PRELIMINARY REVIEW OF BILLFISH HOOKING DEPTH MEASURED BY SMALL BATHYTHERMOGRAPH SYSTEMS ATTACHED TO LONGLINE GEAR

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SUMMARY

Hooking depths of several billfish species were measured and analyzed based on small bathythermograph systems in the experimental longline operations conducted in the Pacific and Indian Oceans. A TDR line sensor was directly hooked on the branch line and catch by branch-line number was recorded and analyzed. A total of 22 individuals of five billfish species were observed, 21 of which occurred in the Pacific Ocean. Striped marlin (Tetrapturus audax)*, shortbill spearfish* (Tetrapturus angustirostris) *and blue marlin* (Makaira mazara) *were hooked mainly at depths shallower than 120m and mainly in the thermocline zone. On the other hand, swordfish* (Xiphias gladius) *was hooked at a wider depth range (43-212m). Catch by branch line, which may reflect the vertical distribution of species, did not coincide with the results by bathythermograph systems. As the number of observations is still small, more surveys and analyses are necessary to reach definitive conclusions.*

RESUMEN

En el curso de operaciones experimentales de palangreras llevadas a cabo en los océanos Pacífico e Indico, se midió la profundidad de los anzuelos en relación con varias especies de marlín y se analizó basándose en pequeños sistemas de batitermógrafo. En la liña principal se colocó un sensor TDR y se registró y analizó la captura por número de liña principal. Se registró un total de 22 ejemplares de cinco especies de marlín, 21 de las cuales eran del Pacífico. El marlín rayado (Tetrapturus audax)*, el pez aguja corta* (Tetrapturus angustirostris) *y el marlín azul* (Makaira mazara) *se capturaron principalmente a menos de 120 m y en la zona de termoclina. Por otra parte, el pez espada* (Xiphias gladius) *se capturó a mayor profundidad (32-212 m). La captura por liña principal, que podría reflejar la distribución vertical de la especie, no coincidía con los resultados de los sistemas de batitermógrafo. El número de observaciones es aún escaso, por lo que es necesario realizar más encuestas y análisis antes de llegar a conclusiones definitivas.*

RÉSUMÉ

Les profondeurs des hameçons de plusieurs espèces d'istiophoridés ont été mesurées et analysées sur la base de petits systèmes bathythermographes dans les opérations palangrières expérimentales menées dans les océans Pacifique et Indien. Un détecteur TDR a été directement rattaché à l'avançon et la capture par numéro d'avançons a été enregistrée et analysée. Au total, 22 spécimens de cinq espèces d'istiophoridés ont été observés, dont 21 se trouvaient dans l'océan Pacifique. Le makaire (Tetrapturus audax)*, le marlin* (Tetrapturus angustirostris) *et le makaire bleu* (Makaira mazara) *ont été capturés par moins de 120 m de fond et principalement dans la zone thermocline. D'autre part, l'espadon* (Xiphias gladius) *a été capturé dans une gamme plus ample de profondeur (43-212 m). La capture par avançon, qui peut refléter la distribution verticale des espèces, n'a pas coïncidé avec les résultats obtenus par les systèmes bathythermographes. Étant donné que le nombre d'observations est encore limité, il est nécessaire de réaliser de nouvelles prospections et analyses afin de parvenir à des conclusions définitives.*

KEYWORDS

Tuna Fisheries, Billfish, Long lining, Hooking depth

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INTRODUCTION

Knowing the swimming depth of large pelagic fish is important in assessing CPUE for longline fishery. Several methods have been used for measuring or estimating swimming depth, for example, catch by branch line of longline (Hanamoto 1979, Nishi 1990, Mohri *et al*. 1997, Matsumoto and Miyabe 1997, 1998 and 1999) or vertical longline operation (Saito and Sasaki 1974, Saito 1975), acoustic surveys (Fujiishi *et al*. 1969), utilization of "archival" tags and tracking by ultrasonic telemetry (Jolley and Irby 1979, Carey and Robison 1981, Holland *et al*. 1990, Holtz and Bedford 1990, Block *et al.* 1992, Block *et al.* 1997, Brill *et al.* 1999), and measuring hooking depth of longline gear by small bathythermograph system (Boggs 1992, Berkeley and Edwards 1997, Uozumi and Okamoto 1997).

