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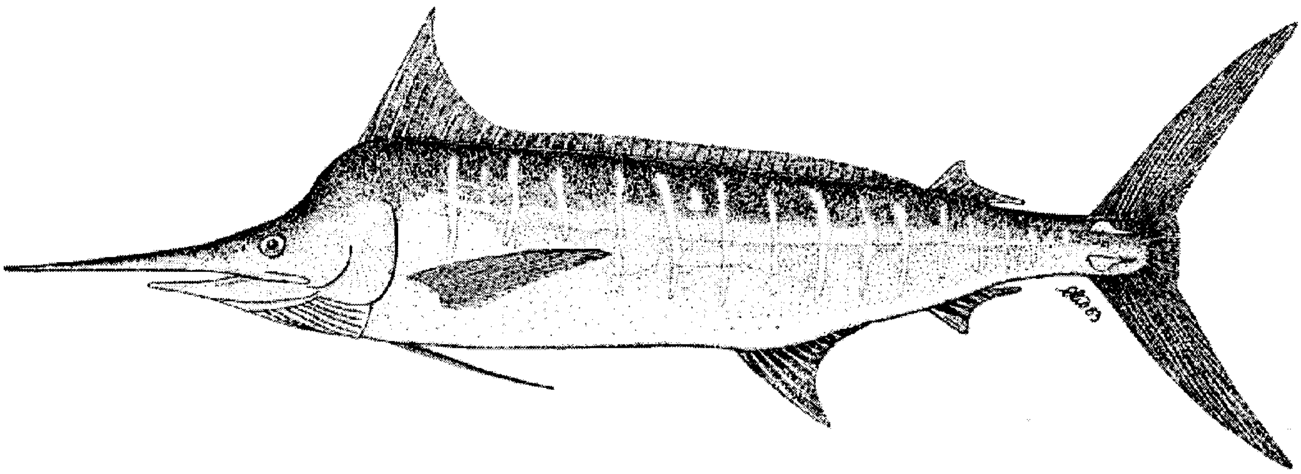
Preliminary review of billfish hooking depth measured by small bathythermograph systems attached to longline gear.



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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 in the Pacific and Indian Ocean. Catch by branch line number was also recorded and analyzed. A total of 22 individuals (21 were in the Pacific Ocean) were observed (directory hooked on the branch line a TDR line sensor was attached) for the five billfish species. Striped marlin, shortbill spearfish and blue marlin were hooked mainly at shallower depth than 120m and also mainly in the thermocline zone. On the other hand, swordfish was hooked at wider depth layer (43-212m). Catch by branch line, which may reflect vertical distribution of species, did not coincide with the results by bathythermograph systems. As the number of observations is still insufficient, more surveys and analyses are necessary.

1. Introduction

Knowing 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, 1997,1998,1999) or vertical longline operation (Saito and Sasaki, 1974; Saito, 1975), acoustic survey (Fujiishi et al., 1969), utilization of "archival" tags, 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; Verkeley and Edwards, 1997; Uozumi and Okamoto, 1997).

Some papers say that the billfish species (striped marlin *Tetrapturus audax* and shortbill spearfish *Tetrapturus angustirostris*) were caught at 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* in 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 CPUE by longline fishery. In recent years small bathythermograph system has been devised and put to practical use (Mizuno et al., 1996; Okazaki et al., 1997) and we recently began to use this system mainly in several experimental or commercial longline operations for investigation of underwater shape of longline gear or hooking depth, temperature and time of hooking. In this paper we review hooking depth of billfish species measured

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by bathythermograph system in the experimental longline operations.

2. 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, Uozumi and Okamoto, 1997) and "SBT-500" (Murayama Electronics Co., Ltd., 170mm in length, 18mm in diameter and 37g in water, Mizuno et al., 1996), were used during experimental longline operations by research and chartered vessels (Table 1). In this paper we call these systems as 'TDR (Time Depth Recorder)'. TDRs were attached to the branch lines (about 2-3m above the hook) (Fig. 1). TDR sensors recorded time, temperature (to the nearest 0.1℃) and depth (to the nearest 1m) at every 4 or 10 second and the data were analyzed by personal computers. 10 to 163 sensors were used in one longline operation. When a fish is hooked on the branch line, which a TDR was attached, catch depth was estimated from the depth trajectory graph (an example is shown in Fig. 2).

