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Analysis of Catch Depth by species for Tuna Longline Fishery Based on Catch by Branch Lines

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Abstract

It is important to know the catch depth of fish for longline fishery to examine the fishing efficiency of the longline gear on species, and to understand the vertical distribution of fish. Since Japanese tuna longline fishery historically has been changing its gear depth, it is also important to compare the efficiency of shallow and deep longline gear for all species caught periodically. Recent information on catch by branch line of tuna longline was available during the four research cruises conducted in three areas in the Pacific Ocean from 1992 to 1995. Catch rates by depth were calculated using a depth estimation formula in which the mainline was assumed to hang in a catenary curve. Each species caught was classified into three categories respect to trend of catch rate by depth, i.e., a decrease, an increase and no clear difference groups with depth. Albacore (*Thunnus alalunga*), bigeye tuna (*T. obesus*), opah (*Lampris guttatus*), Pacific lancetfish (*Alepisaurus ferox*), sickle pomfret (*Taractichthys steindachneri*) and bigeye thresher (*Alopias superciliosus*) were classified as a group in which catch rates increased with depth. In contrast, the catch rate decreased with depth for skipjack tuna (*Katsuwonus pelamis*), striped marlin (*Tetrapturus audax*), Pacific blue marlin (*Makaira mazara*), sailfish (*Istiophorus platypterus*), shortbill spearfish (*T. angustirostris*), wahoo (*Acanthocybium solandri*), snake mackerel (*Gempylus serpens*) and oceanic whitetip shark (*Carcharhinus longimanus*). Yellowfin tuna (*T. albacares*), swordfish (*Xiphias gladius*), escolar (*Lepidocybium flavobrunneum*), shortfin mako shark (*Isurus oxyrinchus*) and blue shark (*Prionace glauca*) showed no clear trends of catch rate with depth. In the equatorial eastern Pacific, the depths for high catch rate tends to be shallower than eastern area off Hawaii and the equatorial central Pacific for albacore, bigeye tuna, wahoo, opah and shortfin mako shark. A comparison of the means of catch rate between shallow and deep setting of hooks showed thirteen of twenty two species with a significant difference between shallow and deep catch rates. Species in which catch rates increased with depth had values of 1.51 to 20.6 (i.e., albacore 1.51–2.15, bigeye tuna 2.14–3.14, opah 20.6, Pacific lancetfish 1.63, sickle pomfret 6.76 and bigeye thresher 2.67) in the ratio of deep to shallow longline catch rates. Species in which catch rates decreased with depth showed a range of the ratios from 0.4 to 0.92 (i.e., striped marlin 0.4–0.64,

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Pacific blue marlin 0.75, sailfish 0.92, shortbill spearfish 0.42–0.74, dolphinfish 0.46, snake mackerel 0.72).

Introduction

Hook depths of the Japanese tuna longline fishery has been setting deeper after 1975, due to more targeting to commercially important bigeye tuna (*Thunnus obesus*), which inhabits deeper waters (Suzuki et al. 1977). Setting to longline hooks deeper is generally accomplished by increasing number of branch lines between floats, since distance between individual branch lines remained unchanged, about 50m.

It is well known that tuna catch rate in a longline fishery differs by hook depth for each species (Hanamoto 1974, Nishi 1990, Boggs 1992). Therefore, information on the gear configuration of the longline, such as the number of branch lines between floats (which is indicating of relative depth), has to be included as one of the parameters affecting the catch rate (Punsly and Nakano 1992). For comparison of catch rate between shallow and deep longline gears of the tuna longline fishery, the catch rates of branch lines shallower than 180 m (which is the maximum depth of the shallow longline gear mentioned by Suzuki et al. (1977)) and that of overall branch lines, which corresponds to deep longline, were calculated by set for each species.

In order to know the actual catch depths, an observation of the depth of each hook is needed, since hook depth differs among the branch lines between the floats. Hanamoto (1974) reported a difference between observed hook depth by depth recorder and that calculated based on a catenary curve. He pointed out that for shallow longline gear (i.e. 5 branch lines between floats), the maximum hook depth obtained by depth recorder ranged between 60–160m, while theoretical values were between 90–170m. Boggs (1992) pointed out that observed set depths were only 54% to 68% of the predicted depths of deeper longline gear (i.e. 12–20 branch lines between floats). Longline gear is sometimes blown up by the horizontal shear of ocean currents (Mizuno et al. 1997), which indicates direct depth observations are recommended in studies of the vertical distribution of catches by longline gear.

However, collection of information on the catch by branch line in a longline fishery is a simple and practical way to investigate the difference of catch rate by depth. Furthermore, it has some very important merit over direct depth observation, namely it is easy to collect a huge quantity of catch and effort information from different fishing areas with hook depths estimated by assuming the hooks hang from a catenary curve (Yoshihara 1951). Although previous studies pointed out that the actual depth of hooks tends to be shallower than the depth estimated (Hanamoto 1974, Nishi 1990, Boggs 1992), the latter is the practical approach because direct measurements of catch depth from depth recorders attached to longline gear are seldom available so far.

It is also important to estimate catch depth for all species caught, since international concerns for the conservation of non–target species have been increasing. Here, we estimate hook depth and then compare the catch rate of the longline gear by depth, for both target and non–target species.

Materials and Methods

Catch records by branch line from the tuna longline fishery were collected by researchers, including the authors, while aboard three fishery high school training vessels i.e., *Miyagi–maru* (FAJ 1994), *Ashu–maru* (Nakano and Seki 1995), and *Shinkai–maru* (Okazaki and Nakano 1995), and also while aboard the research vessel, *Kaihatsu–maru* of the Japan Marine Fishery Resources Research Center (JAMARC 1996).

Longline research cruises were conducted in three areas of the Pacific Ocean from 1992 to 1995: an area of the equatorial central Pacific (two cruises), an eastern area off Hawaii, and an area of the equatorial eastern Pacific (Figure 1). Research periods, areas, number of longline operations conducted, and number of branch lines used between floats are shown in Table 1. A total of 153

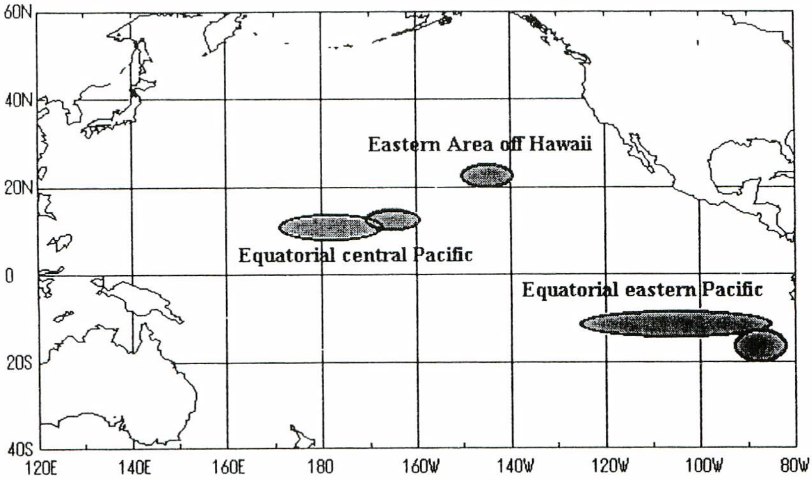

Fig. 1. Areas of the longline data collected during 1992 to 1995 and provided for the present study.

Table 1. Research periods, areas, number of operations and number of branch lines between floats for research vessels from which the present analysis was made.

