STUDY OF BATHYMETRY EFFECTS ON THE NOMINAL HOOKING RATES OF YELLOWFIN TUNA (*THUNNUS ALBACARES*) AND BIGEYE TUNA (*THUNNUS OBESUS*) EXPLOITED BY THE JAPANESE TUNA LONGLINE FISHERIES IN THE INDIAN OCEAN

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ABSTRACT

We attempted to examine how steep bathymetry affected tuna catch rates by analyzing the digital depth data and hooking rates data of the Japanese longline fisheries in the Indian Ocean. Results suggest (a) yellowfin tuna CPUE generally becomes higher as quantities of steep bathymetry zones become larger, (b) this tendency is much stronger when the slope boundary is higher value, i.e., 15^o < slope and (c) bigeye tuna CPUE are more or less constant in any ranges except those in the study area off South Africa during 2nd-3rd quarter where CPUE shows the increasing trend as steep bathymetry zones become larger.

INTRODUCTION

There have been occasional discussions on the bathymetry effect over the tuna longline hooking rates in various tuna meetings in the past (for example, pelagic fish program workshop, Hawaii, 2000). The reason of the effect is simple, i.e., the steep bathymetry areas such as the continental slopes, sea mounts, sea basins and sea canyons (Fig. 1) produce upwelling, which create rich and nutritious waters, hence a good tuna fishing grounds are formed. Therefore, many tuna longline fleets concentrate in such waters for profitable operations. However, other factors are also involved for tuna school aggregations such as sea temperature, currents, moon phases, temperature gradients and etc (refer to WPM/01/___ by Nishida, 2001). Hence, in general, aggregations of tuna schools will occur when these favorable factors are formed synthetically (Uda, 1960; Campbell *et al*, 1994). In the Indian Ocean, there are numbers of such areas as observed in Map. 1.

Numerical relationships between hooking rates of tuna longline fisheries and various environmental factors have been studies and reported. However, numerical analyses for the effect of bathymetry over hooking rates have not been yet conducted and reported, although it has been well understood among fishers and tuna scientists that the steep bathymetry positively affects the hooking rates. Thus, in this paper, we attempted to examine how such steep bathymetry affected tuna catch rates by analyzing the digital depth data and hooking rates data of the Japanese longline fisheries in the Indian Ocean. If such relations were statistically significant, we need to incorporate the bathymetry effect in the GLM analyses for hooking rates (CPUE) standardization process to obtain more reliable estimates in the future.

REVIEWS

In the fishing operations, the submarine topography (such as reef, bank and shoal) is generally used as means to search for high density fishing grounds (Nasu, 1975; Ishino, 1982). In the tuna longline fisheries, fishers also check the submarine topography to search good fishing grounds (Yamada, 1994).

Uda (1960) defines the steep bathymetry zones as "protruded natural gathering places for fish schools". This is because in such zones, nutrients are raised from deeper waters which breed phytoplankton and zooplankton, consequently, small fishes gather around these planktons and large fish gather around small fishes. He also adds that whirlpool are produced by disturbance of the streamline around steep bathymetry zones which make fish schools coming from outsides aggregated and furthermore, these unique geographic forms naturally protect fish schools from predators.

In case of tuna schools, Hanamoto (1971; 1974; 1982) reported that steep bathymetry zones located in sea bank, sea mount, sea trench, guyot, and ocean ridge (refer to Fig.1) create good fishing grounds for bigeye tuna, yellowfin tuna, southern bluefin tuna and Pacific northern bluefin tuna. In addition, Hanamoto (1978) reported that immature tuna schools are primarily aggregated in the steep bathymetry zones for them to feed actively, while spawning mature tuna are not aggregated in such steep topography areas. He also reported that there are additional factors for aggregation of schools, which are temperature, currents, moon phases, temperature gradients, besides the geographical factor of the steep bathymetry.