Also, the hooking depths were compared with the depth of thermocline measured by CTD, XBT or by TDR itself. Thermocline was defined as the layer in which water temperature decreases sharply (judged from the graph, for example, see Fig. 3).

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

3. Results

3.1. Observed hooking depths

A total of 22 (one in the Indian Ocean and the others in the Pacific Ocean) billfish individuals were hooked on the branch line 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 individuals of 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 individuals, which were analyzed in this study, were not hooked while hooks were sinking during gear setting or rising during retrieval. Frequency of catch depth for four species is shown in Fig. 4.

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

3.2. Catch number by branch lines

Catch number by branch lines for three species is shown in Fig. 5 for the four cruises used in the present study. Striped marlin was mainly hooked by shallower branch lines, but was partly caught by deeper ones. Blue marlin was also hooked by both shallower and deeper branch lines. In some cruises blue marlin 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 hook in the middle part of the basket (middle number in the figure), though the depth of deepest hook was variable due to the oceanographic condition. Table 3 shows the most hooks in the middle part of the basket were set at deeper water column than the depth of hooking observed by TDRs shown in Fig. 4. But Fig. 5 shows such hooks set at deeper layer caught frequently billfish.

Fig. 6 also shows the catch number 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 target species of the observed two vessels were bigeye tuna and the 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 catenaries shape for the main line under the water with standard sagging rate. The depth of shallowest hook was estimated as about 125m depth and the depth of deepest one as 275m depth.

There is a very clear contrast between the right and left figures in Fig. 6, though the operations of the both vessels were carried out in the similar area and similar season. The catch by branch lines of *No. 31 Koyo-Maru* (left figure) suggested that blue marlin is distributed to deeper water column, but it of *No. 81 Sumiyoshi-Maru* (right figure) suggested that the distribution of blue marlin is limited to the shallower water column as shown by the TDR records.

3.3. Relationship between hooking depth and thermocline depth

Upper and lower limits of thermocline corresponding to each catch position where hooking was 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 upper and lower limit of 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 observation was done by CTD or XBT.

4. Discussion

4.1 Vertical distribution of billfishes

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

The tendency of the hooking depth of blue marlin observed by TDR is also similar to the results of Holland et al. (1990) or Block et al. (1992). Hinton and Nakano (1996) also says 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 lines (Fig. 5) shows this species was not necessarily caught by shallower branch lines. The result of Atlantic blue marlin *Makaira nigricans* (Fig. 6) also shows that it is not necessarily the case that this species is caught by shallower branch lines. The cause of the disagreement between TDR and catch by branch line is not clear, but they might be resulted from unstableness of underwater shape of longline gear due to water current or difference of vertical distribution of billfishes among areas. The clear differences in the catch by branch lines between similar area shown in Fig. 6 suggested that there is a possibility that the differences in the tendency of catch number by branch lines between cruises were due to the difference in the oceanographic condition within the local operation area or the difference of the material and setting of longline gear between vessels.

As for shortbill spearfish, the result is similar to those in Boggs (1992), but Boggs (1992) also showed that the several individuals were hooked at deeper layer than 300m. Catch by branch lines data (Fig. 5) support Boggs (1992) that deeper branch lines also caught this species.

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

4.2 Vertical coverage by longline

The longline gear, which is usually used in tuna fishery, just covers the depth range approximately between 50 and 400m depth as shown in Table 3. Therefore, it is very hard to get quantitative information from out of this depth range. Some observations with sonic tags indicated billfish are distributed in the shallower water column than this depth range of longline gear, and swordfish is distributed in the 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 the longline does not cover the vertical range of billfish distributions sufficiently.

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

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

4.3 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 (Fig. 4) and the rough estimation by catch by branch lines (Figs. 5 and 6). The estimation by catch by branch lines shows the hooking depth ranged to deeper water column than TDR observations. There are some potential causes for this difference. Catch by rising or sinking hooks may affect to make depth range estimated by the catch by branch lines deeper than direct observation with TDRs. Another potential reason for the difference is that some of the hooks of deeper branch line do not attain to deeper layer due to the oceanographic condition such as share current. This phenomenon is usually observed during the operations when there is some share current in the water column (Mizuno et al., 1997). We could not analyze this factor by the direct observations with TDR because of insufficient number of the observations in the present study.