Some papers mention that the billfish species (striped marlin Tetrapturus audax and shortbill spearfish Tetrapturus angustirostris) were caught at a mainly shallow range of depth by longline gear (Hanamoto 1979, Boggs 1992). On the other hand, swordfish Xiphias gladius has been reported to swim in the deeper layer (Carey and Robison 1981). Hinton and Nakano (1996) tried to take into account this information on the vertical distribution of blue marlin Makaira mazara during CPUE standardization. But there is not much detailed information about swimming depth of billfishes and it is difficult to elucidate the general trend, which prevents or biases further analyses of longline CPUE. In recent years a small bathythermograph system has been devised and put to practical use (Mizuno *et al.* 1996, Okazaki *et al.* 1997) which we recently began to use mainly in several experimental and commercial longline operations for investigating either the underwater shape of longline gear, or the hooking depth, temperature and time of hooking. In this paper we review hooking depth of billfish species measured by a bathythermograph system in experimental longline operations.

METHODS

Three types of bathythermograph systems, "DTM-2M" and "DTM-512K" (Kankyo Keisoku System Co., Ltd., 160mm in length, 20mm in diameter and 30g in water; see Uozumi and Okamoto 1997) and "SBT-500" (Murayama Electronics Co., Ltd., 170mm in length, 18mm in diameter and 37g in water; see Mizuno *et al.* 1996), were used during experimental longline operations by research and chartered vessels (Table 1). In this paper we refer to these as 'TDR (Time Depth Recorder) systems'. TDRs were attached to the branch lines (about 2-3m above the hook; Figure 1). TDR sensors recorded time, temperature (to the nearest 0.1ºC) and depth (to the nearest 1 m) every 4 or 10 seconds and the data were analyzed by personal computers. Ten to 163 sensors were used in one longline operation. When a fish is hooked on the branch line with an attached TDR, catch depth was estimated from the depth trajectory graph (an example is shown in Figure 2). Also, the hooking depths were compared with the depth of thermocline measured by CTD, XBT or by the TDR itself. Thermocline was defined as the layer in which water temperature decreases sharply (judged from the graph; for example, see Figure 3).

Branch line number was recorded for each catch. Based on these data, frequency of catch by branch line numbers, which may reflect the vertical distribution of fish, was calculated and compared with TDR results.

RESULTS

Observed hooking depths

A total of 22 (one in the Indian Ocean and the others in the Pacific Ocean) billfish were hooked on the branch line on which TDR sensor was attached. That is, nine striped marlin, five swordfish, four blue marlin, three shortbill spearfish, and one black marlin Makaira indica (Indian Ocean) (Table 2). There were two striped marlin whose hooking time was unidentified, because another fish was hooked on another branch line in the same basket. Except for these individuals, all billfish which were analyzed in this study were not hooked while the hooks were sinking during gear setting or rising during retrieval. Frequency of catch depth for four species is shown in Figure 4.

The tendencies for each species are as follows. Out of nine striped marlin, five individuals were caught between 80 and 120 m depth. One of three shortbill spearfish was hooked at 55 m depth and the others were caught deeper than 110 m. Three of the four blue marlin individuals were hooked at depths shallower than 100 m. As for black marlin, only one individual was recorded in the Indian Ocean and its hooking depth was 111 m. Hooking depth of swordfish ranged over a wide depth layer, from 43 to 212 m. Among the species observed, swordfish was hooked in the deepest layer on average (average depth = 128 m) and also exhibited the largest hooking depth range.

Catch number by branch lines

Catch number by branch lines for three species is shown in Figure 6 for the four cruises in the present study. Striped marlin were mainly hooked by shallower branch lines, but were also partly caught by deeper ones. Blue marlin were also hooked by both shallower and deeper branch lines. In some cruises, blue marlin were hooked by deeper branch lines than striped marlin. As for shortbill spearfish, the tendencies differed among the cruises, but this species was caught not only by shallower branch lines but also by deeper ones.

