Does vertical shear current affect catch rates of tuna longline fisheries and do we need in CPUE standardization?

Preliminary study for yellowfin, bigeye, albacore and swordfish exploited by Japanese tuna longline fisheries in the Indian Ocean (1980-2015)

Part I: Basic study (this document)
Part II: Examination in CPUE standardization (to be conducted in the future)

Tom Nishida [1/] and Hiroshi Matsuura [2/]

1/ National Research Institute of Far Seas Fisheries, Shimizu, Shizuoka, Japan
2/ Cygnus Research International, Yokosuka, Kanagawa, Japan

October 2017

Abstract

We investigated effects of vertical shear currents on tuna longline fisheries (LL) for three LL categories in terms of number of hooks between floats, i.e., shallow/Regular, Deep and Ultra-deep. As a case study, we analyzed nominal CPUE from Japanese tuna LL operating in the Indian Ocean and covered four speices, i.e., YFT (yellowfin tuna), BET (bigeye tuna), ALB (albacore tuna) and SWO (swordfish). Major fishing ground of each species was used for analyses. As for vertical shear currents data, we used Global Ocean Data Assimilation System (GODAS) data avaialble in National Centers for Environmental Prediction (NCEP) (NOAA, USA). We classified vertical shear currents data into three classes, i.e., Strong, Medium and Low and applied also for major fishing gounds of four species. We analyzed month and 1°x1° based data for 36 years (1980-2015). Followings are summary of this study:

- There are a number of uncertainties in this study, thus results should be looked with caution;
- Four major uncertainties are (a) vertical shear currents data are derived by assimilations, (b) time-area scales of vertical shear currents are unknown, (c) actual LL depth ranges may be different from predicted ones and (d) materials of main and branch lines,which were not usedin this study;
- Although there are a number of uncertainties, we could get results very close to predicted ones in case for BET and ALB, while not for YFT and SWO, which particularly disturbed by uncertainties, (c) and (d);
- It will be worth to attempt CPUE standardization incorporating vertical shear currents and line materials in the future (Part II). In such case, we also need to use other influential environemtal factors becasue effects on nominal CPUE may be integratedly created; and
- The IOTC First CPUE workshop (2013) suggested that CPUE standardization should be conducted in specific areas (not whole Indian Ocean), where the variability pattern of the environmental signature is well identified. Thus, the future study may be a good opportunity to examine this suggestion.

Contents

Submitted to the IOTC WPTT19 (October 17-22, 2017), Victoria, Seychelles

1. INTRODUCTION

We investigated effects of vertical shear currents on tuna longline fisheries (LL) for three LL categories in terms of number of hooks between floats, i.e., shallow/Regular, Deep and Ultra-deep. As a case study, we analyzed nominal CPUE from Japanese tuna LL operating in the Indian Ocean and covered four speices, i.e., YFT (yellowfin tuna), BET (bigeye tuna), ALB (albacore tuna) and SWO (swordfish). Major fishing ground of each species was used for analyses. As for vertical shear currents data, we used Global Ocean Data Assimilation System (GODAS) data avaialble in National Centers for Environmental Prediction (NCEP) (NOAA, USA). We classified vertical shear currents data into three classes, i.e., Strong, Medium and Low and applied also for major fishing gounds of four species. We analyzed month and $1^o x 1^o$ based data for 36 years (1980-2015).

2. DATA

(1) Japanese tuna longline fishereis data in the Indian Ocean

We use set-by-set nominal CPUE data (YFT+BET+ALB+SWO) available in the database of National Research Institute of Far Seas Fisheries for 36 years (1980-2015) by year, month and $1^o x 1^o$ block. We excluded low effort data (number of hooks less than 1,000).

(2) Shear currents

We used horizontal currents data available in the NCEP Global Ocean Data Assimilation System (GODAS) monthly data (http://cfs.ncep.noaa.gov/cfs/godas/monthly) (1980-2015). The Original data include temperature, salinity and horizontal currents (u, v) digital data for 28 depth layers, i.e., every 5 m starting from 5m depth to 225m with extra 4 deeper depth layers, i.e., 5m, 15m, 25m, 35m, 45m, 55m ,65m, 75m, 85m, 95m, 105m, 115m, 125m, 135m, 145m, 155m, 165m, 175m, 185m, 195m, 205m, 215m, 225m, 238m, 262m, 303m, 366m and 459m.

The resolutions of the original data is (1/3) degrees in latitude and 1 degree in longitude. These depth specific data were estmated by asimulation using the spatial models developed by the NCEP. For details refer to the above mentioned web site.