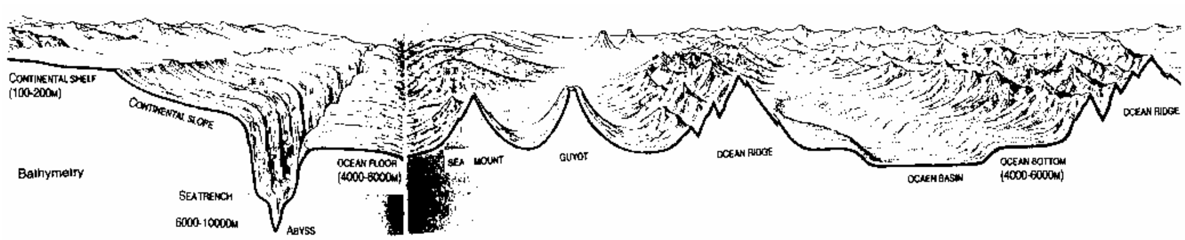
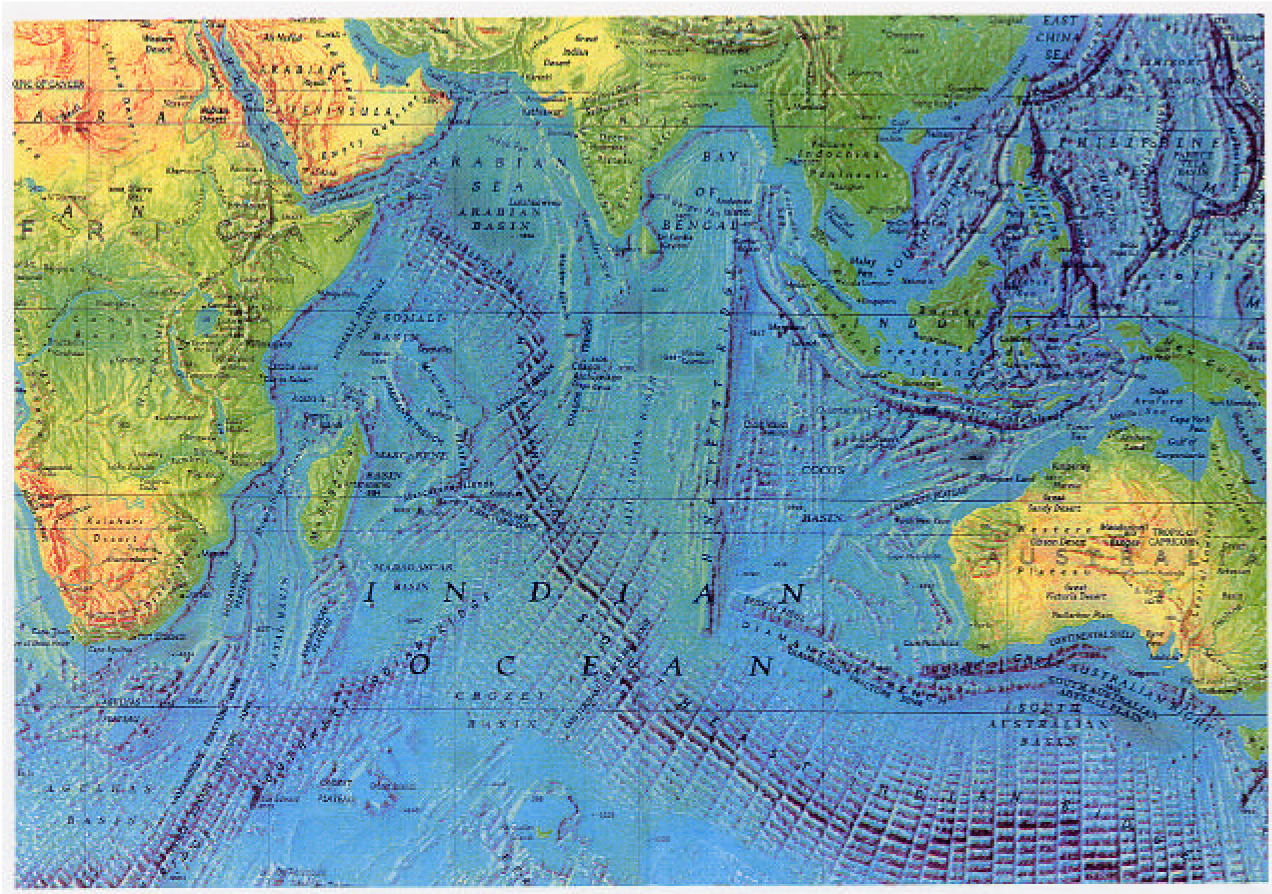


Fig. 1 Cartoon of bathymetry. Steep zones are indicated by with arrows.



Map 1 Geographical location of unique bathymetry areas such as basin, ridge, trench, plateau, etc. in the Indian Ocean.

DATA

Types and sources of information used in this paper are explained as follow:

Bathymetry

Worldwide digital bathymetry data by 2 minutes pixel are obtained from National Geological Data Center. This bathymetry data are estimated based on the satellite information using the 'geoid' surface.

Hooking rates

Japanese longline fisheries (LL) data stored in the database of the National Research Institute of Far Seas Fisheries (NRIFSF) are used. One degree based nominal catch (YFT: yellowfin tuna and BET: bigeye tuna) and effort (hooks) data for 17 years from 1971-97 are used.

Study area

As a test trial, we select two fishing grounds off Somalia and off South Africa for the analyses. The area off Somalia is defined by the rectangular waters enclosed 50^o-70^o E and 10^oN-5^oS, while the one off South Africa (Agulhas Basin) is 20^o-30^oE and 30^o-45^oS (Maps 2-3).