There are necessities to continue this type of surveys for investigation for hooking depth and it relationship with oceanographic condition, and furthermore the relationship between underwater-movement of longline gear and oceanographic condition. This information will be valuable for stock assessment, especially for the CPUE standardization of longline fishery.

Acknowledgements

We are thankful to the crew of *Wakatori-maru*, *Wakatake-maru*, *Taikei* and *Shoyo-maru*, who cooperated for the surveys.

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Table 1 Summery 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 of hooked billfish directly on the branch line TDR sensor was attached.

Cruise (for details, see Table 1)	Catch position		Catch date	Species	Hooking time of day	Hooking depth (m)	Eye fork length (cm)	Depth of thermocline (m)	
	Latitude	Longitude						Upper limit	Lower limit
Shoyo98-99	13°00'N	120°01'E	1999/1/10	Black marlin	12:36	111	207	60	220
Taikei99	13°06'N	133°48'E	1999/5/12	Blue marlin	8:58	138	146	100	300
Taikei99	13°17'N	133°45'E	1999/5/19	Blue marlin	11:37	88	134	120	350
Shoyo99-00	6°39'N	109°54'W	1999/10/17	Blue marlin	15:26	75	181.6	60	150
Shoyo99-00	4°42'N	104°18'W	1999/10/24	Blue marlin	14:12	71	202.2	60	130
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	280
Shoyo97	6°49'N	96°38'W	1997/7/14	Striped marlin	12:37	50	179.4	40	90
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	400
Shoyo99-00	4°20'N	109°21'W	1999/10/21	Striped marlin	16:46	97	148.5	60	130
Shoyo99-00	4°49'N	109°43'W	1999/10/22	Striped marlin	14:22	110	162.4	70	120
Shoyo99-00	4°42'N	104°18'W	1999/10/24	Striped marlin	12:17	79		60	130
Shoyo99-00	4°42'N	104°18'W	1999/10/24	Striped marlin	9:13	104	185.2	60	130
Shoyo99-00	4°46'N	101°34'W	1999/10/25	Striped marlin	9:10	90	185.5	70	130
Shoyo99-00	11°01'S	114°26'W	1999/11/22	Striped marlin	17:48	100	171.3	70	260
Shoyo95	4°09'S	105°34'W	1995/5/19	Swordfish	15:52	184	145.7	60	100
Shoyo95	4°18'S	95°54'W	1995/6/23	Swordfish	11:47	212	65.0	30	70
Shoyo99-00	11°01'S	114°26'W	1999/11/22	Swordfish	2:15	86	151.2	70	260
Shoyo99-00	11°01'S	114°26'W	1999/11/22	Swordfish	22:40	117	115.2	70	260
Shoyo99-00	10°57'S	114°47'W	1999/11/23	Swordfish	4:35	43	110.7	100	210

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. 5. The data of *NO. 31 Koyo-Maru* (whose number of catch of Atlantic blue marlin is shown in Fig. 6) 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
NO. 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