The vertical shear currents, as defined by Bigelow et al (2006), is calculated throughout the water column, as an integration of the horizontal current ($\vec{u}$) from the near-surface to a given depth (Z), usually defined as the maximum depth reached by the hooks of the longline gear:

$$K = \log\left(\frac{\int_0^z \left\| \frac{\partial \vec{u}}{\partial z} \right\| dz}{Z}\right)$$

that can be approximated by

$$\tilde{K} = \log\left\{ \frac{\sum_{n=1}^{N} \left[\left(\frac{u_{n+1} - u_n}{z_{n+1} - z_n} \right)^2 + \left(\frac{v_{n+1} - v_n}{z_{n+1} - z_n} \right)^2 \right]^{1/2} (z_{n+1} - z_n)}{\sum_{n=1}^{N} (z_{n+1} - z_n)} \right\}$$

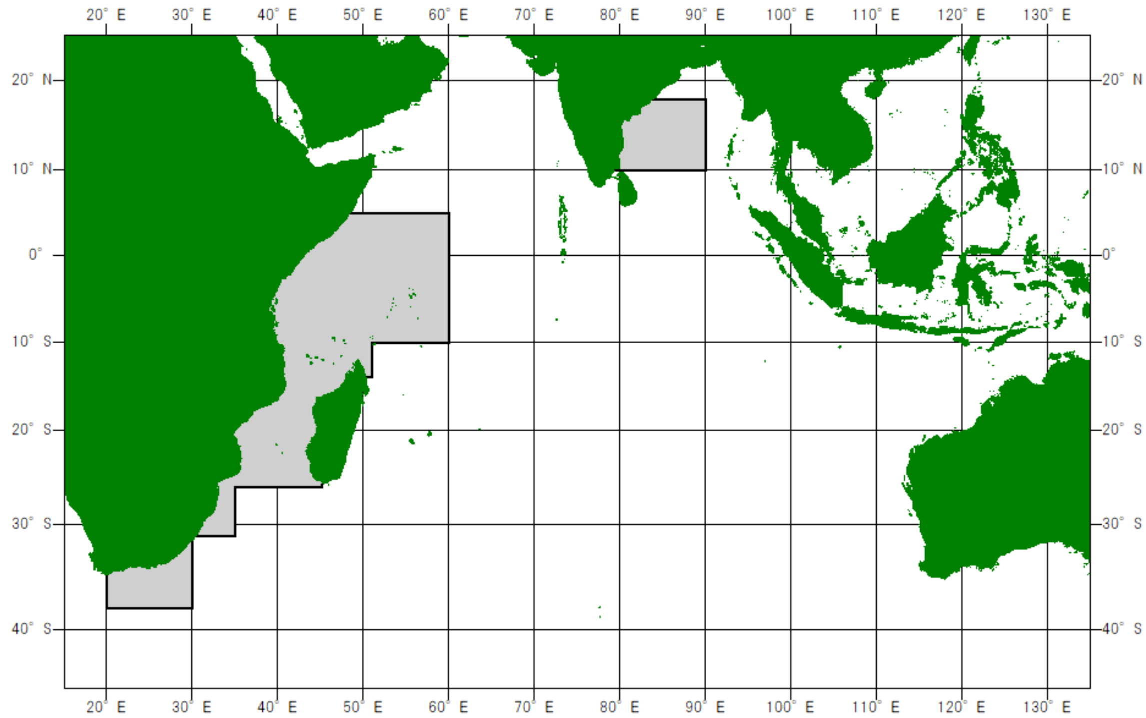
where $\tilde{K}$ is the log-transformed vertical shear [(cm/second)/m], u_n the zonal (east-west) velocity (cm/second) component of layer n, v_n the meridional (north-south) velocity (cm/second) component of layer n and z_n is the depth (m) of layer n. The vertical shear currents in this study was estimated from the NCEP model by integrating from 5m to 366 m. We estimated the vertical shear currents by year, month and 1°x1° block (same resolution as for nominal CPUE data).

