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A STUDY OF LIVE AND DEAD BILLFISHES CAUGHT ON LONGLINE GEAR

By

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INTRODUCTION

The Fishery Conservation and Management Act of 1976 (FCMA) declared a Fishery Conservation Zone (FCZ) within which all fisheries except for highly migratory species of tunas are to be managed. The FCMA mandates the regulation of foreign fishing activity within the FCZ, a band of 200 nautical miles bordering all coasts of the U.S. and its possessions, through the vehicle of Fishery Management Plans (FMP). Fishing for highly migratory tunas, however, is exempt from regulatory measures authorized by the FCMA.

A common method, perhaps the most common method of foreign fishermen, of fishing for tunas is the longline. In addition to tunas the longline catches other large pelagic predators such as billfishes and sharks whose habitats overlap those of the tunas. The nonspecific nature of longline catches created a problem of finding a way to regulate fishing for billfishes without interfering with tuna fishing operations. The Preliminary Management Plan which provides interim regulations for billfishes, sharks, wahoo, _Acanthocybium solandri_, and mahimahi, _Coryphaena hippurus_, until the FMP for these species is developed, handles the problem by declaring nonretention zones within the FCZ. In these zones all billfishes caught beyond a species quota are to be returned to the sea whether they are alive or not.

The effectiveness of a policy of nonretention as a conservation measure depends upon the number of live releases. This study reports on the numbers of live and dead billfishes by species caught on a series of longline sets and investigates some of the factors which may be related to a fish being alive or dead at the time of boating. Billfish species in the Pacific Ocean are: swordfish, _Xiphias gladius_; sailfish, _Istiophorus platypterus_; shortbill spearfish, _Tetrapturus angustirostris_; striped marlin, _T. audax_; black marlin, _Makaira indica_; and blue marlin, _M. nigricans_.

SOURCES AND DESCRIPTION OF DATA

Data were obtained from three sources: the Honolulu Laboratory (HL), the Far Seas Fisheries Research Laboratory (FSFRL) of Japan, and the Southeast Fisheries Center (SEFC) of the National Marine Fisheries Service. The data from HL came from detailed records of exploratory longline fishing expeditions in the Pacific Ocean between 1950 and 1970 inclusive from ships operated by or chartered by the HL. The data from FSFRL and SEFC were summaries of live and dead billfishes on longline gear. The data from Japan were collected on exploratory research expeditions in the Pacific and Atlantic Oceans during the period 1952-66. The data from SEFC were collected by U.S. observers placed on commercial Japanese longline vessels fishing in the Atlantic Ocean and the Gulf of Mexico during 1978. Species of billfish caught in the Atlantic Ocean are: swordfish; Atlantic sailfish; longbill spearfish, *T. pfluegeri*; white marlin, *T. albidus*; and blue marlin.

On the HL fishing expeditions, descriptions of each longline set were systematically recorded in detail by highly trained observers. Recorded information used in this study are:

1. Date.
2. Location.
3. Description of gear details.
4. Beginning and ending times of each set.
5. Time each basket was hauled.
6. Sea-surface temperature at positon of first basket hauled.
7. Species of each fish caught.
8. Size (length, weight, or both) of some of the fish caught.
9. Sex of some of the fish caught.
10. Position of hook on which fish was caught.
11. Condition of fish at time of boating, e.g., alive, dead, shark damaged.

Typically the line was set before dawn and retrieval began at noon. Retrieval time depended upon the number of baskets set, the amount of breaks and tangles of the line encountered during hauling, and the number of large fish caught. The length of the mainline was 384 m (210 fathoms) per basket. Sixty baskets were used on most sets. The length of the floatline was 18.3 m (10 fathoms) except when it was varied experimentally. The number of evenly spaced hooks in a basket varied from 6 to 21 but was 6 most of the time. The length of the gangions was inversely related to the number of hooks in a basket to prevent adjacent hooks from tangling.

On a standardized log for longline sets the observer routinely described the gear variables such as the number of baskets, number of hooks per basket, and length of floatlines for each set. He recorded the times for the beginning and the ending of the gear setting operation. During the retrieval process he recorded the time when each buoy was brought in. Since the baskets of gear are separated by these buoys, the times represent the start and end of the hauling of each basket. The observer also carefully monitored the hooks as they were retrieved so that he knew which hook and which basket caught any given fish.

Sea-surface temperatures were measured with a bucket thermometer to accompany the thermograms which were obtained just before line retrieval began.

