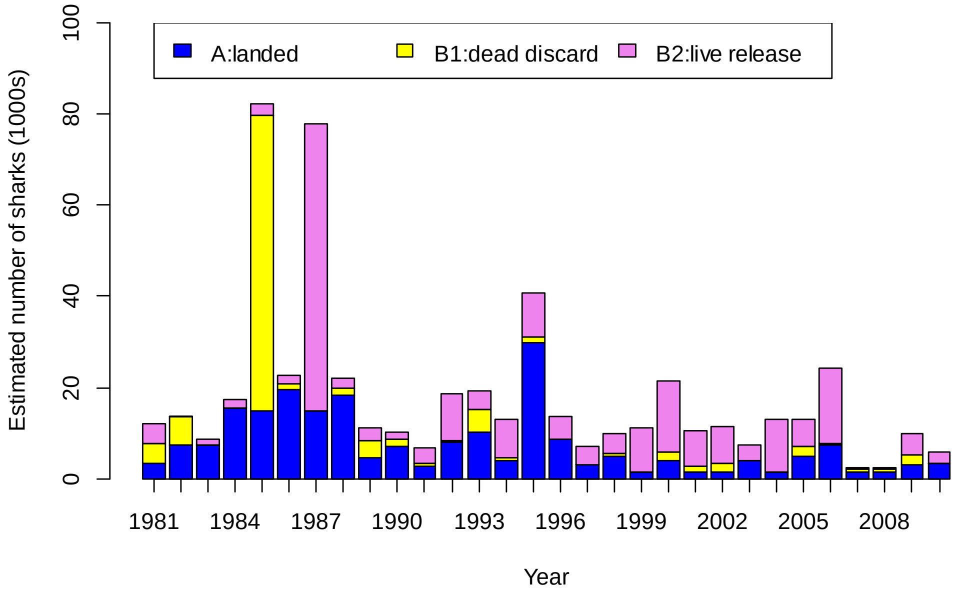

Figure 5. Total number of shortfin mako sharks landed, discarded dead or released alive in the U.S. recreational fishery in the Atlantic and Gulf of Mexico, as estimated by the MRFSS, using intercept surveys expanded with estimates of total effort.