Vessel name	Research Period	Research Area	Number of Operations	Branch lines between floats
Miyagi–maru	Oct.–Nov.1992	Eastern area off Hawaii	32	13
Ashu–maru	Jan.–Mar.1995	Equatorial central Pacific	38	12
Shinkai–maru	Jan.–Mar.1995	Equatorial central Pacific	38	12
Kaihatsu–maru	Jun.–Jul.1994	Equatorial eastern Pacific	45	10–15

longline operations were conducted during the research periods. The number of hooks used ranged from 2,254 to 2,400 per operation. Longline gear was set in the early morning and was retrieved from noon to midnight. During the research, the branch line number was recorded whenever a fish was caught (coverage 45 to 100% by species by cruise).

A total of twenty seven species, including four tunas, five billfishes, swordfish, eight other teleosts, and nine elasmobranchs were recorded. Scientific, English common, and Japanese names of the observed species are shown in Table 2. The number of observations (catches) by species are shown in Table 3. Catch of a total of 10,921 individuals were recorded by branch line.

Table 2. Scientific, English common and Japanese names of the fish caught by the longline research.

Scientific name	English common name	Japanese name
Thunnus alalunga	Albacore	Binnaga
Thunnus obesus	Bigeye tuna	Mebachi
Thunnus albacares	Yellowfin tuna	Kihada
Katsuwonus pelamis	Skipjack tuna	Katsuo
Xiphias gladius	Swordfish	Mekajiki
Tetrapturus audax	Striped marlin	Makajiki
Makaira mazara	Pacific blue marlin	Kurokajiki
Makaira indica	Black marlin	Shirokajiki
Istiophorus platypterus	Sailfish	Basyoukajiki
Tetrapturus angustirostris	Shortbill spearfish	Fuuraikajiki
Acanthocybium solandri	Wahoo	Kamasusawara
Coryphaena hippurus	Dolphinfish	Shiira
Lampris guttatus	Opah	Akamanbou
Lepidocybium flavobrunneum	Escolar	Aburasokomutsu
Alepisaurus ferox	Pacific lancetfish	Mizuuo
Gempylus serpens	Snake mackerel	Kurotachikamasu
Taractichthys steindachneri	Sickele pomfret	Hirejiromanzaiuo
Taractes rubescens	Dagger pomfret	Tsurugiechiopia
Pseudocarcharias kamoharai	Crocodile shark	Mizuwani
Alopias superciliosus	Bigeye thresher	Hachiware
Alopias pelagicus	Pelagic thresher	Nitari
Isurus oxyrinchus	Shortfin mako	Aozame
Isurus paucus	Longfin mako	Bakeaozame
Carcharhinus falcifarmis	Silky shark	Kurotogarizame
Carcharhinus longimanus	Oceanic whitetip shark	Yogore
Prionace glauca	Blue shark	Yoshikirizame
Dasyatis violacea	Blue stingray	Karasuei

The hanging depths of hooks on branch lines were calculated using the theoretical method described by Yoshihara (1951), in which the mainline is assumed to be hanging in a catenary curve. This method requires information on the construction details of the longline gear and on the sagging rate. The latter is approximately determined by the setting speed of a gear of a particular construction. For example, when the vessel moved 500 m from float to float during setting gear and the length of main rope between floats was 1000m, the sagging rate was 0.5.

The catch rate in number caught per 1,000 hooks by species by depth was calculated as:

Table 3. Number of fish recorded by branch line by research vessel.

Species	*Miyagi-maru*	*Ashu-maru*	*Shinkai-maru*	*Kaihatsu-maru*
Albacore	177	1121	628	1291
Bigeye tuna	840	923	894	268
Yellowfin tuna	27	376	295	325
Skipjack tuna	9	120	252	
Swordfish	8	9	3	30
Striped marlin	195	256	112	15
Pacific blue marlin	13	151	90	4
Black marlin	2			
Sailfish	3	1	1	
Shortbill spearfish	35	161	118	8
Wahoo	37			67
Dolphinfish	235			
Opah	70			52
Escolar	20			
Pacific lancetfish	463			
Snake mackerel	171			
Sickele pomfret	22			
Dagger pomfret	5			
Crocodile shark	1	14	1	
Bigeye thresher	34	24	15	
Pelagic thresher		1	1	
Shortfin mako	15			85
Longfin mako	2	2	1	
Silky shark		2	3	
Oceanic whitetip shark	3	24	14	
Blue shark	218	243	302	
Blue stingray	13			
Total	2618	3428	2730	2145

$$CR_{ij} = 1000 \times R_i \times C_{ij} / H_j$$

where CR_{ij} ; catch rate of the species i by the depth j,

R_i ; raising factor of the species i,

C_{ij} ; observed catch number of the species i by the depth j,

H_j ; number of hooks by the depth j,

The raising factor is the ratio of total number of the catch by species to number of caught with branch line information by species. Since branch line information was not recorded for all fish caught, the number of fish with branch line information was raised to the total number caught.

These catch rates were calculated for each cruise separately, and profiles of catch rate of the different species by depth were compared.

The means and variances of these respective catch rates were calculated for species caught. The difference in the means of catch rate between shallow and deep for each species was examined by t–test. Ratios of the catch rate for deep to catch rate of the shallower lines, which approximate the swimming depth of hooked species, were also calculated.

Results

1) Catch rate by depth

Catch rate by depth for tunas and billfishes show similar trends for each species among the three research cruises conducted in the central tropical Pacific by *Ashu–maru, Shinkai–maru* and an eastern area off Hawaii by *Miyagi–maru* (Figs. 2, 3, 4). *Kaihatsu–maru* reveals rather shallower catch than other three areas in an area of tropical eastern Pacific Ocean (Fig. 5). The difference was described in details in the next section. The results of the observations from *Ashu–maru* are shown in Figure 2. For the tunas, the catch rate for albacore (*T. alalunga*) and bigeye tuna catch rates increased with depths. In contrast, the catch rates of skipjack (*Katsuwonus pelamis*) decreased with depths. Yellowfin tuna (*T. albacares*) showed neither an increasing nor a decreasing trend with depth. For all billfishes showed a trend of decreased catch rate with deeper depth of hooks. But there was no clear trend for swordfish (*Xiphias gladius*), although number of observation was very small (N=9).

Figure 3 shows catch rates by depth for other teleosts caught by the *Miyagi–maru.* Three species, i.e. wahoo (*Acanthocybium solandri*), dolphinfish (*Coryphaena hippurus*), and snake mackerel (*Gempylus serpens*) showed increased catch rates at shallower depths. Three other species, opah (*Lampris guttatus*), Pacific lancetfish (*Alepisaurus ferox*), and sickle pomfret (*Taractichthys steindachneri*), were caught more frequently as the depth of hooks increased. The escolar (*Lepidocybium flavobrunneum*) indicated no clear trend by depth.