Fish were weighed on a steelyard. The fish weights are expected to have varying amounts of error depending on the sea state and roll characteristics of the ship. The error is presumed to be small and unbiased. Sex of the fish was determined by examination of the gonads.

TREATMENT OF DATA

Chi-square tests and analyses of variance, whichever was appropriate, were applied to HL data to determine if the proportion of fish which reached the ship alive was associated with the following variables: size, sex, species, location, time of year, depth of capture, and fishing time. Possibilities of interactions among variables affecting the proportion of live fish were not investigated because of insufficient data. Data from the other two sources were not detailed enough to be included in the analyses above. They were compared with data from the HL, however, to determine if the proportions of live fish from the three sources were significantly different.

Locations of capture were grouped into three broad zones for the analyses. The three areas are: north of lat. 10°N, 10°N-10°S, and south of 10°S.

Time of year was grouped into quarters of the year beginning with January.

Depth of capture was derived from data on position of the fish-catching hook and length of the floatline. Depth from hook position was calculated from the catenary model assuming a distance of 293 m (160 fathoms) between buoys. This distance was the median of distance between buoy measurements by Murphy and Shomura (1953, 1955). The length of the floatline was added to the depth calculated from hook position. Three main sources of error which cause the approximated depth of capture to differ from the real depth of capture are: (1) variability in the distance between buoys in which case the overestimations should equal the underestimations; (2) currents causing the line to hang at some angle other than vertical, in which case all errors would be overestimates; and (3) fish getting caught while the line was being set or retrieved and not while it was at its maximum depth, in which case all errors would be overestimates. For the chi-square test the depths were grouped into three categories: 0-74 m (0-40 fathoms), 75-129 m (41-70 fathoms), and greater than 129 m.

Fishing duration is defined in this study as the length of time during which a hook may catch a fish. It is a variable associated with each individual hook and does not refer to the time the entire gear is in the water nor the duration of the longline expedition. It was calculated by subtracting the time at the end of the set from the time the front end of the basket containing the hook reached the ship.

RESULTS

Species

The HL data included observations on 933 billfishes. The percent living at time of boating ranged from 18% for sailfish to 54% for striped marlin (Table 1). A highly significant chi-square indicated that the proportion living is dependent on species. Striped marlin, however, was the only species having a significantly different percentage alive. When the striped marlin data were excluded, the chi-square value was 6.42 ($0.2 > P > 0.1$).

Table 1.--Numbers of longline caught billfishes alive and dead by species.

Species	Alive	Dead	Percent alive
Sailfish	10	46	17.9
Shortbill spearfish	36	76	32.1
Black marlin	9	26	25.7
Blue marlin	110	268	29.1
Striped marlin	170	142	54.5
Swordfish	16	24	40.0

$\chi^2 = 62.48$, d.f. = 5, $P < 0.01$

Areas

As mentioned earlier the locations of capture were grouped into three categories: north of lat. 10°N, 10°N-10°S, and south of 10°S. Except for blue marlin, catches for the area south of lat. 10°S were too small for statistical testing. For all species the percent alive in the northern area was smaller than that in the equatorial area (Table 2). Only in the case of the black marlin, however, was the difference between the areas great enough to be significant.

Seasons

The numbers alive and dead are tabulated by species and the chi-square tests indicated that the percent alive was independent of the time of year (Table 3).

Table 2.--Numbers of longline-caught billfishes alive and dead by areas.

Species	Latitude north of 10°N		Latitude 10°N-10°S		Latitude south of 10°S	
	Alive	Dead	Alive	Dead	Alive	Dead
Sailfish	6	32	4	9	0	5
Shortbill spearfish	7	22	29	47	0	7
Black marlin	5	25	3	1	1	0
Blue marlin	69	201	28	38	13	29
Striped marlin	34	35	136	106	0	1
Swordfish	7	15	9	9	0	0

Sailfish $\chi^2 = 1.38$, d.f. = 1, $0.2 < P < 0.3$
Shortbill spearfish $\chi^2 = 1.83$, d.f. = 1, $0.1 < P < 0.2$
Black marlin $\chi^2 = 6.67$, d.f. = 1, $P < 0.01$
Blue marlin $\chi^2 = 7.39$, d.f. = 2, $0.02 < P < 0.05$
Striped marlin $\chi^2 = 1.04$, d.f. = 1, $0.3 < P < 0.5$
Swordfish $\chi^2 = 1.36$, d.f. = 1, $0.2 < P < 0.3$

Table 3.--Numbers of longline-caught billfishes alive and dead by quarters of the year.

