ANALYSIS OF ANNUAL LENGTH-FREQUENCY CHANGES OF BILLFISH IN THE WESTERN ATLANTIC OCEAN 1987-1993

SCRS/1994/146

Col.Vol.Sci.Pap. ICCAT, 44 (3) : 1-5 (1995)

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SUMMARY

Length-frequency data collected from shore-based and at-sea sampling activities of the ICCAT Enhanced Research Program for Billfish in the western Atlantic Ocean are presented. Size data were analyzed for annual changes for blue marlin, while marlin, and longbill spearfish. All data sets were converted to lower-jaw fork-length based on existing regression equations. General liner models (GLMs), multiple comparison tests, and non-parametric techniques were used to determine statistical significance in size changes. Annual mean sizes are relatively consistent for most species examined, though variances are not constant due to unbalanced samples between years and species. Landings data suggest that blue marlin length-frequencies may have increased during the time series. Some recommendations are presented for future investigation of changes in size frequency.

RESUME

Des données de fréquence-taille collectées lors d'activités d'échantillonnage à terre et en mer, dans le cadre du Programme ICCAT de Recherche Intensive sur les istiophoridés dans l'Atlantique Ouest, sont présentées dans ce document. Les données de taille ont été analysées pour connaître les changements annuels du makaire bleu, du makaire blanc, du voilier et du "spearfish". Tous les jeux de données ont été convertis en longueur maxillaire-fourche avec les équations de régression existantes. On a utilisé des modèles généraux linéaires (GLM), divers tests comparatifs et des techniques non-paramétriques pour déterminer les conséquences statistiques des changements de taille. Les tailles moyennes annuelles sont relativement cohérentes pour la plupart des espèces examinées, même si les variations sont inconstantes du fait que les échantillonnages ne sont pas équilibrés entre les années et les espèces. Les données de débarquements suggèrent que les fréquences-tailles du makaire bleu ont pu augmenter au cours de la série temporelle. Quelques recommandations sont présentées pour les futures recherches sur les changements de fréquences de taille.

RESUMEN

Se presentan los datos de frecuencias de talla recolectados en actividades de muestreo en tierra y en la mar del Programa ICCAT de Investigación Intensiva sobre Marlines en el Océano Atlántico oeste. Se analizaron los datos de talla para conocer los cambios anuales de aguja azul, aguja blanca, pez vela y *Tetrapturus pfluegeri* + *T. belone*. Todos los conjuntos de datos se convirtieron a mandíbula inferior longitud a la horquilla basándose en ecuaciones de regresión existentes. Se utilizaron modelos lineales generalizados (GLM), múltiples ensayos comparativos y técnicas no paramétricas para determinar la importancia estadística en los cambios de talla. Los promedios anuales de tallas son relativamente coherentes para la mayor parte de las especies e xaminadas, aunque las varianzas no son constantes debido a muestras no equilibradas entre años y especies. Los datos de desembarques sugieren que las frecuencias de talla de la alguja azul pueden haberse incrementado durante la serie temporal. Se presentan algunas recomendaciones para investigación futura de los cambios en las frecuencias de talla.

INTRODUCTION

The Enhanced Research Program for Billfish by the International Commission for the Conservation of Atlantic Tunas (ICCAT) was first approved at the 1986 SCRS meeting following concerns about the status of Atlantic billfish stocks expressed by ICCAT since the late 1970's (Prince and Brown 1994). At the time, the billfish data base was determined to be less then adequate for modern stock assessment techniques (Prince and Brown 1991). Research activities were approved by ICCAT to begin during the 1987 season in order to strengthen the billfish data base. Providing more detailed catch, effort, and size-frequency data were among the original objectives of the program as described by Prince and Brown (1994). This paper examines size frequency data collected by the ICCAT Enhanced Research Program for Billfish and compares changes in size using annual at-sea and shore-based landings data collected in the Western Atlantic Ocean for blue marlin (*Makaira nigricans*), white marlin (*Tetrapturus albidus*), sailfish (*Istiophorus platypterus*), and longbill spearfish (*Tetrapturus pfluegeri*).