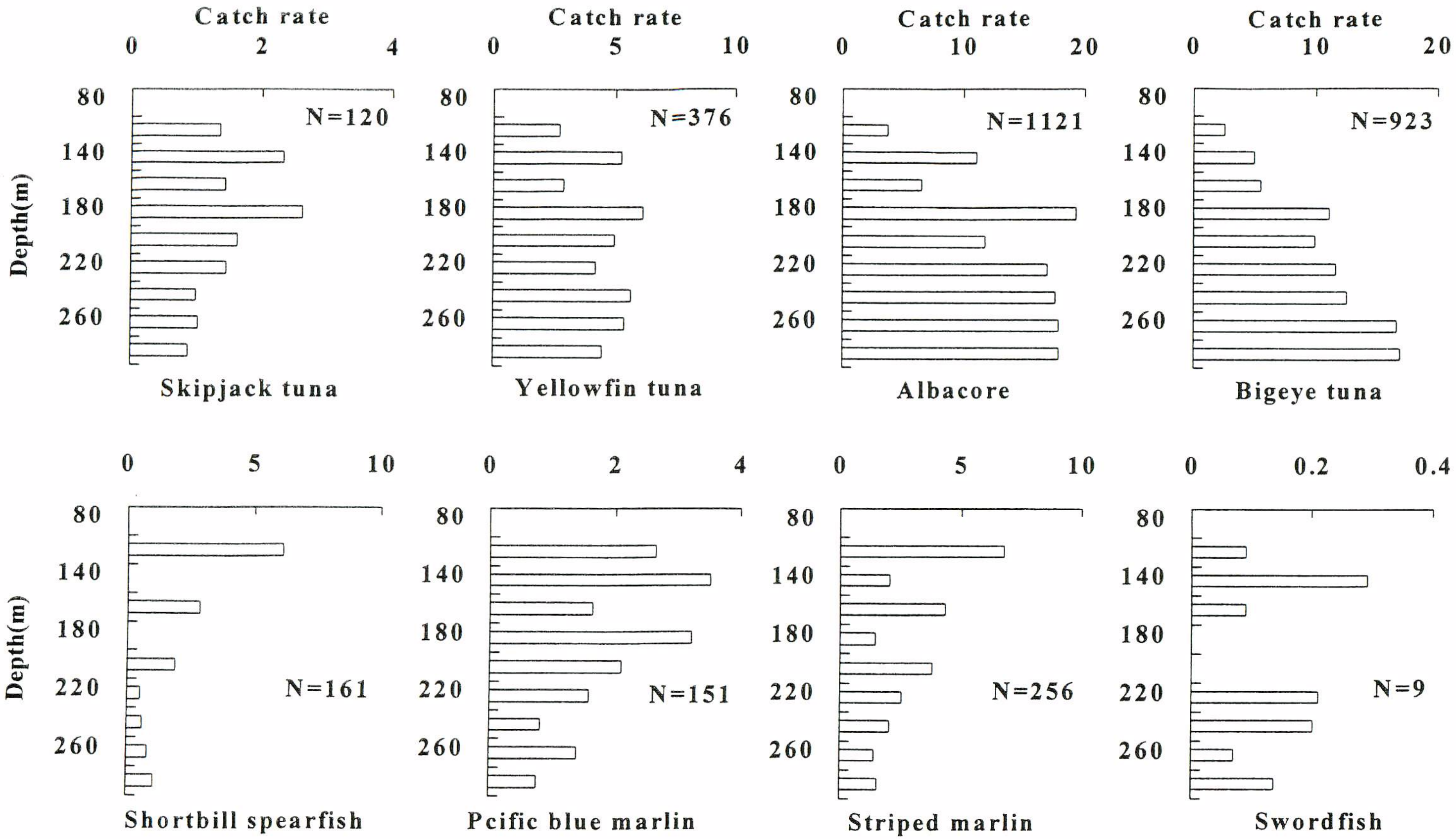

Fig 2. Catch rate by depth for tunas and billfishes caught by *Ashu–maru*.

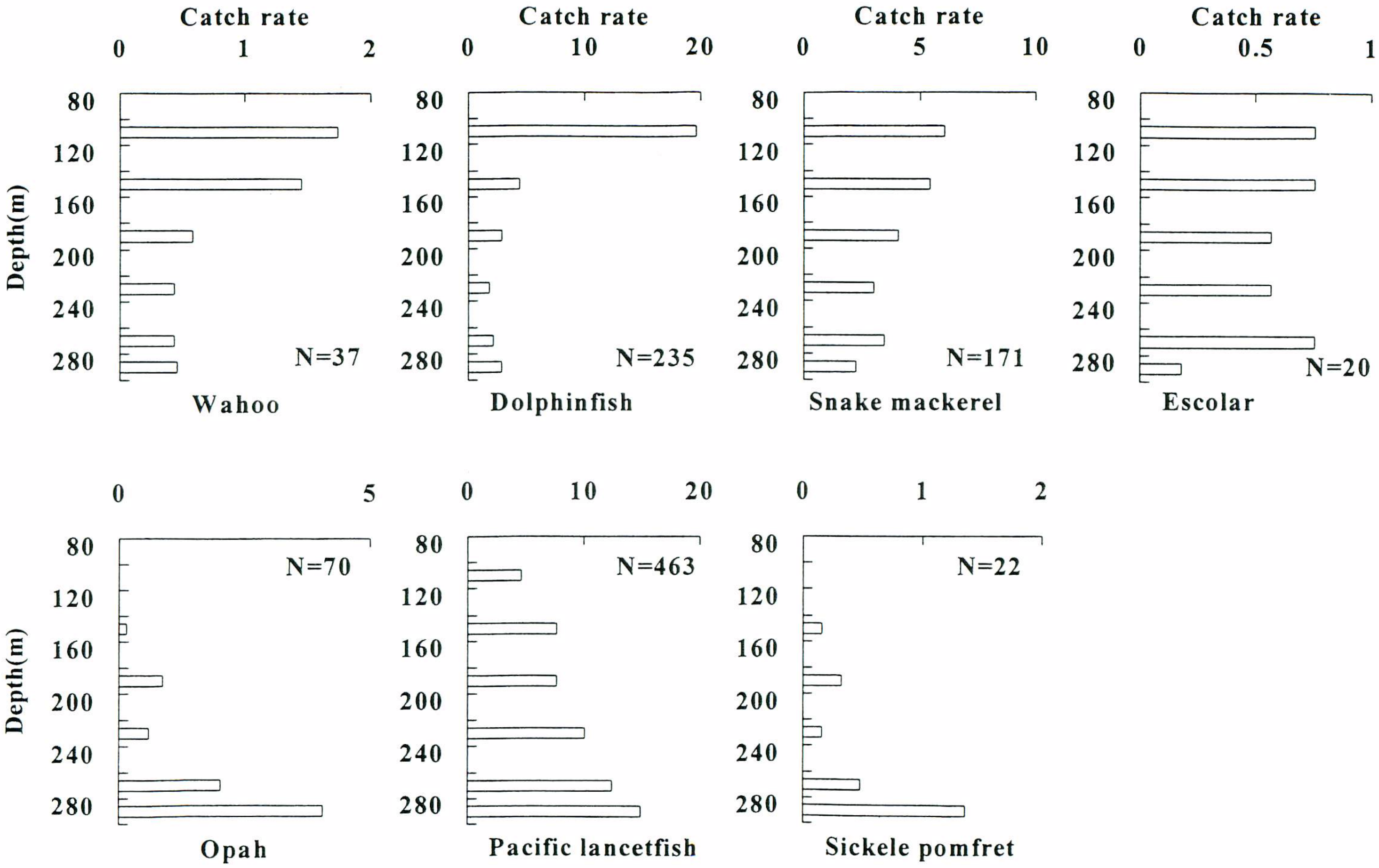

Fig 3. Catch rate by depth for other teleosts caught by *Miyagi–maru*.