3. STUDY AREAS

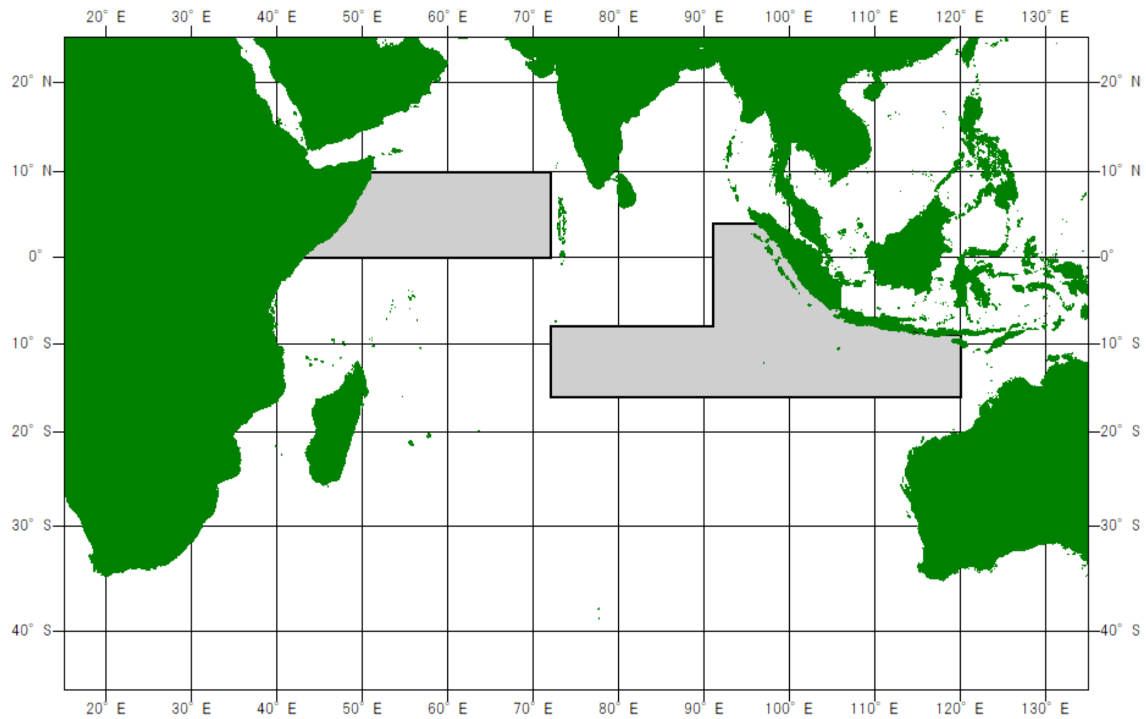
We define major fishing grounds of Japanese tuna longline fishereis for four species in 36 years as follows: First we excluded 0 catch (CPUE) data, then we extracted average nominal CPUE more than top 25 % tiles by species. Table 1 shows the thrshhold values of 25% tile by species. Maps 1-4 show study areas defined as good (high nominal CPUE) fishing gounds.

Table 1 Threshhold valuers of nominal CPUE defined as good fishing grounds for BET+YFT+ALB+SWO. Threshhold values are the top 25% tile of the non-zero nominal CPUE by species.

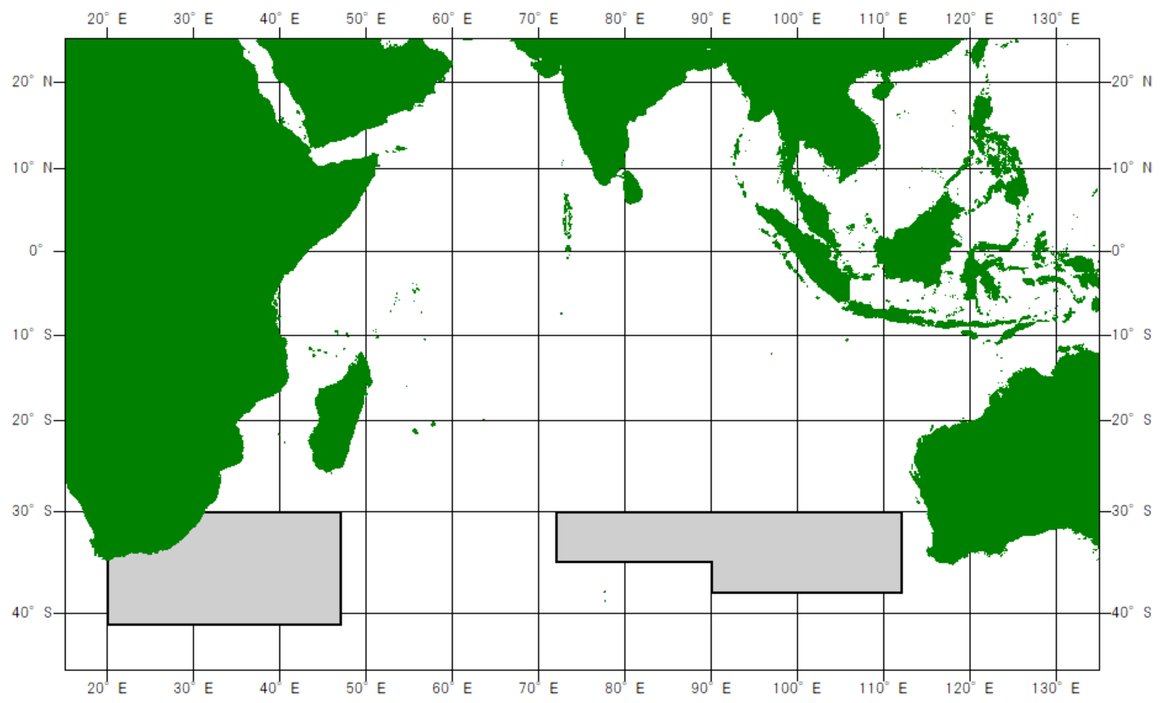
Species	Threshhold values of niminal CPUE define as good fishing gorunds (number of fish/1,000 hooks)
YFT (Yellow tuna)	5.99
BET (Bigeye tuna)	6.15
ALB (Albacore tuna)	6.07
SWO (Awordfish)	0.85