DATA PREPARATION

Data were collected from two broad sampling program sources: shore-based, a dock side survey of recreational and commercial fishing activities; and at-sea, data collected by observers on commercial longline boats targeting tuna and swordfish. A detailed description of sampling techniques used to acquire all data analyzed here is presented in Carter (1994). Shore-based data on blue marlin, white marlin, and sailfish were collected from 1987 through 1993 (Table 1) from Barbados, Dominican Republic, Grenada, Jamaica, Las Palmas, St. Maarten, Trinidad, and Venezuela. Since there were relatively few records collected in 1987, this year was dropped from the analysis. The majority of blue marlin data is from Venezuela (60%), followed by Jamaica (10.9%) and Grenada (9.4%). Almost all the white marlin data came from Venezuela (72.5%) and St. Maarten (22.5%). Venezuelan sampling also dominates the sailfish database (71.4%), followed by Grenada (19.5%).

The commercial fleet fishing from Cumana, Venezuela, was the sole source for at-sea data collection. At-sea data includes blue marlin, white marlin, and sailfish landings from 1987 through 1993, and spearfish data collected from 1990 through 1993 (Table 2).

Annual size data were recorded in various measurements: lower-jaw fork-length (LJFL), pectoral fork-length (PFL), pectoral second dorsal length (PDL), pectoral anus length (PAL), and cleithrum keel length (CK). Since lower-jaw fork-length (LJFL) measurements in centimeters were preferred, length measurements reported in units other than LJFL were converted using regression equations presented by Prager et al. (1994). Sex data was unavailable from the shore-based data set and was available only for a limited number of the at-sea samplings. Therefore, sex data was not included in the analysis. Both sets of data had unequal numbers of observations throughout the time series.

METHODS

Annual shore-based and at-sea landings data were analyzed for each species both separately and pooled. A Bartlett's test was performed on each set of LJFL data to test for homogeneity of variance. If homogenous variances were not found, logarithmic transform of LJFL were made for each species and the test for homogeneity of variance was repeated. Each observation was assumed independent with a normally distributed measurement error.

A least-squares general linear model (GLM) (SAS, 1991) was used with year as the classification to provide the analysis of variance for each data set of the shore-based and at-sea data separately, and then combined. The GLM is a robust procedure that relaxes sample balance and homogeneity assumptions in fixed effect models that may not be homoscedastic before or after data transformation (Hampel et al., 1986). After the GLM was constructed, a GT2 multiple comparison test (Hochberg, 1974) was used to compare means that were significantly different between years. The GT2 method is appropriate for testing main effect means when sample sizes are unequal. In addition to the GLM, we analyzed variates using a Kruskal-Wallis non-parametric procedure for comparative purposes, since homogeneity could not be achieved with log-transformation for all cases.

RESULTS

Shore-Based Database

Blue Marlin

The annual mean and range of LJFL measurements (in cm) from shore-based sampled western Atlantic blue marlin from 1988-1993 are illustrated in Figure 1A. In general, the data appear log-normally distributed for most years. Annual means ranged from 183.8 cm LJFL in 1988 to 202.1 cm LJFL in 1993 (Table 1). Although variances were not homogeneous between years for the raw data, homogeneity was achieved after a log transformation of the LJFL measurements. The GLM revealed significant differences in size between years (α=0.05, $P<0.0001$). The Kruskal-Wallis provided similar results. Multiple comparison tests indicated that there was no change in size during years 1988-1990 and 1991-1993, but statistically significant increases in LJFL occurred between the two periods.

White Marlin

The annual mean and range of LJFL measurements (in cm) from shore-based sampled western Atlantic white marlin from 1988-1993 are illustrated in Figure 1B. Annual means ranged from 152.9 cm LJFL in 1989 to 161.5 cm LJFL in 1992 (Table 1). The Bartlett's test revealed a lack homogeneity of variance in the raw data between years, which was not improved by the log transformation. The Kruskal-Wallis chi-square approximation revealed significant differences between years, and the GLM provided similar results. Multiple comparison tests indicate statistically larger mean LJFL measurements sampled during the 1991-1992 season than the 1988-1989 period. There was no difference in length measurements in 1990 or 1993 compared to previous sampling periods.