Note: the study area off South Africa is not indicated in Maps 2-3.

HYPOTHESIS

We set up the following hypothesis:

Ho: Steep bathymetry areas positively affect YFT & BET LL hooking rates especially for young adult feeding schools, but less for the spawning schools.

We set up this hypothesis to examine the Hanamoto (1978)'s suggestion, i.e., young adult of bigeye tuna and yellowfin tuna during the feeding migration are effectively exploited by the longliners in extremely steep bathymetry zones, while those during the spawning migrations are not well related with any bathymetry forms.

METHODS AND RESULTS

Estimation of bathymetry slope (steepness)

Bathymetry slope (steepness) in the 2'x2' area is prepared for the analyses, which is defined in Figure 2. Map 2 shows the bathymetry of the Indian Ocean and Map 3 shows the distribution of the bathymetry slopes estimated by the method described in Fig. 2

	(N)? (i-1, j)	
(W)? (i, j-1)	(bathymetry slope in 2'x2' area) (i, j)	(i, j+1) ? (E)
	(i+1,j)?(S)	

where, (Bathymetry slope/steepness)

= (Bathymetry gradient)$_{ij}$ = Max { angle of slope $_{(NS)}$, angle of slope $_{(EW)}$ } $_{ij}$

, where ij: ij-th pixel (2' x 2' square area)

slope : Arctan (*? bathymerty /? d)* (in degree)

? bathymetry: difference of depth between two neighboring pixels of the ij pixel (m) (NS or EW direction).

? d : distances between two neighboring pixels of the ij-th pixel (m), i.e., distances of 2'.

(note) distance in the NS (latitude) direction in 2'x2' pixel

=1000 (m)*(2p r/4/90/30) = 3706.5 m

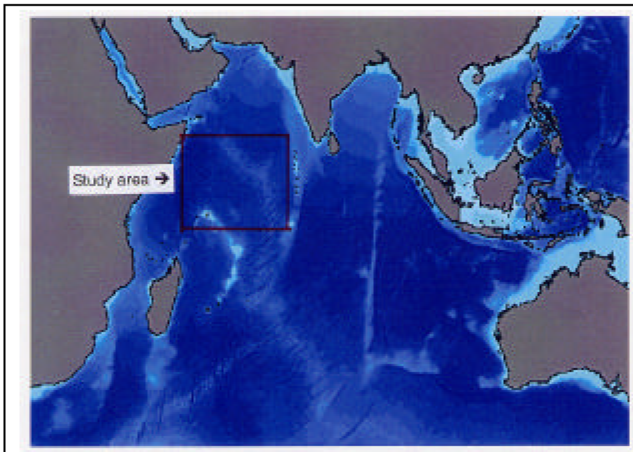
distance in the EW (longitude) direction in the 2'x2' pixel

=1000 (m)*cos (lat)*(2p r/4/90/30)

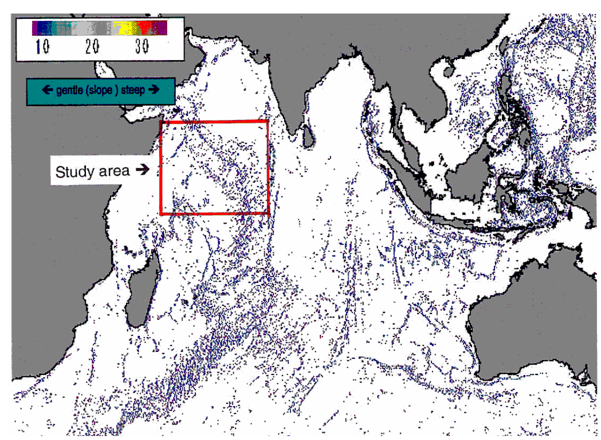
= 3706.5xcos (lat)

where, r =6371Km (radius of the earth)

Fig. 2 Definition of the bathymetry slope (steepness) in the 2'x2' area.



Map 2 Bathymetry in the Indian Ocean



Map 3 Bathymetry slope (degrees) in the Indian Ocean based on the 2'x2' area (pixel)

Three categories of the bathymetry slopes are defined by concerning its steepness as below:

Gentle slope : 0^o<= slope < 5^o

Steep slope : 5^o <=slope < 10^o

Protruded (very steeo) slope: 10^o<= slope

Based on this category, its compositions in two study areas off Somalia and off South Africa are computed.

Table 1 and Fig. 3 show the results. Majority of bathymetry in the study areas are composed of the gentle slopes (81% and 90% respectively), while only a few percents are the protruded (very steep) slope zones.