Table 3 shows the deepest depth of hooks in the middle part of the basket (middle number in the figure), though the actual position of the deepest hook was variable depending on oceanographic conditions. Table 3 shows that most hooks in the middle part of the basket were set deeper than the depth of hooking observed by TDRs shown in Figure 4. But, Figure 6 shows that such hooks set deep caught frequently billfish.

Figure 8 also shows the catch (in numbers) of Atlantic blue marlin in the Atlantic Ocean by branch lines, which was obtained through the 1999 observer program for the Japanese tuna longline fishery in the Atlantic Ocean (Matsumoto and Miyabe 1999). The two vessels operated almost in the same area and season, although the duration of one vessel's (No. 31 Koyo-maru) operation was much longer than that of another vessel (No. 81 Sumiyoshi-maru). The target species of the two vessels was bigeye tuna and deep longline gear with 18 or 19 branch lines was used. There was no direct measurement of the depth of gear for both cruises, but the depth was estimated under the assumption of catenary shape for the main line under the water with standard sagging rate. The depth of the shallowest hook was estimated as being about 125 m and the depth of deepest one as 275 m.

The tendency of hooking depth between vessels was similar in that Atlantic blue marlin was mainly caught by shallower branch lines. But a slight difference was observed between the vessels (right and left panels in Figure 6): in one vessel this species was hooked only by shallow branch lines, which was not the case in the other vessel.

Relationship between hooking depth and thermocline depth

Upper and lower thermocline limits corresponding to each catch position where hooking took place are shown in Table 2 and the relationship between hooking depth and thermocline depth is summarized in Table 4. From Table 4, most blue marlin and striped marlin were hooked between the upper and lower limits of the thermocline. On the other hand, no clear relationship was observed for swordfish during the present surveys. As for shortbill spearfish, the relationship for two individuals was unclear because no oceanographic observations were made by CTD or XBT.

DISCUSSION

Vertical distribution of billfishes

In this study, some species-specific tendency in catch depth and in the relationship between catch depth and thermocline were observed for the four billfish species by TDR, though the number of observation was very limited. For striped marlin, hooking depth was comparatively shallow (seven of nine individuals were hooked at depths shallower than 120 m). These results roughly coincide with those of Hanamoto (1979), which say that catch rate for this species was highest in shallowest branch lines (approximately 60-90 m depth) in the north of Hawaii Islands and the Southern Coral Sea, and with those of Boggs (1992), which say this species was hooked mainly between 40 and 120 m depth based on TDRs off Hawaii Islands. According to Brill *et al.* (1993), ultrasonic telemetry near the Hawaii Islands showed that striped marlin spent almost 30% of the time at depths shallower than 10 m, but frequently dived to 50-180 m depth, which supports the results of our TDR study.

The observations of hooking depth of blue marlin made by TDR are also similar to the results of Holland *et al.* (1990) or Block *et al.* (1992). Hinton and Nakano (1996) also state that this species is mainly distributed in the mixed layer on the basis of the result by XBT and telemetry experiments, which are basis for their CPUE standardization. But catch by branch line (Figure 6) shows that this species was not necessarily caught by shallower branch lines. The results for Atlantic blue marlin *Makaira nigricans* (Figure 8) also show that it is not necessarily the case that this species is caught only by shallower branch lines. The reasons for the disagreement between TDR observations and catch by branch line are not clear, but they might have resulted from unstable underwater shape of the longline gear due to water current or from differences in the vertical distribution of billfishes among areas. The differences in the catch by branch lines between similar areas shown in Figure 8 suggests differences in local oceanographic conditions or differences in the materials and setting of longline gear between vessels.

As for shortbill spearfish, the results are similar to those of Boggs (1992). However, Boggs (1992) also showed that several individuals were hooked deeper than 300m. Catch by branch line data (Figure 6) support Boggs´ (1992) finding that deeper branch lines also caught this species.

As for swordfish, hooking was observed through a wide range of depths between 43 and 212 m. According to Carey and Robison (1981), the swimming depth of swordfish is limited by the oxygen-minimum layer which reaches temporarily about 600 m in the daytime in the Atlantic Ocean. In the present study, the maximum hook-setting depth was about 300 m or less, so the entire depth range of swordfish could not be covered.