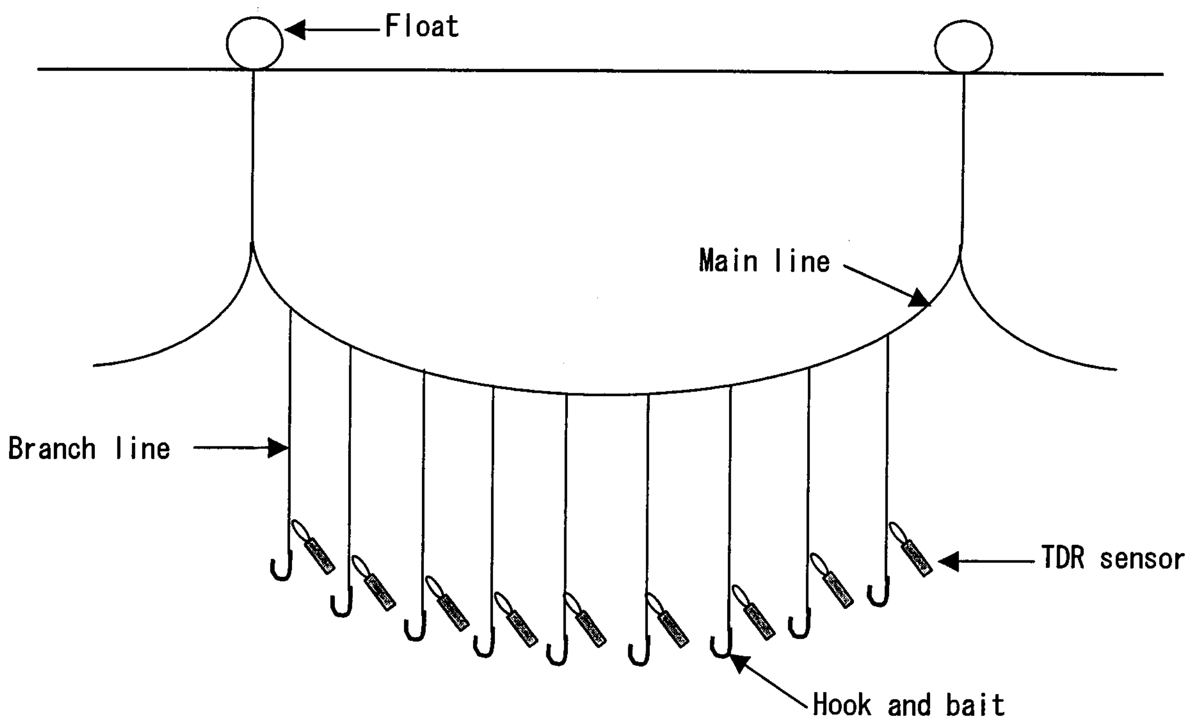

Fig. 1 Setting of longline gear and position of TDR sensors (the proportion is different from the real set).

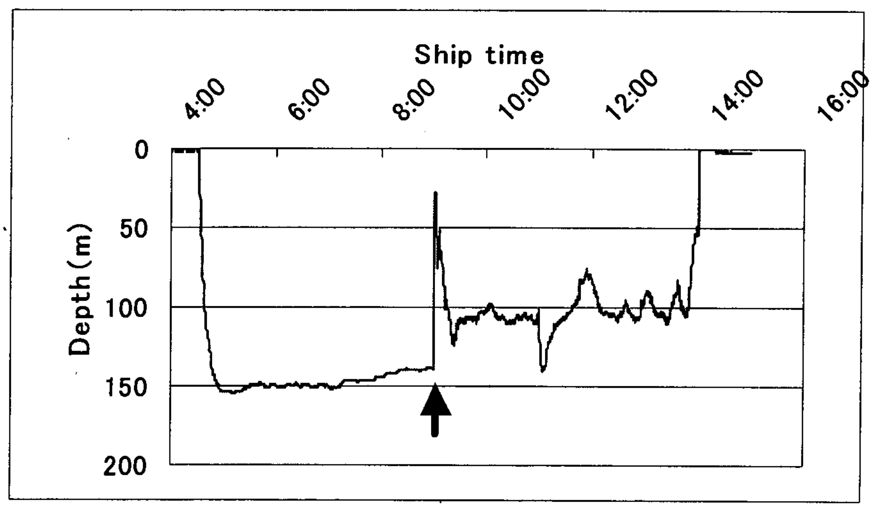

Fig. 2 Example of depth trajectory of the branch line measured by TDR (SBT-500). The arrow in the graph shows the estimated hooking time. The species of this catch is blue marlin, 146cm in eye folk length, caught in the western Pacific Ocean (13° 06'N,133° 48'E).