Table 1 Compositions by type of bathymetry slope in the two study areas off Somalia and South Africa.

Type of bathymetry slope	Definition	Compositions (off Somalia)	Compositions (off South Africa)
Gentle	0^o <= slope < 5^o	81%	90%
Steep	5^o<= slope < 10^o	16%	8%
Protrude (very steep)	10^o<= slope	3%	2%

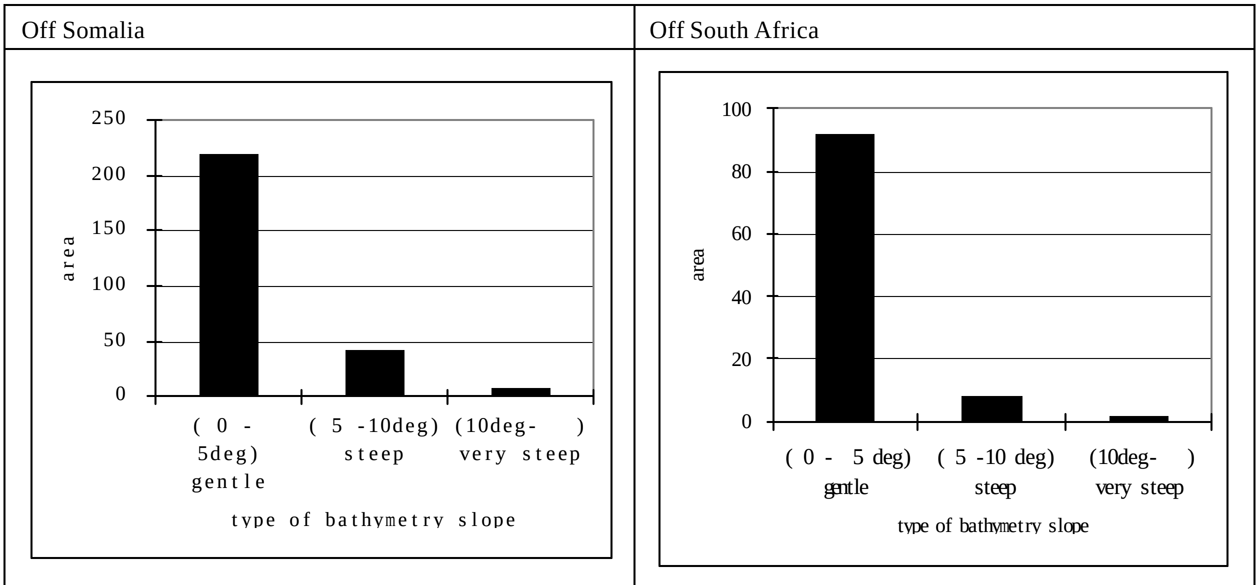


Figure 3. Situation of bathymetry slopes off Somalia and South Africa.

Note : Areas are represented by number of 2'x2' pixels in 1000.

5.2 Analyses

Using the estimated bathymetry slope data, correlations with the quarterly CPUE data are investigated. As the CPUE information is based on the 1ox1o area, while the bathymetry slope data are based on the 2'x2' area, we need to adjust the bathymetry slope data into the 1ox1o area unit. This means the maximum of 900 pixel points of the 2' x2' pixel data (30 pixels x 30 pixels in one 1ox1o unit) need to be converted to one value to represent the bathymetry slope.

If we take the simple average of the bathymetry slopes of 900 points data, the steep slope zones will be masked as the majority of bathymetry slopes are very gentle less than 5 degrees (see Table 1 and Fig. 3). To avoid this risk, we will use the compositions (%) of the steep zones (2'x2' units) in the 1ox1o area. To do this, we classify compositions of the steep zones into three ranges i.e., 0-5%, 5-10% and 10%-. In each range, average quarterly CPUE are computed for two study areas. We use two boundary criteria for the steep zones, i.e., 10o < slope and 15o < slope. Then, average CPUE are plotted by composition ranges of steep zones. Box 1 explains this concept.

Box 1 Concept of three compositions ranges (0-5%, 5-10% and 10 %-) of steep bathymetry zones.

Sample area based on the 1^ox1^o area.

(A)5%	1%	4%	17%	32%
3%	12%	9%	0%	1%
Land		2%	Island	
		3%		
		0%		

For example, (A) is one 1^ox1^o area and contains 5% of steep bathymetry (steep means 15^o< slope as an example). This means that there are 45 numbers of 2'x2' pixels, which slopes are larger than 15^o. This is because there are 900 of 2x2' pixels in a 1^ox1^o area and 5% of 900 pixels is 45. Then, in this whole sample area, we classify compositions (%) of steep bathymetry into three ranges (0-5%, 5-10% and 10%-). Then, for each range, CPUE is computed by species and quarter. In this way, Figs. 5 –6 were created.