Species	Jan.-Mar.		Apr.-June		July-Sept.		Oct.-Dec.	
	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead
Sailfish	4	8	0	2	1	6	1	4
Shortbill spearfish	22	21	8	13	6	4	0	11
Black marlin	2	3	2	4	3	3	2	1
Blue marlin	42	109	17	46	28	75	23	38
Striped marlin	103	64	24	19	12	15	31	44
Swordfish	4	5	6	6	2	8	4	5

Sailfish $\chi^2 = 0.14$, d.f. = 2, $0.90 < P < 0.95$
Shortbill spearfish $\chi^2 = 1.56$, d.f. = 2, $0.3 < P < 0.5$
Black marlin $\chi^2 = 1.01$, d.f. = 3, $0.7 < P < 0.8$
Blue marlin $\chi^2 = 2.63$, d.f. = 3, $0.3 < P < 0.5$
Striped marlin $\chi^2 = 4.38$, d.f. = 3, $0.2 < P < 0.3$
Swordfish $\chi^2 = 2.31$, d.f. = 3, $0.5 < P < 0.7$

Depth of Capture

Table 4 shows the numbers of live and dead fish by species caught in the three depth categories. Except for shortbill spearfish, the condition of being alive or dead was not dependent on depth of capture. Shortbill spearfish, on the other hand, had a greater tendency to be alive the deeper they were caught.

Table 4.--Numbers of longline caught billfishes alive and dead by depth of capture.

Species	Depth of capture (m) 0-74 Alive	0-74 Dead	75-129 Alive	75-129 Dead	> 129 Alive	> 129 Dead
Sailfish	3	16	3	19	4	11
Shortbill spearfish	5	23	15	35	16	18
Black marlin	2	10	6	9	1	7
Blue marlin	34	79	42	111	34	78
Striped marlin	48	32	68	66	54	44
Swordfish	3	9	7	7	6	8

Sailfish $\chi^2 = 1.12$, d.f. = 2, $0.5 < P < 0.7$
Shortbill spearfish $\chi^2 = 6.19$, d.f. = 2, $0.02 < P < 0.05$
Black marlin $\chi^2 = 2.85$, d.f. = 2, $0.2 < P < 0.3$
Blue marlin $\chi^2 = 0.34$, d.f. = 2, $0.8 < P < 0.9$
Striped marlin $\chi^2 = 1.75$, d.f. = 2, $0.3 < P < 0.5$
Swordfish $\chi^2 = 1.76$, d.f. = 2, $0.3 < P < 0.5$

Surface Temperatures

The range of surface temperatures at the locations where the longline was set varied with the three areas. North of lat. 10°N the range was 22.9°-29.2°C with 96% of the observations above 25.0°C. Between lat. 10°N and 10°S surface temperatures ranged from 15.8° to 29.0°C with 96% of the temperature records higher than 23.0°C. South of lat. 10°S the surface temperature range was 22.9°-29.8°C. Within those temperature ranges, whether the fish was alive or dead when it was brought alongside the ship was not a function of surface temperature.

Size

Comparisons were made of the sizes of live fish and dead fish. For blue marlin, striped marlin, and shortbill spearfish, the mean sizes of the live fish were greater than the mean sizes of the dead fish while the reverse was true for black marlin and sailfish (Table 5). Only in the case of the blue marlin was the difference statistically significant ($P < 0.05$). Apparently, large blue marlin are more likely to survive the capture process than smaller ones. The relationship is indicated coarsely in Figure 1 in which the percent of live fish is grouped in 100-lb classes and plotted against mean weight.

Fishing Duration

The mean fishing duration for hooks that returned dead fish was higher than the mean fishing duration of hooks that returned live fish (Table 6). Although this was true for all species, only in the cases of sailfish and blue marlin were the differences significant at the 0.05 probability level.

Table 5.--Numbers, mean weights, and standard deviations of live and dead billfishes caught on longlines.

Species	Number in sample		Mean weight (kg)		Standard deviation	
	Alive	Dead	Alive	Dead	Alive	Dead
Sailfish	3	5	21.3	25.7	2.53	10.52
Shortbill spearfish	14	9	14.0	13.8	3.52	3.92
Black marlin	3	9	65.6	142.1	61.23	61.44
Blue marlin	20	35	114.9	76.4	73.20	42.66
Striped marlin	46	14	47.6	35.7	30.57	23.01

Sailfish	$F = 0.48$
Shortbill spearfish	$F = 0.02$
Black marlin	$F = 3.49$
Blue marlin	$F = 6.08$*
Striped marlin	$F = 1.82$

*Significant at 0.05 level.