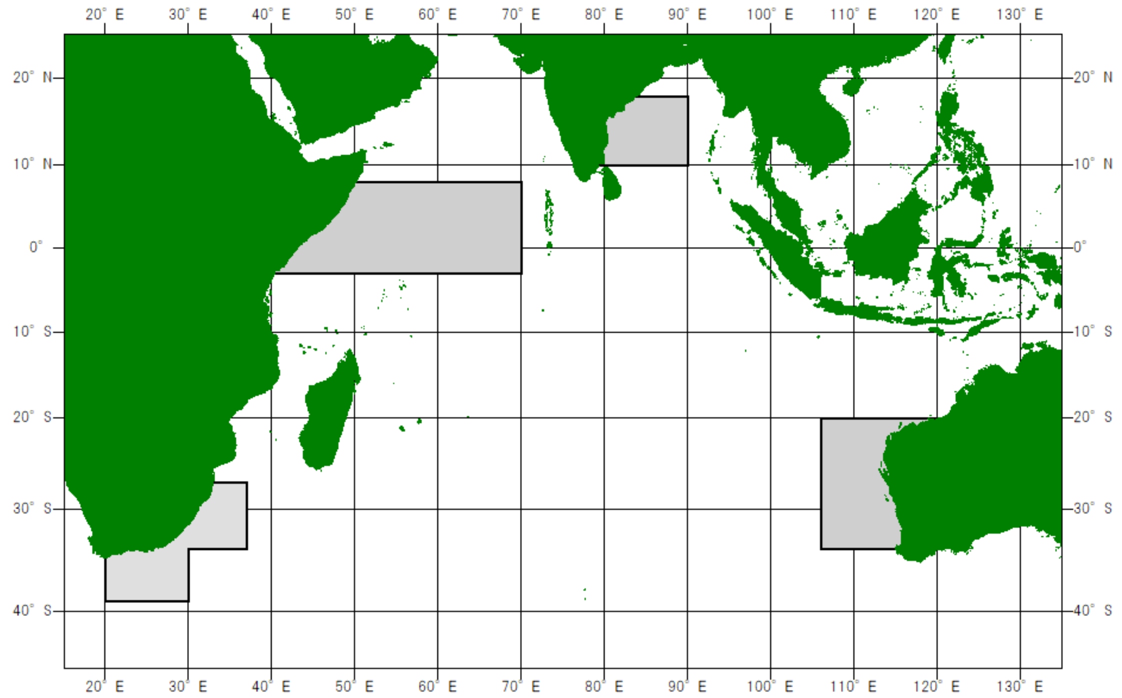
Map 1 Study area (Yellowfin tuna)



Map 2 Study area (Bigeye tuna)



Map 3 Study area (Albacore tuna)



Map 4 Study area (Sworfish)

4. Analyses

4.1 Data set-up

In order to study vertical shear currents effects on nominal CPUE meangfully, we investigated effects for three different types of longline gears, i.e., Shallow and Regular LL (4-10), Deep LL (11-16) and Ultra deep (17-30) (unit: numbner of hooks belween floats) .

Fig. 1 shows historical changes of number of hooks between floats in the Indian Ocean. Shallow/Regular LL and Deep LL dominate before 1990, afterwards Deep LL and Ultra-deep LL.