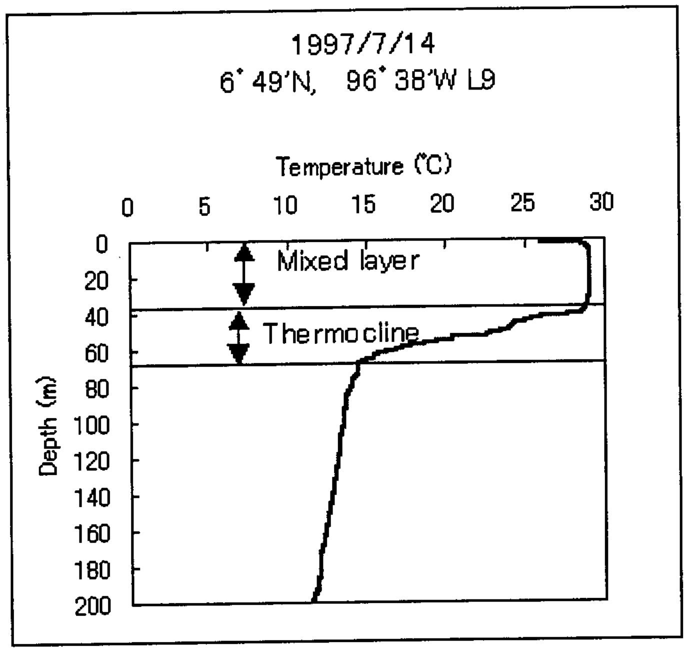

Fig. 3 Definition of thermocline used in this paper (observed by XBT).

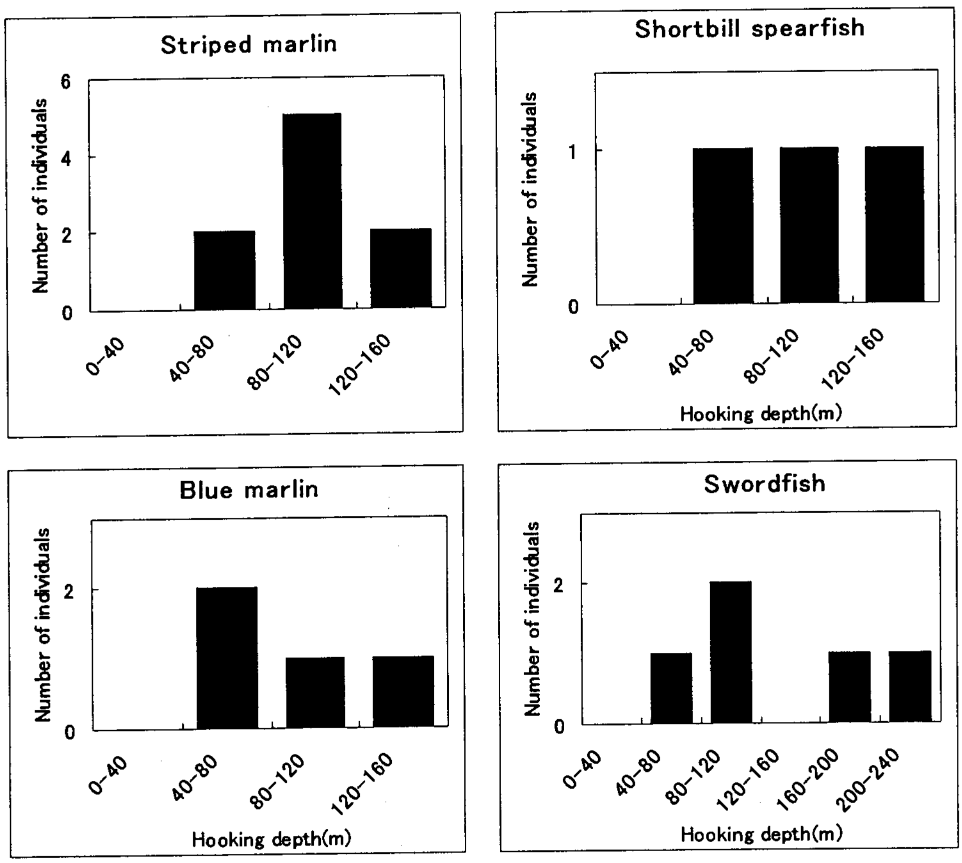

Fig. 4 Frequencies of hooking depth of four billfish species.