Figs. 5 and 6 show average CPUE (YFT/BET) for three composition ranges of the steep bathymetry zones (0-5%, 5-10% and 10% or more) with slope boundary < 10^o and slope< 15^o, respectively.

Results are summarized as follows:

- YFT CPUE generally becomes higher as quantities of steep bathymetry zones become larger.
- This tendency is much stronger when the slope boundary is higher value, i.e., 15^o < slope
- BET CPUE are more or less constant in any ranges except those in the study area off South Africa during 2^{nd}-3^{rd} quarter where CPUE shows the increasing trend as steep bathymetry zones become larger.

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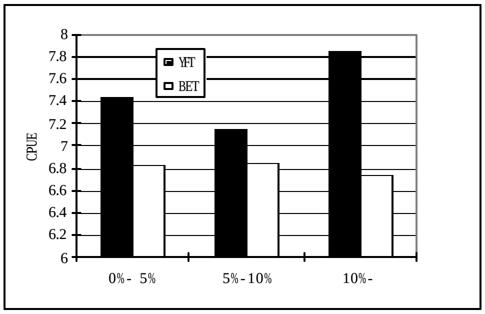
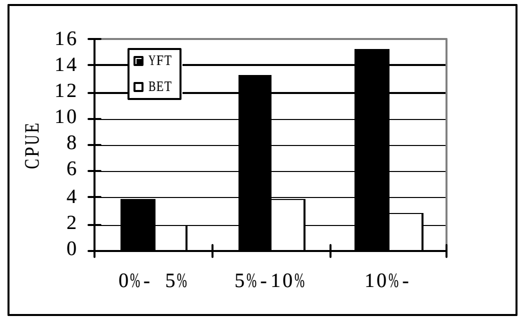
<tr><td>1</td><td>
</td><td>
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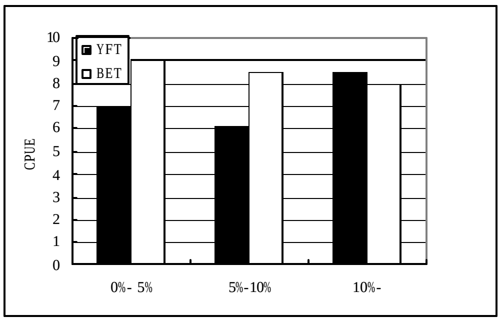
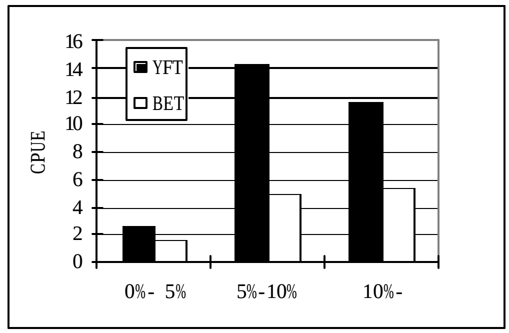
<tr><td>2</td><td>
</td><td>
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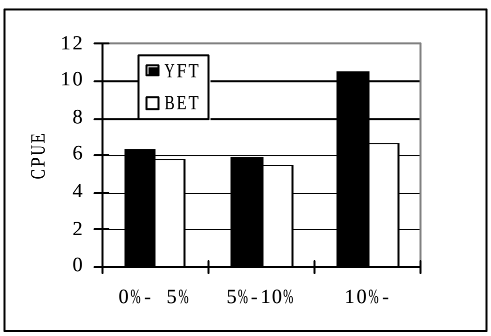
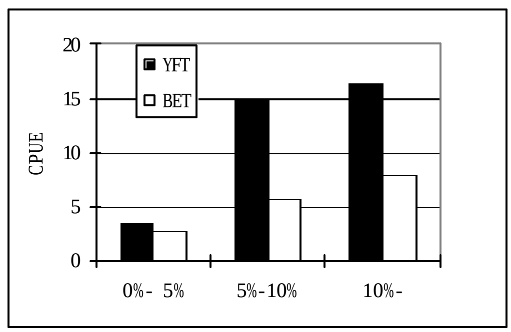
<tr><td>3</td><td>
</td><td>
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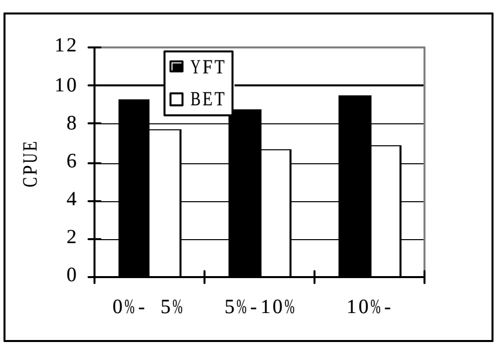
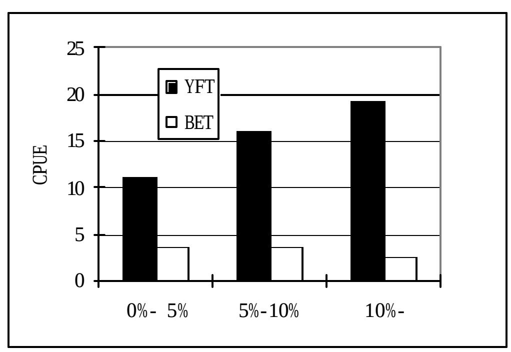
<tr><td>4</td><td>
</td><td>
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</table>