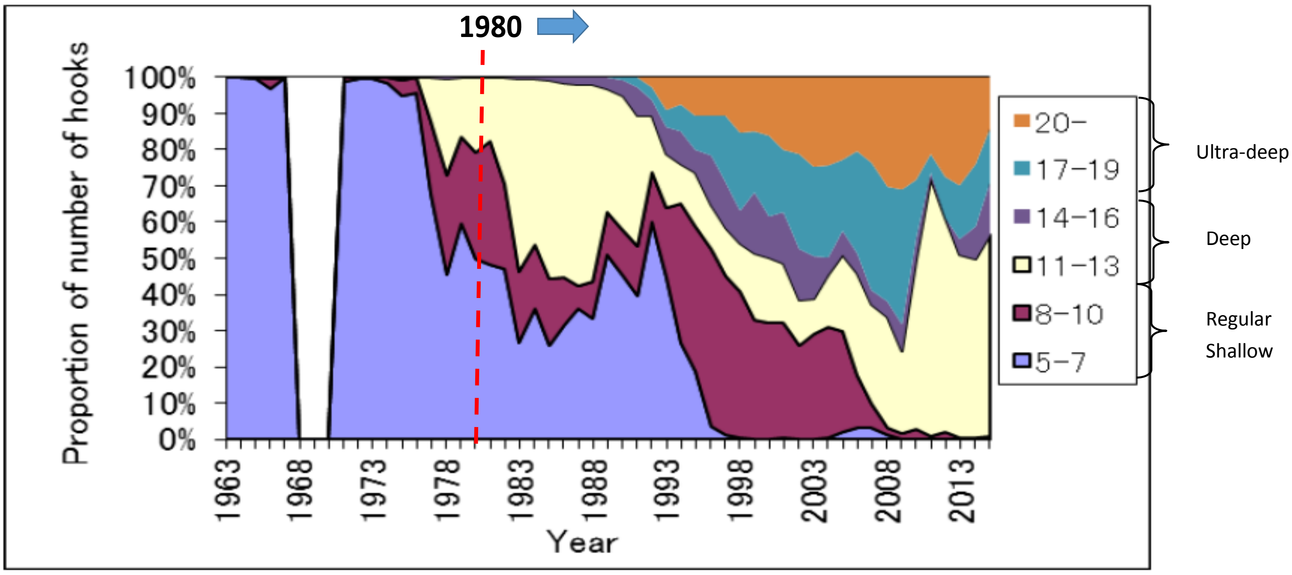


Fig.1 Historical change of number of hooks between floats in the Indian Ocean

[Note] Shallow/Regular LL: 5-10, Deep: 6-16 and Ultra deep: 17 or more

(unit) number of hooks between float

Similary vertical shear currents [s] are categorized by three classes [unit: (m/s)/m] , i.e., High (strong) ([s] <=-4), Medium (-4< [s] <= -3) and Low (-3 <=[s]). Then, we merged nominal CPUE and vertical shear currents by species, year, month, 1°x1° area, LL type and shear class.

4.2 Results of relations between the vertical shear and nominal CPUE

Box 1-4 shows results of the relations between vertical shear currents and nominal CPUE by species, LL type and shear class using the box plots.

4.3 Multiple comparisons among medians of three classes of vertical shear currents

Boxes 1-4 also show the results of multiple comparisons among medians of three classes of vertical shear currents by species and LL type to examine if there are statistical significances among three shear classes ($Pr < 0.01$). We used the Steel-Dwass non-parametric statistical multiple comparison test among medians available in pSDCFlig function of the NSM3 package in "R" language. We used the asymptotic method.

4.4 Interpretation of results

Results represented in Boxes 1-4 may be complicated to understand, hence we interpret using one real example as shown in Fig. 2.

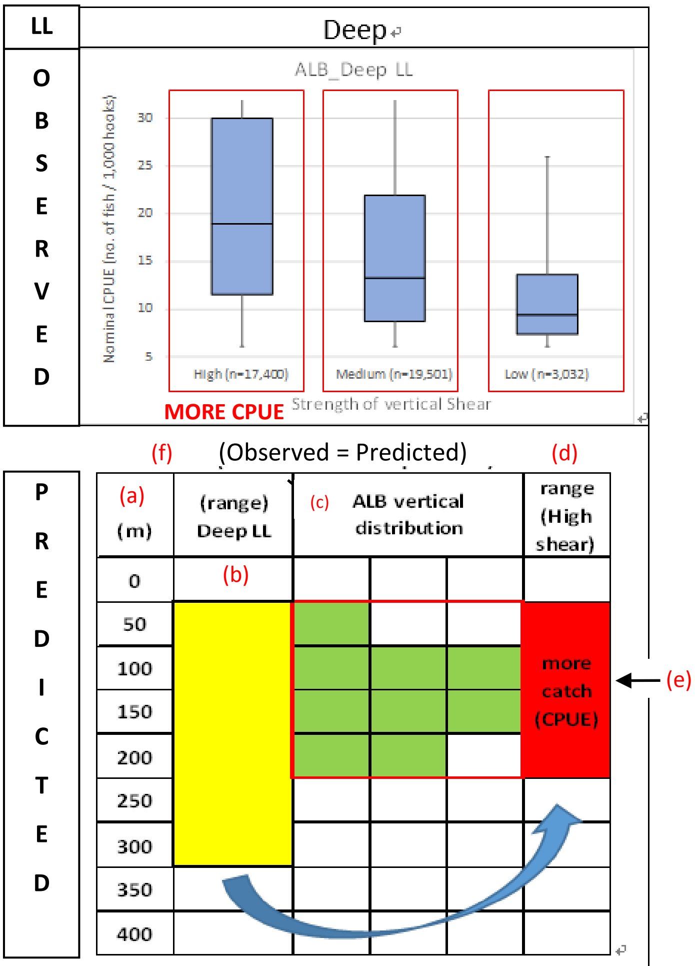


Fig. 2 Interpretation of results (Boxes 1-4) using an example (above)

Legends (left part)

OBSERVED and PREDICTED
"Observed" represents results based on real data analyses in this study, while "Predicted", for predicted results based on average situation from past studies listed in References (page 13-17) (e.g., Kanaiwa *et al*, 1998 and Nishi, 1990).