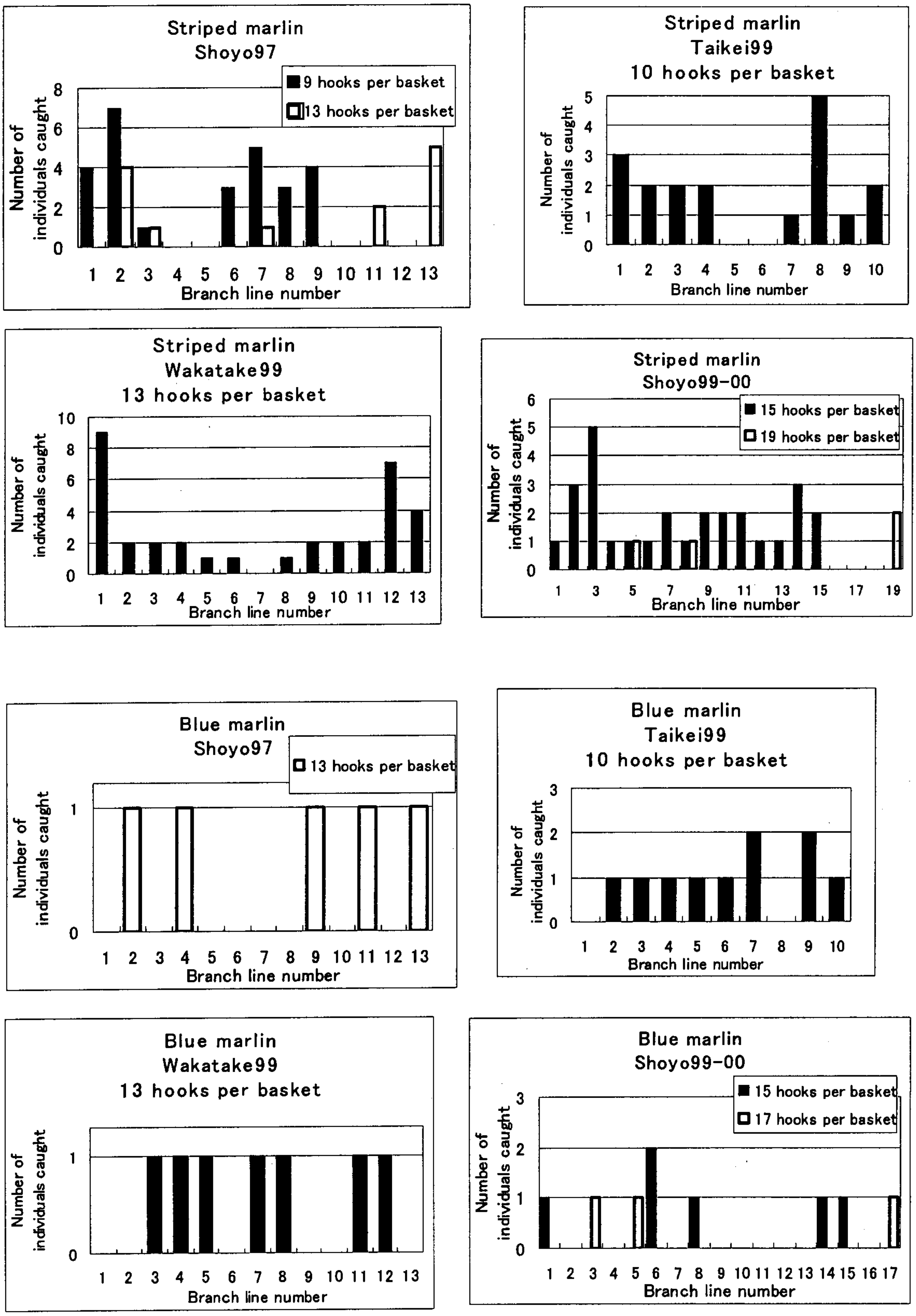

Fig. 5 Number of catch by branch lines for the four cruises and species analyzed in this paper. The cruise name written in the graph (under species name) corresponds to that in Table 1.