Vertical coverage by longline

The longline gear which is usually used in tuna fishery covers approximately the range between 50 and 400 m depth as shown in Table 3. Therefore, it is very hard to get quantitative information out of this limited depth range. Some observations with sonic tags indicated that billfish are distributed in shallower water than this depth range of longline gear, and swordfish are distributed in a wider depth range than longline (Carey and Robison 1981, Holland *et al.* 1990, Holtz and Bedford 1990, Block *et al.* 1992). These results mean that longline does not cover the vertical range of billfish distribution sufficiently to obtain quantitative results.

Within the range of depths reached by longline gear, the hooking depth distribution observed by TDRs is similar to the vertical distribution of billfishes observed by sonic tag experiments, even though the number of direct observations of hooking depth is very small.

In this study all billfish individuals whose hooking time was identified were hooked while longline gear was settled. This result is unlike those obtained by Saito (1973) or Boggs (1992). Boggs (1992) pointed out that rising and sinking hooks are more effective at catching billfish than settled hooks. However, it cannot be concluded that billfish are usually hooked while longline gear is settled due to the insufficient number of observations.

Difference in the results obtained by TDR and catch by branch lines

There is a difference in the hooking depth distribution between direct observations by TDR (Figure 4) and the rough estimation from catch by branch lines (Figs. 5 and 6). The estimation from catch by branch lines shows that the hooking depth ranged to deeper water than did TDR observations. There are some potential causes for this difference. Catch by rising or sinking hooks may make the depth range estimated by the catch by branch lines deeper than that obtained by direct observation with TDRs. Another potential reason for the difference is that some of the hooks of deeper branch lines do not actually attain greater depths due to oceanographic conditions such as shear current. This phenomenon is usually observed during the operations when there is some shear current in the water column (Mizuno *et al.* 1997). We could not analyze this factor by direct TDR observations because of insufficient number of the observations in the present study.

There is a need to continue this type of survey for investigation of hooking depth and its relationship with oceanographic conditions, and of the relationship between underwater-movement of longline gear and oceanographic conditions. This information will be valuable for stock assessment, especially for the standardization of longline fishery CPUE data.

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Table 1. Summary of cruise and longline gear analyzed in this paper.

Cruise	Vessel	Kind of vessel	Duration of survey (longline)	Area	Length of branch line (m)	Interval of branch lines (m)	Length of float line (m)	Number of branch lines per basket	Number of TDR sensors used per set	Number of records of billfish catch on the branch line sensor was attached	Bathythermograph system (for details, see text)
Shoyo95	*Shoyo-maru*	Research vessel	1995/5/14-1995/7/2	Eastern Pacific Ocean	32	50	25	5-15	33-47	2	DTM-2M and DTM-512K
Shoyo97	*Shoyo-maru*	Research vessel	1997/6/29-1997/9/6	Eastern Pacific Ocean	32	Approx. 53	20	7-13	18-64	1	SBT-500
Wakatori98	*Wakatori-maru*	Chartered vessel	1998/2/2-1998/3/17	Central Pacific Ocean	25	50	25	7, 10 or 13	17-45	3	SBT-500
Shoyo98-99	*Shoyo-maru*	Research vessel	1999/1/7-1999/1/13	Western Indian Ocean	33	50	25	15 or 17	67-90	1	SBT-500
Wakatake99	*Wakatake-maru*	Chartered vessel	1999/2/5-1999/2/16	Central Pacific Ocean	35	48	33	13	24-25	1	SBT-500
Taikei99	*Taikei*	Chartered vessel	1999/4/14-1999/7/21	Western Pacific Ocean	22	50	20	4, 5, or 10	10-33	2	SBT-500
Shoyo99-00	*Shoyo-maru*	Research vessel	1999/10/17-2000/1/7	Eastern Pacific Ocean	25	40 or 50	15, 25, or 40	11-21	74-163	12	SBT-500

Table 2. Information on billfish that were hooked directly on the branch line where the TDR sensor was attached.