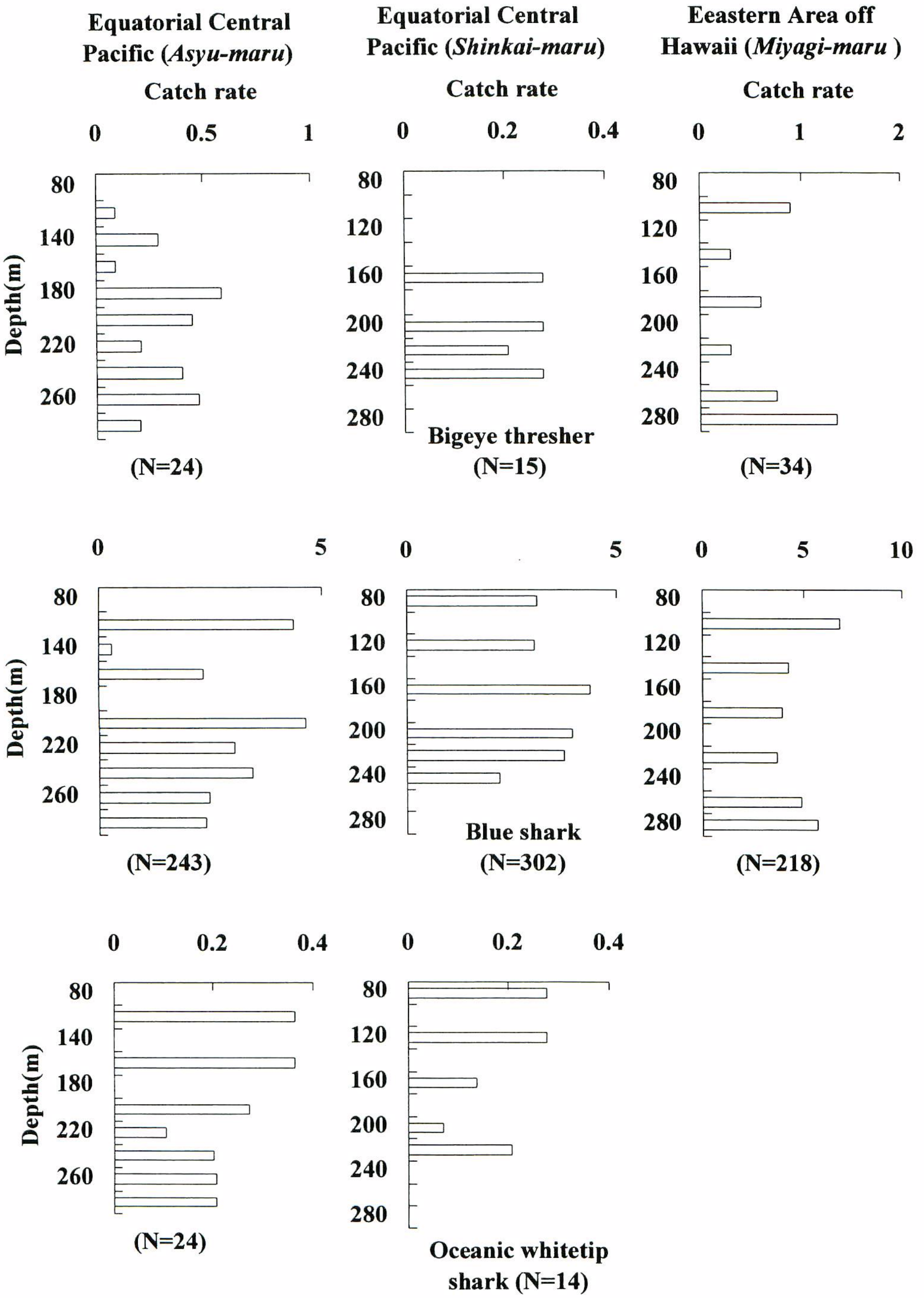

Fig 4. Catch rate by depth for sharks caught by *Ashu–maru, Shinkai–maru* and *Miyagi–maru* from the equatorial area and eastern area off Hawaii.

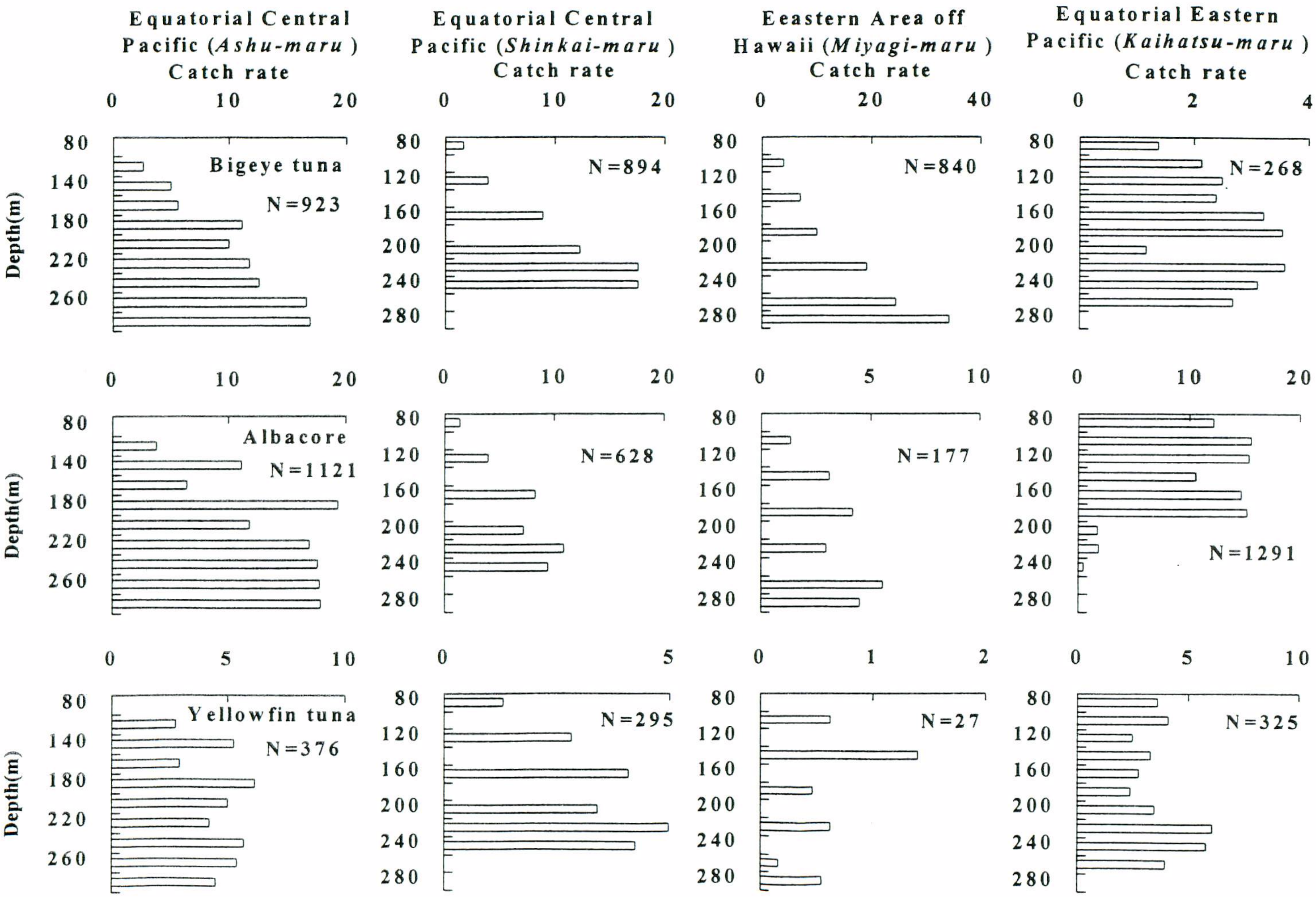

Fig 5. Comparison of tuna catch rate by depth among areas.