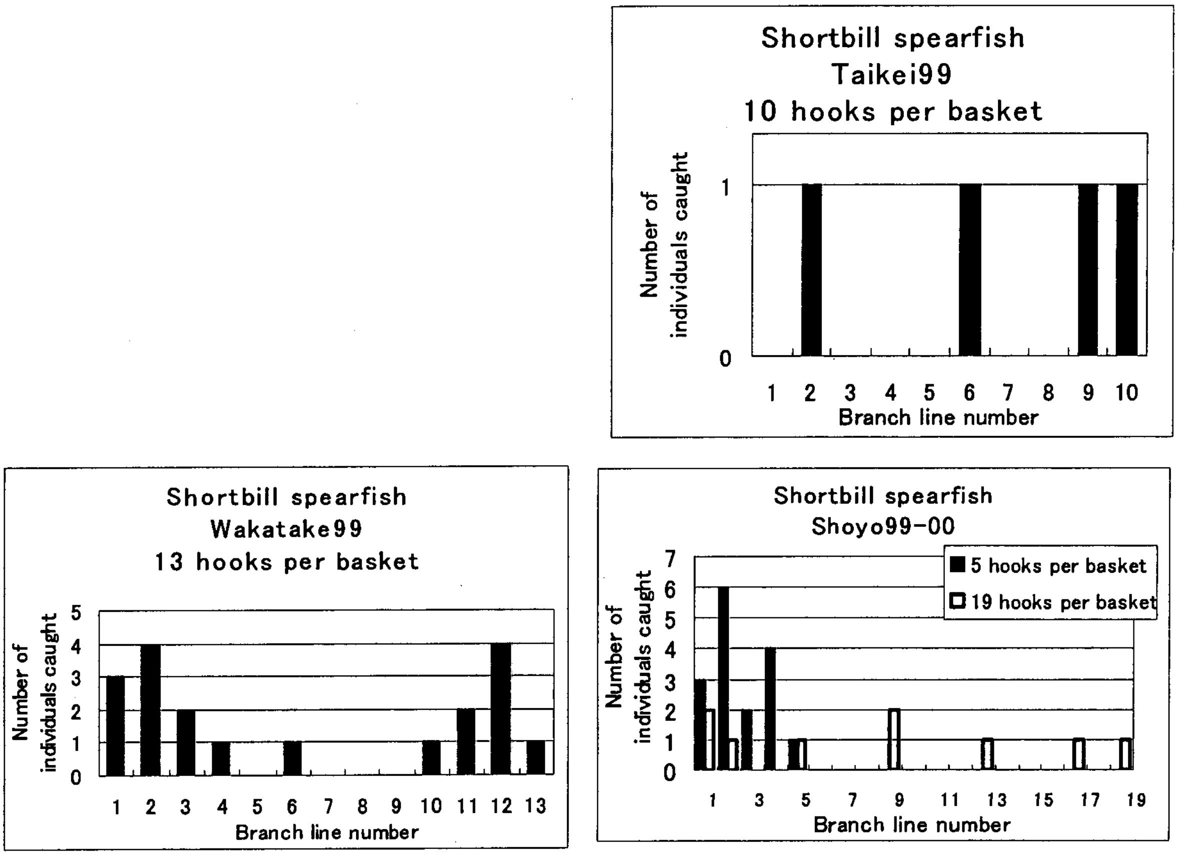

Fig. 5 (continued)

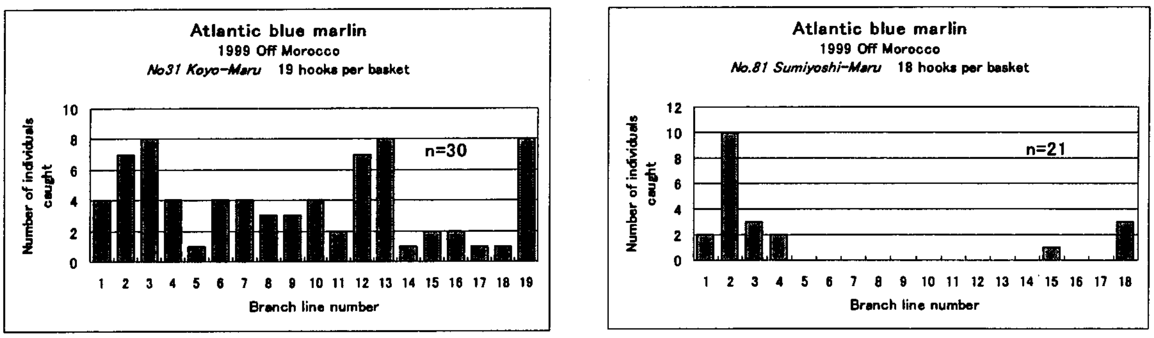

Fig. 6 Catch number of Atlantic blue marlin in the Atlantic Ocean by branch lines of longline gear. From Matsumoto and Miyabe (1999).