Cruise (for details, see Error! Reference source not found.)	Catch position		Catch date	Species	Hooking time of day	Hooking depth (m)	Eye fork length (cm)	Depth of thermocl (m)	
	Latitude	Longitude						Upper limit	Lowe limit
Shoyo98-99	13°00'N	120°01'E	1999/1/10	Black marlin	12:36	111	207	60	
Taikei99	13°06'N	133°48'E	1999/5/12	Blue marlin	8:58	138	146	100	
Taikei99	13°17'N	133°45'E	1999/5/19	Blue marlin	11:37	88	134	120	
Shoyo99-00	6°39'N	109°54'W	1999/10/17	Blue marlin	15:26	75	181.6	60	
Shoyo99-00	4°42'N	104°18'W	1999/10/24	Blue marlin	14:12	71	202.2	60	
Wakatori98	23°00'N	176°00'E	1998/2/8	Shortbill spearfish	8:53	133	144	80	
Wakatori98	24°52'N	167°55'E	1998/2/16	Shortbill spearfish	10:54	111	149	80	
Shoyo99-00	11°02'S	114°05'W	1999/11/18	Shortbill spearfish	17:09	55	142.2	80	
Shoyo97	6°49'N	96°38'W	1997/7/14	Striped marlin	12:37	50	179.4	40	
Wakatori98	24°24'N	171°53'E	1998/2/14	Striped marlin	7:54	133	112	110	
Wakatake99	18°37'N	175°18'E	1999/2/15	Striped marlin	14:44	152		100	
Shoyo99-00	4°20'N	109°21'W	1999/10/21	Striped marlin	16:46	97	148.5	60	
Shoyo99-00	4°49'N	109°43'W	1999/10/22	Striped marlin	14:22	110	162.4	70	
Shoyo99-00	4°42'N	104°18'W	1999/10/24	Striped marlin	12:17	79		60	
Shoyo99-00	4°42'N	104°18'W	1999/10/24	Striped marlin	9:13	104	185.2	60	
Shoyo99-00	4°46'N	101°34'W	1999/10/25	Striped marlin	9:10	90	185.5	70	
Shoyo99-00	11°01'S	114°26'W	1999/11/22	Striped marlin	17:48	100	171.3	70	
Shoyo95	4°09'S	105°34'W	1995/5/19	Swordfish	15:52	184	145.7	60	
Shoyo95	4°18'S	95°54'W	1995/6/23	Swordfish	11:47	212	65.0	30	
Shoyo99-00	11°01'S	114°26'W	1999/11/22	Swordfish	2:15	86	151.2	70	
Shoyo99-00	11°01'S	114°26'W	1999/11/22	Swordfish	22:40	117	115.2	70	
Shoyo99-00	10°57'S	114°47'W	1999/11/23	Swordfish	4:35	43	110.7	100	

Table 3. Maximum depth (m) of shallowest and deepest hook of longline gear for each cruises measured by TDRs. The data are limited to those whose catch number is shown in Fig. 6. The data of N0. 31 Koyo-Maru (whose number of catch of Atlantic blue marlin is shown in Fig. 8) were calculated using catenaly curve.

		Number of hooks per basket					
Cruise		5	9	10	13	15	19
Shoyo97	Shallowest hook		Avg. 80		Avg. 80		
	Deepest hook		Avg. 190		Avg. 210		
Wakatake99	Shallowest hook				116-144		
	Deepest hook				317-376		
Taikei99	Shallowest hook			65-80			
	Deepest hook			147-218			
Shoyo99-00	Shallowest hook	53-68				50-78	68-113
	Deepest hook	70-100				103-185	160-335
N0. 31 Koyo-Maru	Shallowest hook						125
	Deepest hook						275

Table 4. The relationship between hooking depth and thermocline for the four billfish species.