Legends (upper part)

Deep
Type of longline (there are three types in this study, i.e., shallow/Regular, Deep and Ultra deep LL)

Box plots
Y-axis: Nominal CPUE (number of fish/1,000 hooks) (*shaded area represents 25% tile, Median and 75% tile*).
X-axis: three classes of vertical shear magnitudes *(High, Medium and Low)*

Red Rectangle
Indicating statistically significant groups among three medians ($Pr < 0.01$) based on the Steel-Dwass multiple comparison test among medians.

MORE CPUE
MORE CPUE (in this case) means that CPUE was increased during high vertical shear currents, comparing to CPUE during median and low currents.

Legends (lower part)

Color Illustrations (from left)

(a) Depth range by 50m interval.
(b) Predicted depth range covered by deep LL **when no** vertical shears.
(c) Predicted frequency distribution of habitat depth ranges for ALB (green).
(d) Predicted depth range covered by deep LL **when there are high(strong)** vertical shears (red).
(e) Comments in red marker: In this case, it was predicted that ALB are very much affected by higher vertical shears because strong vertical shear currents make LL lift-up to shallower depth ranges and could catch more ALB (means more CPUE) there where main ALB habitat depth ranges.
(f) In this case, OBSERVED=PREDICTED.
(g) The arrow illustrates shifts of LL depth range to the shallower one due to high(strong) vertical shear currents (average/predicted situation based on the past studies).

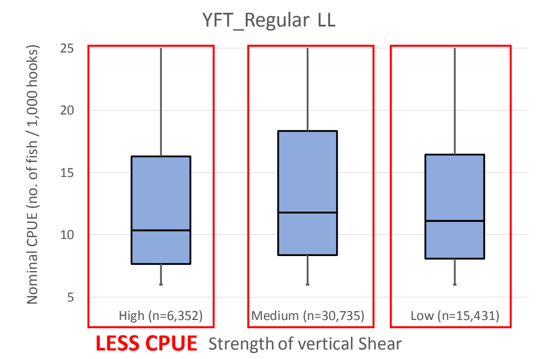
BOX 1 Observed and **Expected** results on effects of vertical shear currents by three class (high, medium and low) to Japanese tuna LL nominal **YFT** nominal CPUE in the Indian Ocean (Shallow/Regular vs. Deep vs. Ultra-deep)

(For detail interpretations on legends and illustrations, please see page 8)