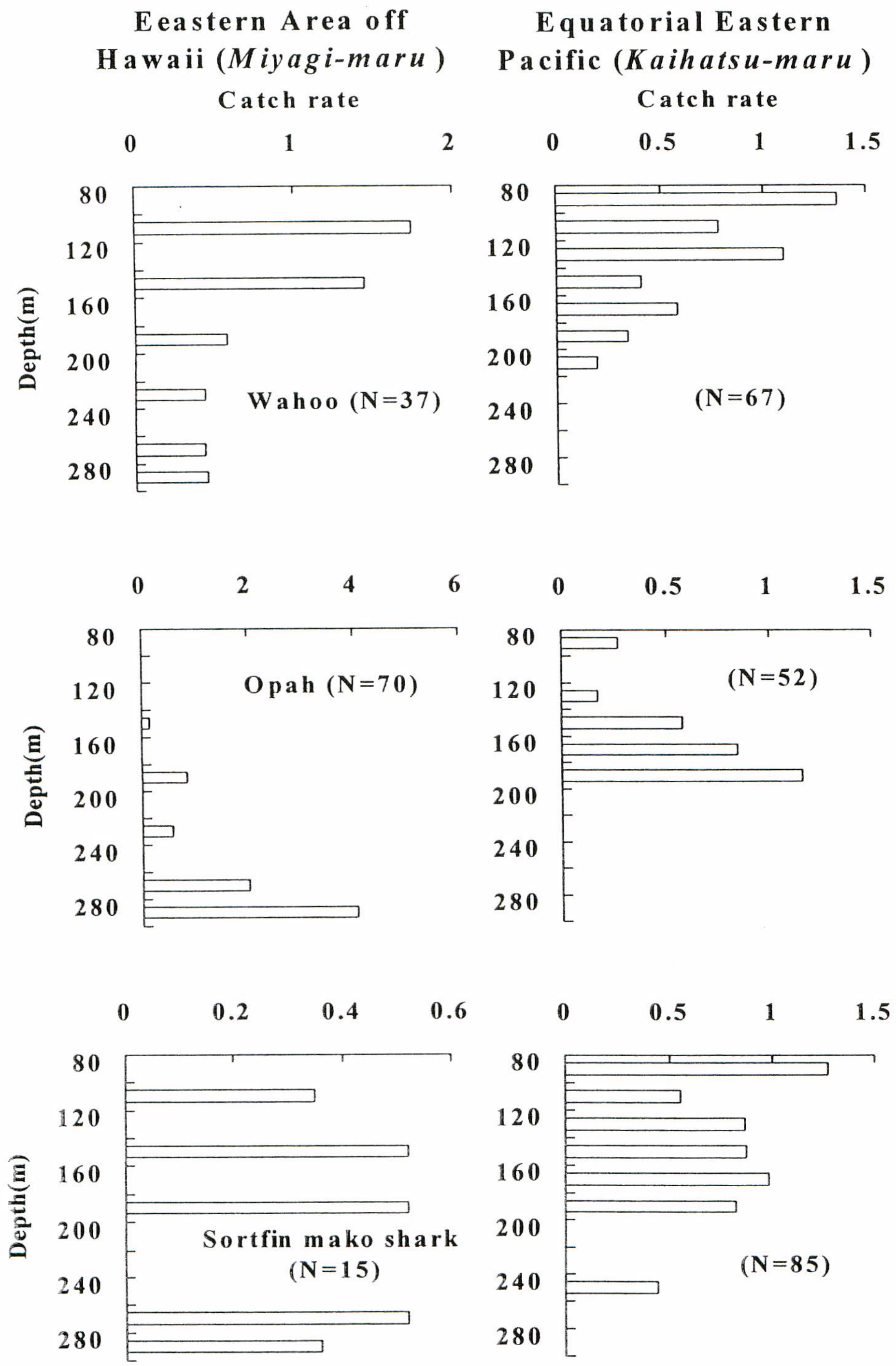

Fig 6. Comparison of catch rate by depth between areas for wahoo, opah and shortfin mako shark.

Catch rates by depth for three shark species are shown in Figure 4 for three research cruises that caught them in the central Pacific Ocean and an area off Hawaii. Catch rates of bigeye thresher (*Alopias superciliosus*) were higher when hooks were set deeper, while the catch rates of the blue shark (*Prionace glauca*) did not show a clear trend with depth of hooks. The catch rates of the oceanic whitetip shark (*Carcharhinus longimanus*) showed a decreasing trend with hook depth.

2) Difference of catch depth by area

Catch rates of three tuna species by the four research cruises in the equatorial central Pacific, an eastern area off Hawaii and the equatorial eastern Pacific are shown in Figure 5, in which the equatorial central Pacific is represented by the data from two different cruises. The catch rate of bigeye tuna increased with depth in the equatorial central Pacific and in an eastern area off Hawaii. However, in the equatorial eastern Pacific, it increased to a maximum at intermediate depths of 180 to 220 m, then decreased at deeper depths. The catch rate of albacore increased with depth in all areas except in the equatorial eastern Pacific, where similar high catch rates occurred at upper depths layer shallower than 200 m. Yellowfin tuna showed no clear trend in catch rate by depth among all the areas.

Differences in catch rate by depth between the eastern area off Hawaii and the equatorial eastern Pacific are shown in Figure 6 for three other species caught in those areas, i.e. wahoo (higher rates at shallow depths), opah (higher rates at deep depths), and shortfin mako shark (*Isurus oxyrinchus*) (showing no clear trend with depth). For all three species, depths of capture were shallower in the equatorial eastern Pacific compared with the eastern area off Hawaii.

3) Comparison of means of catch rate by gear depth

The observations of *Miyagi–maru* from the area east of Hawaii were used in this analysis, since a relatively large numbers of observations were available for a comparison of three tunas, four billfishes, seven teleosts and four elasmobranchs. Table 4 shows means and variances of catch rates for depth of branch lines shallower than 180m and for the deep longline, with the results of t–tests for the difference between the means of the deep longline and the shallow branch lines. The comparison of catch rates was made between branch lines shallower than 180m and the deep longline for its purpose of comparing the fishing efficiency between the two gear types, rather than comparing the catch rate by depth per species. The ratio of deep longline to shallow branch line catch rates are also given for each species. Eleven of eighteen species showed significant difference between their shallow and overall means. Ratios of the catch rate ratios for albacore, bigeye tuna, opah, Pacific lancetfish and sickle pomfret were larger than 1.0 (ranging from 1.63 to 20.6) indicating these fishes inhabit deeper waters and are caught by deep rather than shallow hooks. Striped marlin, sailfish, shortbill spearfish, wahoo and snake mackerel had small ratio values (ranging from 0.42 to 0.92), indicating these fishes inhabit the shallower depths and are caught efficiently by shallow longline gear.

Table 4. Mean catch rates and variances by species for the shallower branch lines and overall branch line during the cruise of *Miyagi–maru* (n=32) are shown respectively. The results of t–test and ratio between overall branch lines and shallower one were also shown.