Fig. 4 Relationship between CPUE vs. composition ranges (%) of steep bathymetry zones in two study areas by species and season (quarter). (note: in case of the steep zone is : 10^0 < slope and CPUE in fish/1000 hooks)

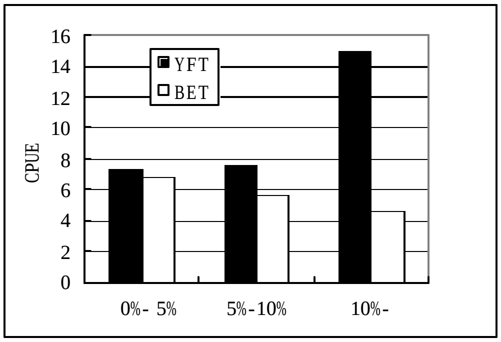
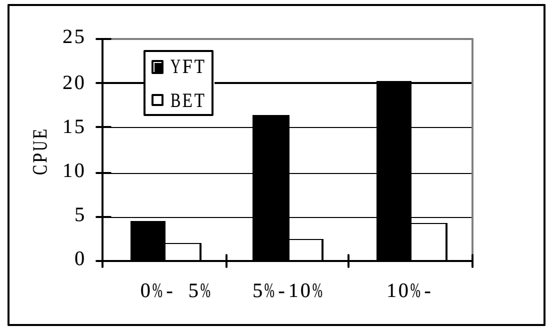
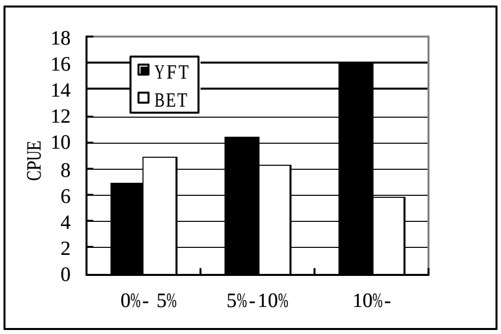
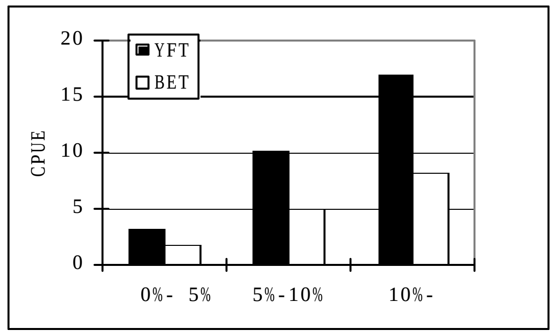
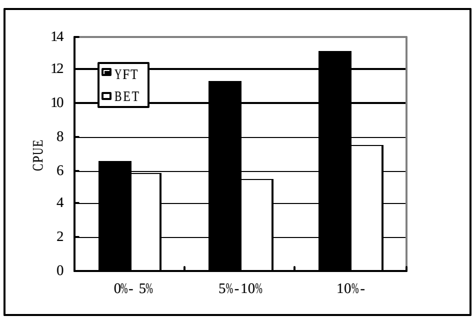
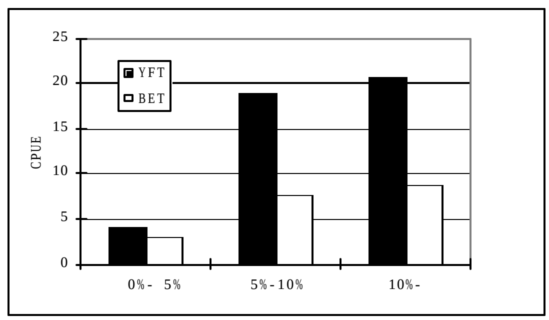
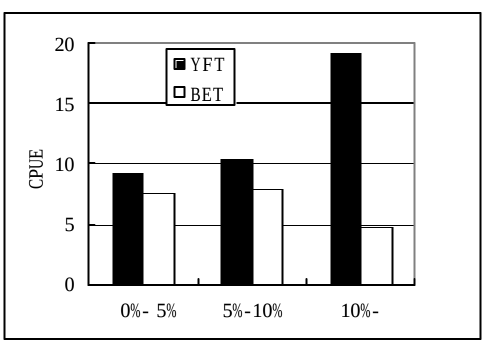
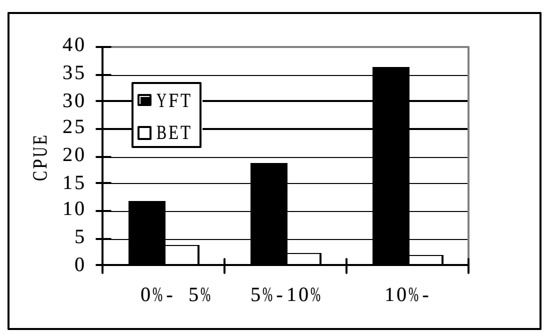
Q	Off Somalia	Off South Africa
1		
2		
3		
4		