Sailfish

The annual mean and range of LJFL measurements (in cm) from shore-based sampled western Atlantic sailfish from 1988-1993 are illustrated in Figure 1C. Annual means ranged from 167.4 cm LJFL in 1988 to 169.9 cm LJFL in 1989 (Table 1). This set was the most unbalanced of the shore-based data series in terms of sample size distribution across years. Heterogeneity of variance between years is evident both in visual observation of LJFL distribution (Figure 1C) and the Bartlett's test, even after log transformations. Both the non-parametric and GLM tests indicated statistical differences in mean size for the time series, with mean lengths significantly higher during 1991-1993 compared to 1988-1989.

At-Sea Database

Blue Marlin

The annual mean and range of LJFL measurements (in cm) from at-sea sampled western Atlantic blue marlin from 1987-1993 are illustrated in Figure 2A. Annual means ranged from 177.7 cm LJFL in 1990 to 196.2 cm LJFL in 1987 (Table 2). There is a substantial difference in sample sizes between years. The size of the variance appears to increase with mean LJFL, thus the log transform is particularly appropriate for this data set. Nevertheless, the data transformation did not result in homoscedasticity between years. Both the Kruskal-Wallis and the GLM indicated no significant differences in mean size between years.

White Marlin

The annual mean and range of LJFL measurements (in cm) from at-sea sampled western Atlantic white marlin from 1987-1993 are illustrated in Figure 2B. Annual means ranged from 150.6 cm LJFL in 1990 to 163.4 cm LJFL in 1988 (Table 2). The Bartlett's test revealed that variances were not homogeneous across years for raw or transformed measurements. Both the Kruskal-Wallis and GLM tests were significant (α=0.05, $P<0.0001$), although multiple comparison results were mixed. There appear to be no systematic trends in size, with the 1988-

1989 measurements significantly higher than the 1987, 1990 and 1992. The 1991 and 1993 samples were not significantly different than the 1987-1989 data.

Sailfish

The annual mean and range of LJFL measurements (in cm) from at-sea sampled western Atlantic sailfish from 1987-1993 are given in Figure 2C. Annual means ranged from 159.8 cm LJFL in 1988 to 168.7 cm LJFL in 1993 (Table 2). This set was extremely unbalanced in terms of yearly sample size distribution. For example, there are 234 observations in 1993 and only 7 in 1988. With the exception of 1987, sample size increases with year (Table 2). Nevertheless, after data transformation, the variances tested homogeneous between years. The GLM analysis indicated no statistically significant changes between years ($\alpha=0.05$, $P<0.4598$), as did the Kruskal-Wallis test ($P<0.0665$).

Spearfish

There is a paucity of collected data for the longbilled spearfish. The annual mean and range of LJFL measurements (in cm) from at-sea sampled western Atlantic spearfish from 1990-1993 are given in Figure 2E. Annual means ranged from 164.0 cm LJFL in 1991 to 166.7 cm LJFL in 1990 (Table 2). Although samples are unbalanced (Figure 2E), with sample size increasing yearly, variance between the years appears relatively consistent. The data are homoscedastic with or without the data transformation. The GLM exhibited no difference between years in mean LJFL ($\alpha=0.05$, $P<0.8657$) as did the non-parametric test ($P<0.5499$).

Combined Shore-Based and At-Sea Database

A direct comparison between shore-based and at-sea data sets is not appropriate since sample sizes and variances are unsuitable for statistical tests. The at-sea database is a smaller sample collected by one source, Venezuela, while the shore-based database is collected from eight sources and is considerably larger. However, observations of frequencies and means are similar between the two databases. Under the assumption that both shore-based and at-sea data sets are collected from the same unit stocks, measurements were combined for each species (blue marlin, white marlin, sailfish) and statistical tests were performed. In all cases, the homogeneity of variance tested heteroscedastic and log transforms were made. Of the three species, only the blue marlin variances were homogenous after transformation. The Kruskal-Wallis and GLMs indicated all data sets were significant for differences in yearly LJFL, with multiple comparisons yielding identical patterns of statistical outcomes as the shore-based results alone.