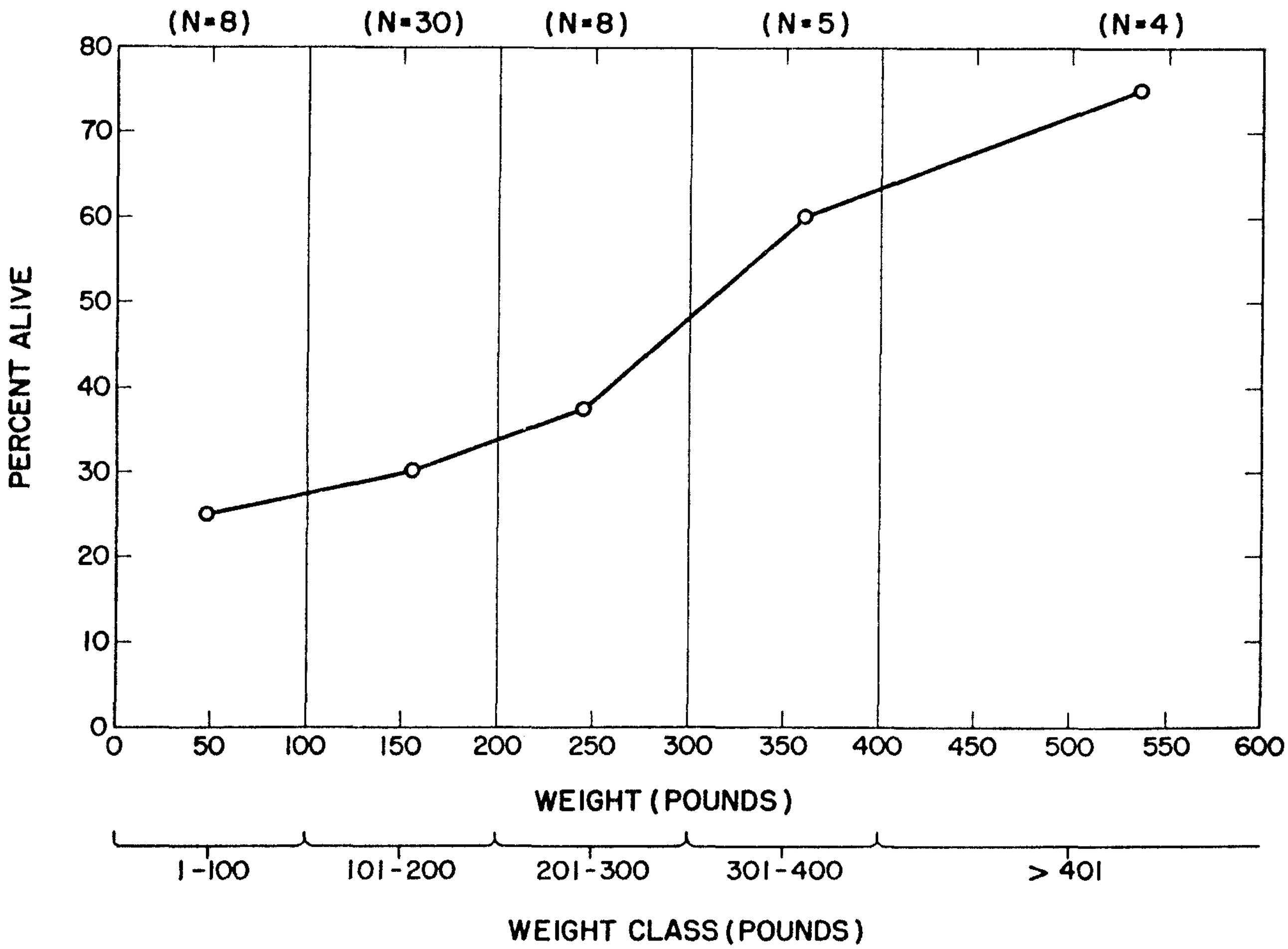

Figure 1.--Survival of blue marlin captured on longline as related to fish size.

Table 6.--Numbers, mean fishing duration, and standard deviation of live and dead billfishes caught on longlines.

Species	Number in sample		Mean fishing duration (h)		Standard deviation		F value
	Alive	Dead	Alive	Dead	Alive	Dead	
Sailfish	10	30	7.52	8.55	1.070	1.203	5.84*
Shortbill spearfish	35	42	8.70	9.02	1.359	1.140	1.25
Black marlin	8	11	8.87	9.41	0.809	1.360	0.94
Blue marlin	109	145	8.29	8.77	1.336	1.518	6.62*
Striped marlin	158	92	8.50	8.83	1.397	1.372	3.22
Swordfish	12	7	8.29	9.96	1.425	2.562	3.40

*Significant at 0.05 level.