Fig. 5 Relationship between CPUE vs. composition ranges (%) of steep bathymetry zones in two study areas by species and season (quarter). (note: in case of the steep zone : 15^{o} < slope and CPUE in fish/1000 hooks)

DISCUSSION

1 YFT nominal hooking rates show the steady increasing trends proportional to bathymetry steepness in both areas off Somalia and off South Africa (Agulhas Basin). On the other hand, BET CPUE does not relate with the bathymetry steepness in the study area off Somalia, but does relate in the study area off South Africa during 2nd –3rd quarters.

Table 2 shows the age classes and migration types of YFT and BET in two study areas. As Hanamoto (1978) suggested, results (Figures 4-5) and Table 2 also imply that (a) higher YFT and BET CPUE tendency occurs in the steeper bathymetry zones when there exist feeding YFT and BET schools and (b) BET spawning schools do not relate to the bathymetry steepness. Thus, our hypothesis is likely accepted qualitatively. But, the quantitative justification (statistical tests) is needed to prove the hypothesis.

Table 2 Age classes and migration types of YFT and BET in two study areas

Area	YFT (Romena, 2000)	BET (Mohri, 2000)
Off Somalia	Adults (age 2 or older) (feeding or spawning migration schools especially in Q2-Q4)	Adult (spawning migration schools) (all year)
Off South Africa	Young adult group (age 2) (feeding migration schools for all years)	Young adult group during 2nd–3rd quarter (feeding migration schools)

2 Although the statistical tests for the hypothesis were not conducted, it was clearly resulted that deeper bathymetry positively affect the nominal YFT CPUE (and also BET CPUE for particular cases). Therefore, it is suggested that steep bathymetry factors need to be included for the GLM analyses for the future CPUE standardization as the steep bathymetry effects the nominal hooking rates.

3 Regarding the relationship between steep bathymetry and nominal hooking rates, we realized that results of this study are consistent with fisher's views and contents of relevant literatures.

4 CPUE of spawning BET are not related with bathymetry, which are rather related with the physical environmental factors such as depth of the thermocline (Mohri, 2000). This was also understood through this study.

FUTURE WORKS

1 Similar study needs to be expanded to the whole Indian Ocean.

2 In this study, CPUE by the 1x1 data were applied. Same study using CPUE by 5x5 area is also needed.

3 Statistical tests are needed to prove this hypothesis quantitatively.

4 There is a concern that particular steep bathymetry zones located in the very deep waters such as in the sea trench (6,000-10,000 m) and the ocean basin (4,000-6,000 m), might not create good fishing grounds because even if there were the local upwelling in the deep waters, it will not come up to the shallower YFT & BET swimming layers (50-300m). In the method used in this study, any steep bathymetry zones such as those in the deep waters are also included. Such effects in the deeper waters on the nominal hooking rates might not exist, thus they need to be carefully investigated. Then, if they do not relate to the hooking rates, bathymetry slope data in the deep zones need to be masked or treated as the missing data in the GLM analyses.

ACKNOWLEDGEMENTS

We thank Dr Nishikawa and Mr Warashina (NRIFSF, Yaizu) and Mr Honda (Taikei Fishing Inc., Ishinomaki) for their suggestions and advices on the relationship between bathymetry and tuna longline fisheries.

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APPENDIX A : DATA PROCESS (? ? ? ? ? ? ? ? ? : ? ? ? ? ? ? ?)

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(4) p-depth /* ?
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(7) ＣＰＵＥ ? ? ? ? : p-comb slope & depth &

(8) CPUE.sas

(9)

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Agurasu plate ? ? ? ? ? ? ? ? ?