DISCUSSION AND CONCLUSION

Size data for the five species examined in this study were highly variable. Problems with the analysis included sample size unbalance by year, species, or sample category, herteroscedasticity, and possible sampling inconsistencies such as rounding or grouping or non-independent observations. In addition, there are established sex related differences in sizes which were not analyzed here due to a lack of data for most specimens sampled. Though examination of several series in this analysis resulted in statistical significance, the practical differences in LJFL were very small. For example, a significant increase in LJFL for the white marlin shore-based occurred between the years 1988 and 1992, but the mean size increased only 5 cm. Although statistically significant changes were detected in this and other analyses, some may have resulted from systematic errors in sampling or Type I error due to non-conformity to model assumptions. This is particularly true for the ANOVA results, which were presented for comparison purposes to the Kruskal-Wallis test. Nonetheless, statistical conclusions of the Kruskal-Wallis test agree with the ANOVA in all cases, and there are some important patterns that emerge from the data.

Mean sizes of landings for all species from the western Atlantic have remained relatively consistent from year to year, fluctuating slightly for most species. The blue marlin shore-based data set suggests that there has been a small, but steady increase in mean size of landings for the time series. There has been an increase in blue marlin LJFL of 18.3 cm from 1988 to 1993. Although this finding conflicts with the analysis of at-sea data for blue marlin, which indicates no change in size between years, the shore based sample series is larger, and is sampled from more locations within the unit stock. Combined data sets continued to indicated a significant increase in size across the time series. Factors contributing to this apparent increase in LJFL are unknown at this time.

In addition to the shore-based sampled billfish examined here, there are also available data on spearfish, with size measurements provided in several different length units. Unfortunately, there are no available length conversion equations at the present time for spearfish. We recommend that an increased effort be undertaken to obtain data for which regression parameters can be estimated so that these data can be converted to a single unit of measurement and also be examined in the future.

As Table 1 and Table 2 demonstrate, data collection has greatly increased over last few years thanks to increasing participation in the ICCAT Enhanced Research Program for Billfish. We suggest that data collection continue and that other analytical methods be employed in the future when more data becomes available. For example, if independent samples are collected on a consistent basis in the future, regression and one tailed significance tests may be used to test systematic increases over time.

ACKNOWLEDGEMENTS

The authors thank Michael Judge, Eric Prince, Mark Farber, and James Zweifel of the NMFS Southeast Fisheries Science Center for comments and suggestions on analytical techniques.

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Table 1. Summary statistics for shore-based samplings of blue marlin, white marlin, and sailfish from the ICCAT Enhanced Research Program for Billfish 1988-1993. Lower jaw fork length (LJFL) is in cm.

YR	N(*LJFL*)	Min	Max	Mean	SD	SD(log *LJFL*)
Blue Marlin						
88	314	111	254	183.8	19.0	0.102
89	311	106	290	186.5	21.3	0.115
90	358	111	313	188.3	27.7	0.143
91	349	123	325	199.7	36.9	0.180
92	490	116	335	199.9	30.8	0.152
93	476	89	370	202.1	27.5	0.140
White Marlin						
88	489	107	219	156.5	11.2	0.072
89	220	124	225	152.9	11.6	0.074
90	485	128	225	157.8	10.3	0.064
91	1322	81	196	160.3	8.10	0.051
92	2238	116	216	161.5	9.60	0.059
93	2314	85	287	159.2	9.70	0.061
Sailfish						
88	326	123	190	167.4	10.0	0.061
89	226	146	192	169.9	8.30	0.049
90	1078	130	203	168.6	10.0	0.062
91	2539	111	223	169.7	11.0	0.066
92	3540	118	240	168.6	9.20	0.054
93	3517	107	222	169.1	8.70	0.052

Table 2. Summary statistics for at-sea samplings of blue marlin, white marlin, sailfish, and spearfish from the ICCAT Enhanced Research Program for Billfish 1987-1993. Lower jaw fork length (LJFL) is in cm.