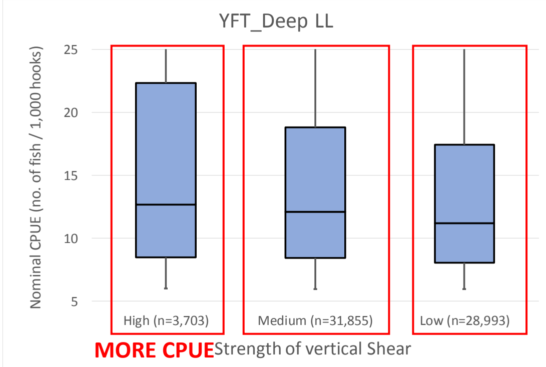
LL	Regular	Deep	Ultra-deep

OBSERVED

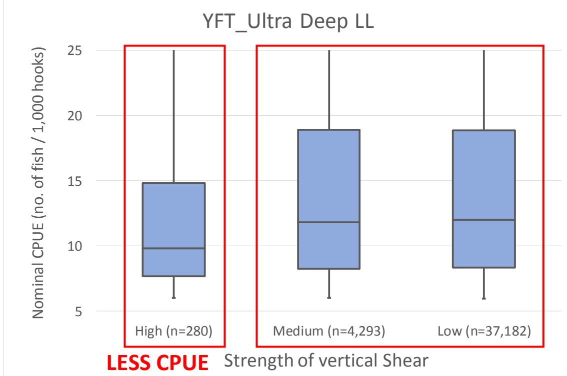
Regular



Deep

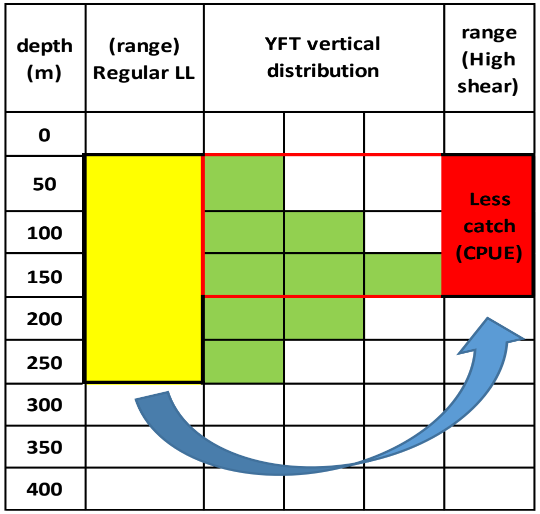


Ultra-deep

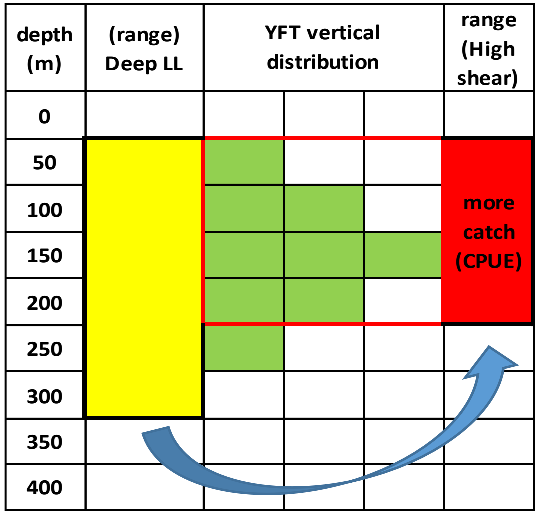


PREDICTED

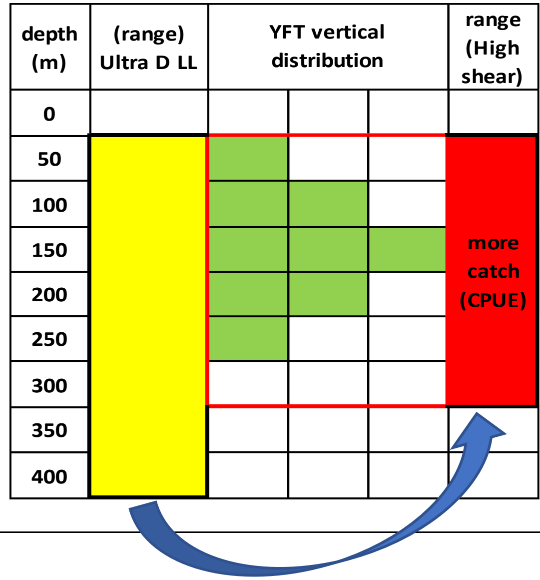
(Observed = Predicted)



(Observed = Predicted)



(Observed ≠ Predicted)



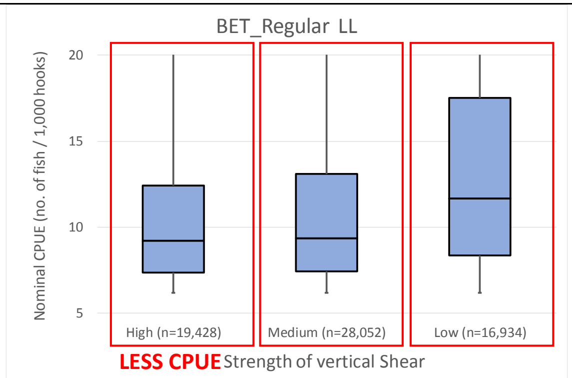
BOX 2 Observed and **Expected** results on effects of vertical shear currents by three class (high, medium and low) to Japanese tuna LL nominal **BET** nominal CPUE in the Indian Ocean (Shallow/Regular vs. Deep vs. Ultra-deep)

(For detail interpretations on legends and illustrations, please see page 8)