Sources of Data

The data from the three sources (Table 7) were compared species by species. Because the data from the HL and the SEFC were from separate oceans with only two species common to both oceans, there were only two comparisons of the HL data and the SEFC data. All other comparisons involved the FSFRL data.

Table 7.--Numbers of live and dead billfishes caught on longlines by source of data; HL (Honolulu Laboratory), FSFRL (Far Seas Fisheries Research Laboratory), and SEFC (Southeast Fisheries Center).

Species	Pacific Ocean				Atlantic Ocean			
	HL		FSFRL		SEFC		FSFRL	
	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead
Sailfish	10	46	84	147	72	74	7	7
Shortbill spearfish	36	76	131	156	--	--	--	--
Longbill spearfish	--	--	--	--	36	68	46	29
Black marlin	9	26	435	379	--	--	--	--
Blue marlin	110	268	674	512	114	158	8	0
Striped marlin	170	142	554	168	--	--	--	--
White marlin	--	--	--	--	447	682	26	13
Swordfish	16	24	86	49	309	643	2	3

Sailfish $\chi^2 = 18.47$, d.f. = 3, $P < 0.01$
Shortbill spearfish $\chi^2 = 6.03$, d.f. = 1, $0.01 < P < 0.02$
Longbill spearfish $\chi^2 = 12.53$, d.f. = 1, $P < 0.01$
Black marlin $\chi^2 = 10.34$, d.f. = 1, $P < 0.01$
Blue marlin $\chi^2 = 102.76$, d.f. = 3, $P < 0.01$
Striped marlin $\chi^2 = 51.35$, d.f. = 1, $P < 0.01$
White marlin $\chi^2 = 11.47$, d.f. = 1, $P < 0.01$
Swordfish $\chi^2 = 50.06$, d.f. = 3, $P < 0.01$

Generally, the proportion of live fish returned by the longlines of the HL was considerably lower than the others and the proportion of live fish returned by the longlines of the FSFRL was considerably higher than the others. The comparison between the data from these two laboratories resulted in chi-square values beyond the 0.01 probability level for sailfish, black marlin, blue marlin, striped marlin, and swordfish, and beyond the 0.02 probability level for the shortbill spearfish.

Chi-square tests of live billfishes returned by the Japanese research ships as compared to Japanese commercial ships in the Atlantic Ocean were highly significant for longbill spearfish, blue marlin, and white marlin and insignificant for sailfish and swordfish.

DISCUSSION

Eight variables were investigated for their effect on billfishes caught on longlines arriving at the fishing vessel alive. The most important variable in this respect was sources of data. That the proportion of live billfishes brought to the ship should differ with the three longline fishing groups, i.e., the HL experimental, the FSFRL experimental, and the Japanese commercial, is not altogether unexpected because each group probably has its own gear design, handles the line differently, and fishes different amounts of gear.

On the basis of amount of gear fished the results were surprising. On the average the HL ships set 60 units of gear, the FSFRL ships set 100 units of gear, and Japanese commercial ships set 300 units of gear. Because the rate of live fish is related to fishing duration and fishing duration is proportional to the amount of gear set, one would expect the highest return of live billfishes to be from the HL ships. In actuality it had the least. I have no explanation for this.

The mean fishing duration for dead fish was consistently longer than the mean for live fish although the difference was statistically significant for only two species. The survival of caught fish is expected to be a function of how long the fish was on the line from the time it was hooked to the time it was pulled to the ship which in turn was a function of fishing duration. If, for example, the probability of catching a fish on a given hook is equal for all instants of time that the hook is in the water, i.e., a fish is just as likely to strike a hook at one instant of time as any other instant of time, then the average length of time a fish is on the line hypothetically would be one-half of fishing duration. I expect, however, that the probability function of when a hook catches a fish to be much more complex than the example given and would include such factors as the diffusion rate of bait odors and the attractiveness and condition of the bait used.

This study has shown that the greatest difference in the proportion of live billfishes brought to the ship depends on who is doing the fishing. This being the case, it would be inappropriate to apply the results of one fishery to another, such as attempting to predict the number of live billfishes expected in the Japanese commercial longline fishery in the Pacific Ocean from the results of the HL data or the FSFRL data.

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