YR	N(*LJFL*)	Min	Max	Mean	SD	SD(log *LJFL*)
Blue Marlin						
87	38	146	363	196.2	45.2	0.207
88	13	132	256	179.7	34.0	0.179
89	11	152	196	166.9	11.8	0.068
90	40	129	282	177.7	31.6	0.170
91	62	144	255	176.0	25.4	0.134
92	88	110	303	193.5	38.2	0.197
93	81	115	308	190.0	29.1	0.151
White Marlin						
87	144	138	197	156.4	7.6	0.047
88	60	135	189	163.4	13.0	0.080
89	51	145	195	161.7	9.5	0.058
90	77	110	177	150.6	13.5	0.092
91	46	143	190	161.4	9.2	0.056
92	100	99	230	155.9	21.2	0.134
93	228	112	210	158.2	12.6	0.082
Sailfish						
87	26	157	190	167.7	8.3	0.049
88	7	131	182	159.8	15.6	0.101
89	18	141	181	165.0	10.0	0.062
90	31	131	185	167.2	12.9	0.081
91	101	119	195	166.0	11.6	0.074
92	137	131	224	168.1	13.1	0.080
93	234	80	193	168.7	13.0	0.091
Spearfish						
90	13	141	19	166.7	14.5	0.087
91	30	130	17	164.0	11.8	0.075
92	39	132	18	166.6	13.0	0.082
93	58	125	19	165.3	13.3	0.084

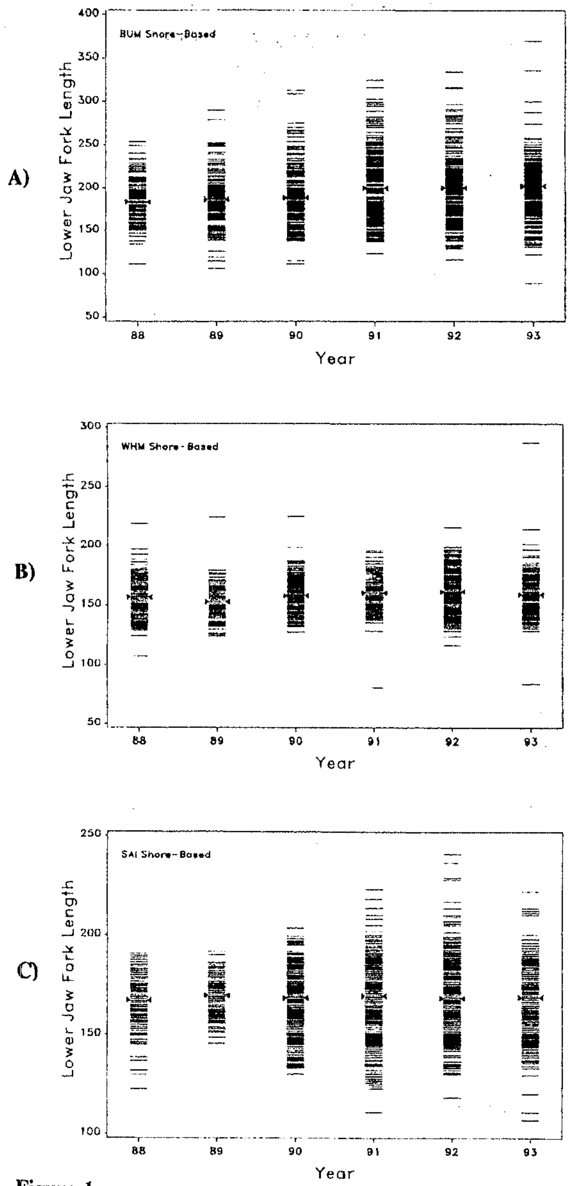

Figure 1.

Length-frequencies of billfish from shore-based samplings of the Western Atlantic Ocean. (A) blue marlin, (B) white marlin, and (C) sailfish from the ICCAT Enhanced Research Program for Billfish 1988-1993. Lower-jaw fork-length is in cm. Pointers indicate annual mean measurement.