Species	Shallow (S) Mean	Shallow (S) Variance	Overall (O) Mean	Overall (O) Variance	t value	Ratio O/S
Albacore	1.613	3.223	2.671	4.510	3.416**	1.66
Bigeye tuna	3.937	12.887	12.378	22.925	13.510**	3.14
Yellowfin tuna	0.664	1.274	0.438	0.443	1.868	0.66
Striped marlin	7.163	23.463	2.875	3.283	7.531**	0.40
Pacific blue marlin	0.142	0.195	0.175	0.077	0.568	1.23
Salifish	0.047	0.070	0.044	0.032	3.827**	0.92
Shortbill spearfish	1.186	2.800	0.496	0.414	3.336**	0.42
Wahoo	1.044	1.326	0.525	0.220	3.614**	0.50
Dolphinfish	7.400	60.624	3.386	11.001	4.859**	0.46
Opah	0.047	0.070	0.978	0.411	7.416**	20.60
Escolar	0.380	0.572	0.292	0.144	0.859	0.77
Pacific lancetfish	4.032	9.655	6.583	8.215	5.534**	1.63
Snake mackerel	3.368	5.074	2.408	2.026	3.244**	0.72
Sickele pomfret	0.047	0.070	0.321	0.125	4.100**	6.76
Shortfin mako	0.380	0.716	0.292	0.144	0.793	0.77
Blue shark	3.605	7.762	3.488	4.630	0.445	0.97
Bigeye thresher	0.380	0.572	0.511	0.351	1.237	1.35
Blue stingray	0.237	0.447	0.190	0.147	0.594	1.80

**Significant at 1% level.

The same calculations were also done for the observations by *Shinkai–maru* and *Ashu–maru,* which operated in the equatorial central Pacific, and by *Kaihatsu–maru* which operated in the equatorial eastern Pacific (Table 5, 6, 7). Three of ten species, seven of eleven species and two of eight species there showed significant differences of the mean catch rates between shallow and overall means, in respectively. Of these, albacore, bigeye tuna and bigeye thresher had high overall to shallow ratios (from 1.51 to 2.67), and striped marlin, Pacific blue marlin, shortbill spearfish and wahoo had low ratios (from 0.52 to 0.83). The latter are caught commonly at shallow depths. Yellowfin tuna revealed various results which includes increase, decrease and no clear trend and was classified into the group which has no clear trend in the catch rate with depth. Skipjack tuna, swordfish, shortfin mako shark and blue shark did not show a statistically significant difference between their catch rate means, they were caught similarly at both shallow and deep depths.

Table 5. Mean catch rates and variances by species for the shallower branch lines and overall branch line during the cruise of *Shinkai–maru* (n=38) are shown respectively. The results of t–test and ratio between overall branch lines and shallower one were also shown.

	Shallow (S)		Overall (O)			Ratio
Species	Mean	Variance	Mean	Variance	t value	O/S
Albacore	4.577	12.739	6.910	25.797	5.728**	1.51
Bigeye tuna	4.852	18.945	10.384	45.840	10.190**	2.14
Yellowfin tuna	2.765	5.927	3.486	5.115	2.383	1.26
Skipjack tuna	2.634	10.807	2.910	11.988	1.338	1.10
Striped marlin	1.551	2.259	1.296	1.098	1.978	0.84
Pacific blue marlin	1.293	4.107	1.039	1.523	1.163	0.80
Shortbill spearfish	1.847	3.444	1.362	1.734	3.657**	0.74
Oceanic whitetip shark	0.231	0.236	0.162	0.067	1.432	0.70
Blue shark	3.509	20.756	3.486	16.148	0.082	0.99
Bigeye thresher	0.092	0.116	0.173	0.214	1.868	1.88

**Significant at 1% level.

Table 6. Mean catch rates and variances by species for the shallower branch lines and overall branch line during the cruise of *Ashu–maru* (n=38) are shown respectively. The results of t–test and ratio between overall branch lines and shallower one were also shown.

	Shallow (S)		Overall (O)			Ratio
Species	Mean	Variance	Mean	Variance	t value	O/S
Albacore	6.094	29.144	13.100	68.516	9.103**	2.15
Bigeye tuna	4.086	11.678	10.653	26.743	8.603**	2.61
Yellowfin tuna	3.116	6.309	4.351	8.322	3.532**	1.40
Skipjack tuna	1.593	6.659	1.385	2.990	1.051	0.87
Striped marlin	4.605	23.092	2.955	5.903	3.819**	0.64
Pacific blue marlin	2.320	4.533	1.743	1.710	2.592**	0.75
Shortbill spearfish	3.601	18.219	1.858	4.756	4.557**	0.52
Oceanic whitetip shark	0.416	0.478	0.289	0.138	1.508	0.69
Crocodile shark	0.069	0.089	0.162	0.098	1.483	2.33
Blue shark	2.597	10.995	2.597	8.335	0.590	1.00
Bigeye thresher	0.104	0.129	0.277	0.233	2.844**	2.67

**Significant at 1% level.

Table 7. Mean catch rates and variances by species for the shallower branch lines and overall branch line during the cruise of *Kaihatsu-maru* (n=32) are shown respectively. The results of t-test and ratio between overall branch lines and shallower one were also shown.

Species	Shallow (S) Mean	Shallow (S) Variance	Overall (O) Mean	Overall (O) Variance	t value	Ratio O/S
Albacore	12.947	151.143	12.624	153.292	0.958	0.98
Bigeye tuna	2.706	3.661	2.876	3.432	1.022	1.06
Yellowfin tuna	4.580	18.932	3.805	10.276	2.811**	0.83
Swordfish	0.185	0.153	0.189	0.093	0.133	1.03
Striped marlin	0.096	0.127	0.160	0.111	1.246	1.67
Wahoo	0.899	0.913	0.701	0.602	3.141**	0.78
Opah	0.442	0.458	0.573	0.692	1.592	1.30
Shortfin mako	0.727	0.965	0.729	0.704	0.028	1.00

**Significant at 1% level.

Discussion

Eight of forty five operations conducted by *Kaihatsu-maru* in the equatorial eastern Pacific were provided with depth recorders which measured the real depth of hooks (JAMARC 1996), but the data are not large enough to determine the degree of possible bias in our estimated depths. The observed maximum depth of hooks ranged 63–240m with average of 175m, while the estimated depths ranged 166–203m with average of 181m. Although both averages are close, wide fluctuations of actual depth may, in general, make estimated depths of capture imprecise. Nevertheless, the data on catch by branch line and their estimated depths can still provide information on the vertical distribution of many target and non-target species.

1) Vertical distribution pattern of pelagic fishes

From the analysis of catch by branch line and the estimated depths, pelagic fishes can be classified into three groups: those having a decrease, those having an increase, and those having no clear trend in catch rate with greater depth (Table 8).

In the first group, the fishes are more frequently caught at shallow depths. These species include skipjack tuna, the billfishes except swordfish, wahoo, dolphinfish, snake mackerel and oceanic whitetip shark. Skipjack tuna is considered an epipelagic species with depth distribution from the surface to about 260m, but it also exhibits a strong tendency to school in surface waters (Collette and Nausen 1983). Skipjack is incidentally and sporadically caught in longline fisheries. Although Pacific blue marlin showed no significant difference in catch rate by depth (Table 4), it does seem to be caught more frequently at shallower depths (Fig. 2). Previous researchers have

Table 8. Summary table for the results. Species caught by longline fishery were classified into three groups: those having a decrease, an increase and no clear trend in catch rate with depth.