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1 ? ? ? ? ? ? ? ? ? CPUE ? ? ? ?
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2 ? ? ? ? ? ? J A M A R C ? ? ? ? ? ? ? ? ? ? ? ?

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MAP2: GRADIENTS (2 ? ? ? ? ? ?) = > 4 ? ? ? ? ? ?

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MAP3: CPUE ? ? ? YFT? BET(2 ?)

= = > ? ? ? ? ? J A M A R C ? ? ? ?

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MAP4: MAP2 ? MAP3 ? ? ? ? ? ? ?

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F I N E S C A L E ? ? C P U E ? ? ?

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5.3 GIS analyses ? ? ? ? ? ? ? ? ?

Marine explorer ver.3.17 (GIS software for fisheries & oceanographic information) was used for mapping the parameters and to overlay the CPUE and the composition maps of the steep bathymetry slopes.

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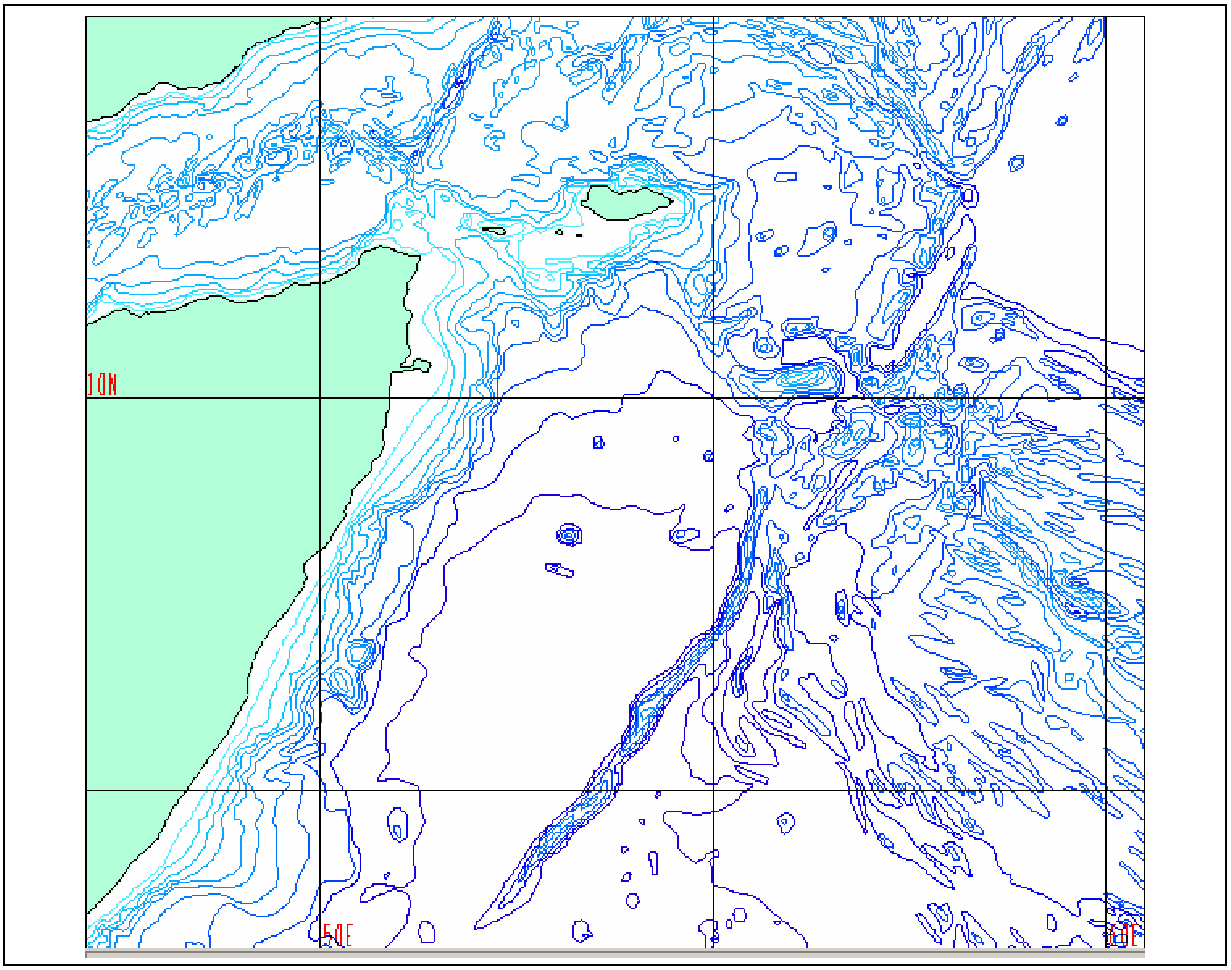
10N
50E
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