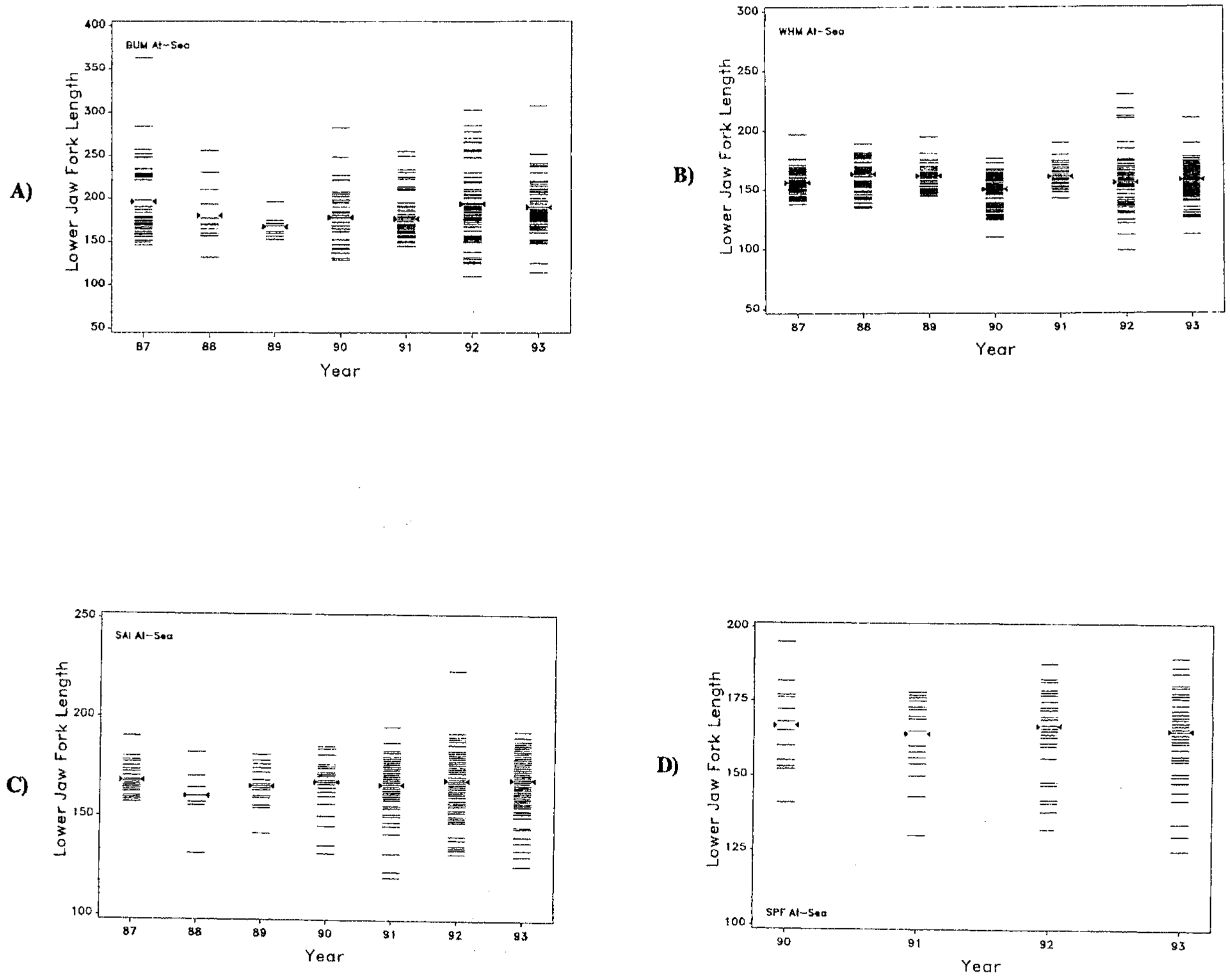

Figure 2.

Length-frequencies of billfish from at-sea samplings of the Western Atlantic. (A) blue marlin, (B) white marlin, (C) sailfish, and (D) longbilled spearfish from the ICCAT Enhanced Research Program for Billfish 1987-1993. Lower-jaw fork-length is in cm. Pointers indicate annual mean measurement.