Catch rate decreasing by depth	Catch rate increasing by depth	No clear trend
Skipjack tuna	Albacore	Yellowfin tuna
Striped marlin	Bigeye tuna	Swordfish
Pacific blue marlin	Opah	Escolar
Black marlin	Pacific lancetfish	Shortfin mako
Sailfish	Sickle pomfret	Blue shark
Shortbill spearfish	Bigeye thresher	
Dolphinfish		
Wahoo		
Snake mackerel		
Oceanic whitetip shark		

also reported that billfishes are caught more at shallow depths (Nishi 1990, Boggs 1992). Suzuki et al. (1977) indicated that billfishes have higher catch rates with shallow rather than deep longline gear. However, Saito and Sasaki (1974) noted that billfishes were also captured at depths from 150m to 300m. Their observation agrees with ours, that billfishes continue to be caught at the maximum depth of hook setting, though with decreasing frequency. Wahoo is known to be an epipelagic, oceanic species (Collette and Nausen 1983), as our data show. Snake mackerel has been described as a epi- and mesopelagic species and known to migrate to surface at night (nyctoepipelagic) (Nakamura and Parin 1993). Dolphinfish has been classified as epipelagic species(Parin 1970). Boggs (1992) reported that the catch depth of dolphinfish was shallower than 100m, while that for wahoo and oceanic whitetip shark were shallower than 200–230m. The oceanic whitetip shark is epipelagic and is reported to occur from the surface to at least 152m depth (Compagno 1984).

Albacore, bigeye tuna, opah, Pacific lancetfish, sickle pomfret and thresher shark are classified into a second group which are mainly caught at deeper depths. In contrast with our observations, however, Hamuro and Ishii (1958) observed the maximum catch rate of albacore was at about 100m depth. Suzuki et al. (1977) reported albacore catch rate by shallow longline gear was higher than with gear set deeper. However, Yoshihara (1951) pointed out the catch rate of albacore was maximum at the deepest hook depth which exceeded 150m. Saito and Sasaki (1974) observed the maximum catch rate in the layer between 250m and 300m. Our observations are similar to the latter results. It is likely that the vertical distribution of this species differs among areas as discussed in the next section. On the catch depth of bigeye tuna, previous researchers reported that the catch rate increased with depth (Hanamoto 1974, Suzuki et al. 1977, Nishi 1990). Furthermore, Saito and Sasaki (1974) observed high catch rates of bigeye tuna at depths of 300m and deeper. Boggs (1992) observed high catch rates at depths ranging from 200–400m and reported that bigeye tuna were most frequently caught at the deepest hooks. Based on the vertical distribution of temperature and dissolved oxygen, Hanamoto (1987) suggested that bigeye tuna are distributed from the surface to a depth of around 600m in the Pacific Ocean. Our results also suggest that the catch rate would become higher at depths deeper than 300m, since the highest catch rate was observed at the deepest depth. Opah and Pacific lancetfish inhabit the lower layer of the epipelagic, and have been classified as holoepipelagic–deepwater (Parin 1970). Sickle pomfret would also be classified similarly. Bigeye thresher and pelagic stingray are known to be deep water species as well, the former ranging from the surface to at least 500m (Compagno 1984).

Yellowfin tuna, swordfish, escolar, shortfin mako and blue shark showed no clear trends in their catch rates by depth in our data. Suzuki et al. (1977) reported relatively high catch rates for yellowfin tuna in shallow longline gear compared to deep one, and Nishi (1990) found two modes of high catch rate at depths of 90–100m and at 120–150m. Boggs (1992) observed high catch rate of yellowfin at depth ranging 40–200m, although his observations were few. More studies with attention paid to differences by area and season are needed. Swordfish is known as a epi– and mesopelagic species (Nakamura 1985). Parin (1970) classified escolar as holoepipelagic–deepwater, whose habitat is the lower layer of epipelagic. Our observations on only twenty individuals of escolar are too few to be the basis of any conclusions. Carey (1983) and Carey and Scharold (1990) studied the vertical, dial behavior of the shortfin mako and blue shark by acoustic telemetry and found the two species to move frequently from the surface to the depths of more than 500m and 600m, respectively. Our observations are in accordance with their results.

2) Difference of catch depth among areas

Hanamoto (1987) suggested that water temperature and level of dissolved oxygen could be limiting factors for the vertical distribution of bigeye tuna. The World Ocean Atlas, published by NOAA (Levitus and Boyer 1994a, 1994b), shows that water temperatures at 150 m depth ranged 18–23℃, 16–20℃ and 13–21℃, for the equatorial, east of Hawaii, and tropical eastern Pacific research areas respectively. Water temperature at 250m depth range from 11–14℃, 11–13℃ and 12–16℃, for the same areas respectively. Similarly, the dissolved oxygen at 150 m depth in these same areas range from 3.0–4.5, 4.5–5.5 and 0.5–4.0 ml/l; at 250m depth the ranges are 1.5–3.5, 3.5–4.5 and 0.5–3.0 ml/l, respectively. Hanamoto (1987) also suggested that bigeye tuna could not live in waters where dissolved oxygen level was lower than 1 ml/l. The lower levels of oxygen in the eastern Pacific are less than Hanamoto's (1987) lower limit, therefore, it is possible that oxygen level there is one of limiting factors for the distribution of fishes that include albacore, bigeye tuna, wahoo, opah and shortfin mako shark.

There is also a difference in the catch depth profile for the blue shark according to latitude which was previously reported by Strasburg (1958). This shark is frequently captured by shallow hooks in high latitude areas, and is abundant at water temperatures ranging from 12–22℃ (Nakano 1994).

It is necessary to study why the difference of catch depth among different areas occurs for several species in the future. For example, a micro bathythermograph system for tuna longline boats developed by Mizuno et al. (1996) and the study using electronic microchip hook timer and time–depth recorders (TDR) (Boggs 1992) provide useful and more accurate and detailed information. Oceanographic study and the observation with newly developed equipment attached to the branch lines as well as archival tag may help to give clues for the causes of differences observed in this study.

3) Comparison of catch rate between the shallow and deep longline.

In the Japanese longline fishery, hook depth became deeper after 1975 because of a more targeting to the bigeye tuna with high commercial value which lives in deeper waters (Suzuki et al. 1977). Suzuki et al. (1977), comparing tuna and billfish catch rates between shallow and deep longline gear, reported that the bigeye tuna catch rate increased, while that of other tunas and billfishes decreased with deep longline gear. Boggs (1992) also compared catch rates by depth of longline gear for bigeye tuna, yellowfin tuna, striped marlin, shortbill spearfish and dolphinfish. He found the highest catch rates with the deepest gear for bigeye tuna and with the shallowest gear for other four species. Our observations of bigeye tuna catch rates are in accordance with their results. However, our data also reveal higher catch rates of albacore with deep longline gear, possibly reflecting the geographically different fishing areas, the different seasons of operation and/or the different growth stages of fish. More data on catches by branch line with direct observations of hook depth are needed, along with expanded areal and seasonal coverage. For other species of tunas and billfishes, our ratios of the means of deep to shallow hook rates are in accordance with the conclusions from previous studies.

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Reference

Boggs, C.H. 1992: Depth, capture time, and hooked longevity of longline–caught pelagic fish: Timing bites of fish with chips. *Fish. Bull.,* 90(4): 642–658.

Carey, F.G. 1983: Experiments with free–swimming fish. *In* Oceanography, The present and future, P.G. Brewer (ed.) Springer–Verlag, New York, 392pp.

Carey, F.G. and J.V. Scharold 1990: Movements of blue shark (*Prionace glauca*) in depth and course. *Mar. Biol.,* 106:329–342.

Collette and Nausen 1983: FAO Species Catalogue Vol. 2 Scombrids of the world., FAO Fisheries Synopsis No.125, Vol.2, 137pp.

Compagno, L.J.V. 1984: FAO Species Catalogue Vol. 4 Sharks of the world. Fisheries Synopsis No.125, Vol.4 Part 2, 248pp.