	Blue marlin	Shortbill spearfish	Striped marlin	Swordfish
Above the upper limit	1	1	0	1
Between upper and lower limit	3	0	8	2
Below the lower limit	0	0	0	2
Unknown	0	2*	1*	0

*At least under the upper limit of thermocline

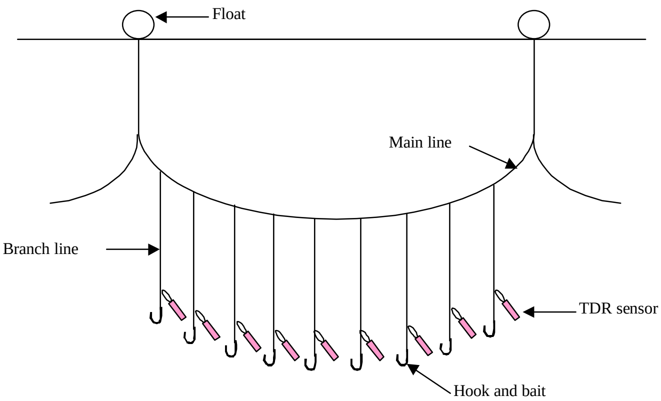

Figure 1. Setting of longline gear and position of TDR sensors (the proportion is different from the real set).

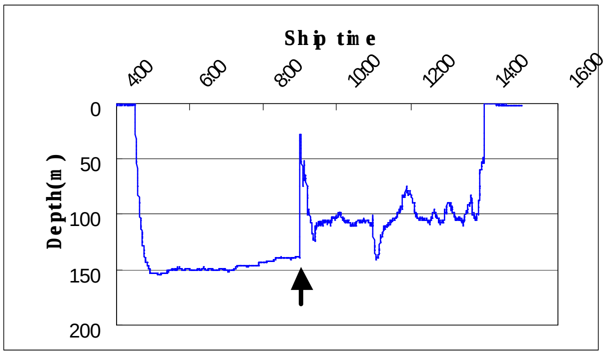

Figure 2. Example of depth trajectory of the branch line measured by TDR (SBT-500). The arrow in the graph shows the estimated hooking time. The species of this catch is blue marlin, 146cm in eye folk length, caught in the western Pacific Ocean (13°06'N,133°48'E).

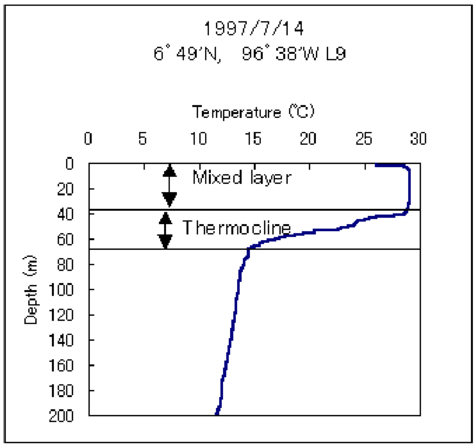

Figure 3. Definition of thermocline used in this paper (observed by XBT).

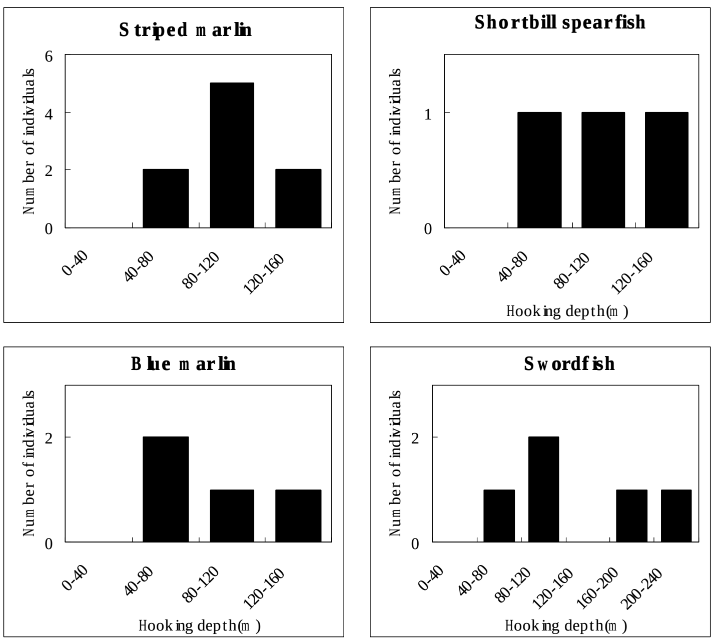

Figure 4. Frequencies of hooking depth of four billfish species.