Fishery Agency of Japan (FAJ) 1994: Cruise report of the Japanese tuna longline fishery (Central North Pacific). National Research Institute of Far Seas Fisheries, 73pp. (In Japanese).

Hamuro, C. and K. Ishii 1958: Analysis of tuna long-line by automatic depth-mater. *Tech. Rep. Fish. Boat.,* 11: 39–119. (In Japanese with English abstract).

Hanamoto, E. 1974: Fishery oceanography of bigeye tuna–I Depth of capture by tuna longline gear in the eastern tropical Pacific Ocean. *La mer,* 13: 58–71. (In Japanese with English abstract).

Hanamoto, E. 1987: Effect of oceanographic environment on bigeye tuna distribution. *Bull. Japan. Soc. Fish. Oceanogr.,* 51(3): 203–216.

JAMARC (Japan Marine Fishery Resources Research Center) 1996: Report of feasibility study on the new fishing grounds of tuna longline fishery. JAMARC. 140pp. (In Japanese).

Levitus, S. and T.P. Boyer 1994a: World ocean atlas 1994 volume 2: oxygen. NOAA Atlas NESDIS 2, 186pp.

Levitus, S. and T.P. Boyer 1994b: World ocean atlas 1994 volume 4: temperature. NOAA Atlas NESDIS 4. 129pp.

Mizuno, K., M. Okazaki, T. Watanabe, and S. Yanagi 1996: A micro bathythermograph system for tuna longline boats in view of large scale ocean observing system. *Nat. Res. Inst. Far Seas Fish. Bull.* 33: 1–15.

Mizuno, K., M. Okazaki, H. Nakano, and H. Okamura 1997: Estimation of underwater shape of longline by using micro-BTs. *Nat. Res. Inst. Far Seas Fish. Bull.* 34: 1–24. (In Japanese with English abstract).

Nakamura, I. 1985: FAO Species Catalogue Vol. 5 Billfishes of the world. Fisheries Synopsis No.125, Vol. 5, 65pp.

Nakamura, I. and N. V. Parin 1993: FAO Species Catalogue Vol. 15 Snake mackerels and cutlassfishes of the world. Fisheries Synopsis No.125, Vol. 15, 136pp.

Nakano, H. 1994: Age, reproduction and migration of blue shark in the North Pacific *Ocean. Nat. Res. Inst. Far Seas Fish. Bull.* 31: 141–256.

Nakano, H. and T. Seki 1995: Cruise report of the Japanese tuna longline fishery (Central Tropical Pacific: *Ashu–maru*). National Research Institute of Far Seas Fisheries, 59pp. (In Japanese).

Nishi, T. 1990: The hourly variations of the depth of hooks and the hooking depth of yellowfin tuna (*Thunnus albacares*), and bigeye tuna (*Thunnus obesus*), of tuna longline in the eastern region of the Indian Ocean. *Mem. Fac. Fish. Kagoshima Univ.,* 39: 81–98. (In Japanese with English abstract).

Okazaki, M. and H. Nakano 1995: Cruise report of the Japanese tuna longline fishery (Central Tropical Pacific: Shinkai–maru). National Research Institute of Far Seas Fisheries, 63pp. (In Japanese).

Parin, N.V. 1970: Ichthyofauna of the epipelagic zone. Moscow: Academy of Sciences of the U.S.S.R. (Translated from Russian by Israel Program for Scientific Translations), Reproduced by the National Technical Information Service, Springfield, Virginia, 206pp.

Punsly, R. and H. Nakano 1992: Analysis of variance and standardization of longline hook rates of bigeye (*Thunnus obesus*) and yellowfin (*Thunnus albacares*) tunas in the eastern Pacific Ocean during 1975–1987. *Inter-Amer. Trop. Tuna Comm.*, Bull., 20(4): 167–184.

Strasburg, D.W. 1958: Distribution, abundance, and habits of pelagic sharks in the central Pacific Ocean. *Fish. Bull.*, 58: 335–361.

Suzuki, Z., Y. Warashina and M. Kishida 1977: The comparison of catches by regular and deep tuna longline gears in the western and central equatorial Pacific. *Bull. Far. Seas. Fish. Res. Lab.*, 15: 51–89.

Yoshihara, T. 1951: Distribution of fishes caught by the longline II Vertical distribution. *Bull. Japan. Soc. Sci. Fish.*, 16: 370–374. (In Japanese with English abstract).

枝縄別漁獲資料を使用したまぐろはえなわ漁業による魚類の漁獲深度の解析

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摘要

まぐろはえなわ漁業で漁獲される魚類の漁獲深度は，漁具の漁獲効率，魚類の生息深度を評価するために有効である。特に日本のまぐろはえなわ漁業は歴史的にその漁具深度を深くしているので，浅縄および深縄の漁獲効率を比較することは，魚種に対する歴史的な漁獲効率の変化を定量的に評価するための基礎的な資料となる。本研究では，まぐろはえなわの枝縄別漁獲資料から，魚種の漁獲水深を推定し，あわせて敷設水深の異なる漁具の漁獲効率についても比較した。まぐろはえなわ操業の枝縄別漁獲資料は1992年から1995年までの間に太平洋の3つの海域から収集された。魚類の深度別釣獲率を懸垂曲線の当てはめにより推定し，魚類を水深が深くなるほど釣獲率が増加するもの，水深が増すと釣獲率が減少するもの，釣獲率が深度で変化しないものの３つのグループに大別した。ビンナガ（*Thunnus alalunga*），メバチ（*T. obesus*），アカマンボウ（*Lampris guttatus*），ミズウオ（*Alepisaurus ferox*），ヒレジロマンザイウオ（*Taractichthys steindachneri*）は釣獲率が深度とともに増加した。一方，カツオ（*Katsuwonus pelamis*），マカジキ（*Tetrapturus audax*），クロカジキ（*Makaira mazara*），バショウカジキ（*Istiophorus platypterus*），フウライカジキ（*T. angustirostris*），シイラ（*Coryphaena hippurus*），カマスサワラ（*Acanthocybium solandri*），クロタチカマス（*Gempylus serpens*），ヨゴレ（*Carcharhinus longimanus*）は水深が深くなると釣獲率が減少した。キハダ（*T. albacares*），メカジキ（*Xiphias gladius*），アブラソコムツ（*Lepidocybium flavobrunneum*），アオザメ（*Isurus oxyrinchus*），ヨシキリザメ（*Prionace glauca*）は釣獲率に水深に伴う顕著な変化が認められなかった。また，東太平洋の調査海域と他の海域間で釣獲率が高くなる深度に違いがみられ，ビンナガ，メバチ，サワラ，アカマンボウ，アオザメなどで釣獲率の高い深度が他の海域より浅くなる傾向が観察された。まぐろはえなわの浅縄と深縄の操業ごとの釣獲率の平均値を魚種ごとに比較した結果，22種のうち13種で平均値間に統計的に有意な差が認められた。深い水深で釣獲率が高い種類の浅い枝縄との釣獲率の比は，1.51～20.6の値を示した（ビンナガ1.51-2.15，メバチ2.14-3.14，アカマンボウ20.6，ミズウオ1.63，ヒレジロマンザイウオ6.76，ハチワレ2.67）。一方，浅い深度で釣獲率の高い種類の比の値は0.4～0.92の範囲であった（マカジキ0.4-0.64，クロカジキ0.75，バショウカジキ0.92，フウライカジキ0.42-0.74，シイラ0.46，クロタチカマス0.72）。