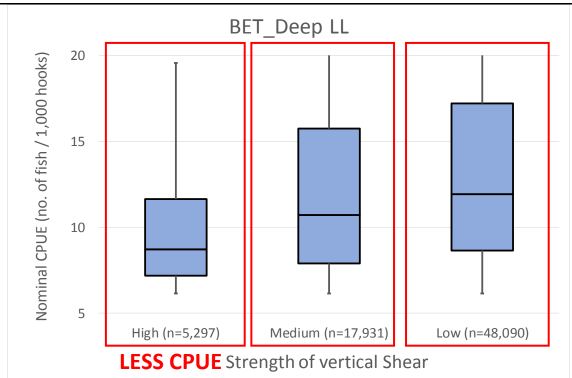
LL

OBSERVED

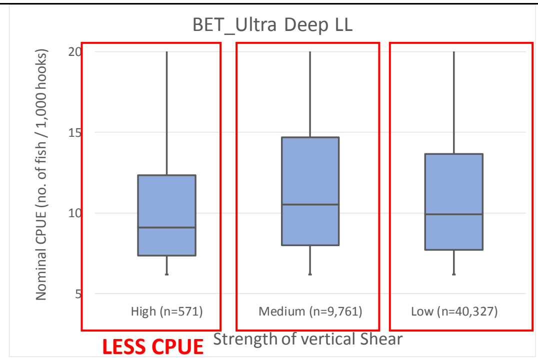
Regular



Deep

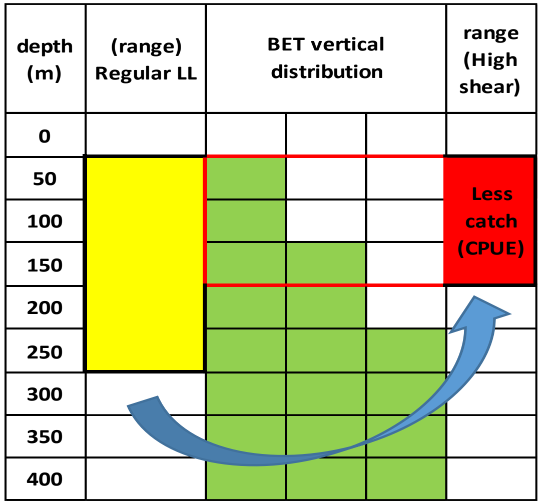


Ultra-deep

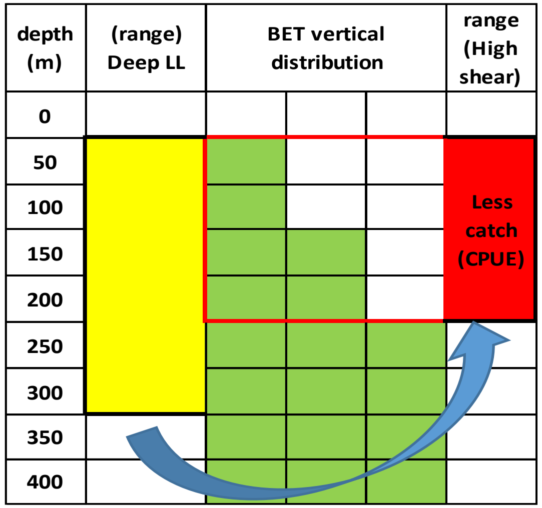


PREDICTED

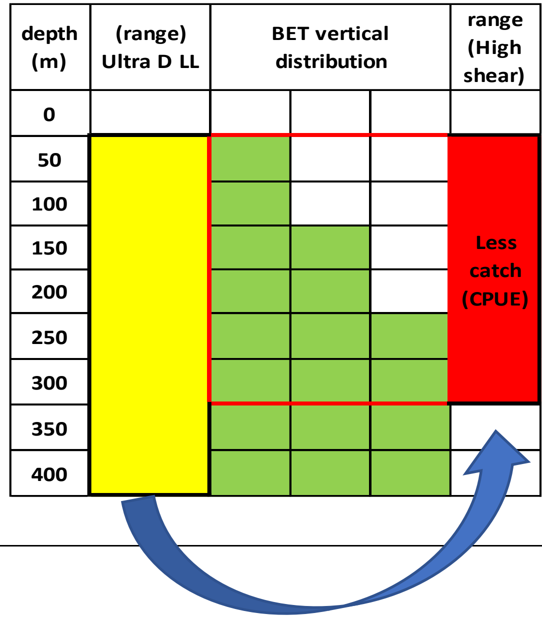
(Observed = Predicted)



(Observed = Predicted)

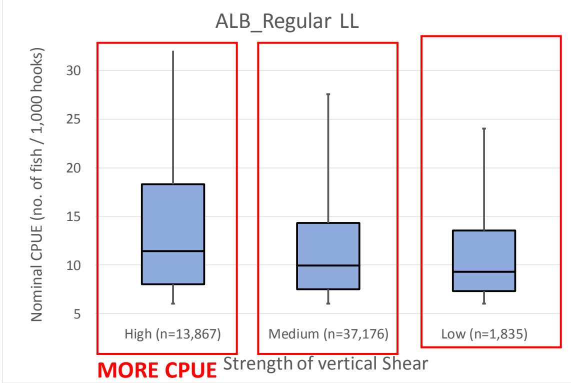
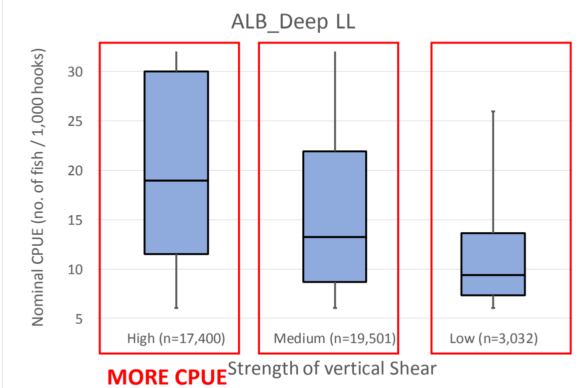
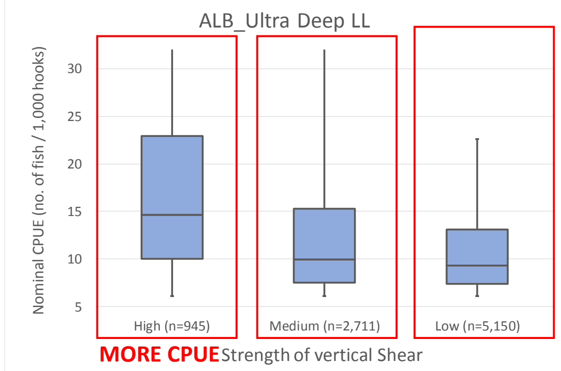
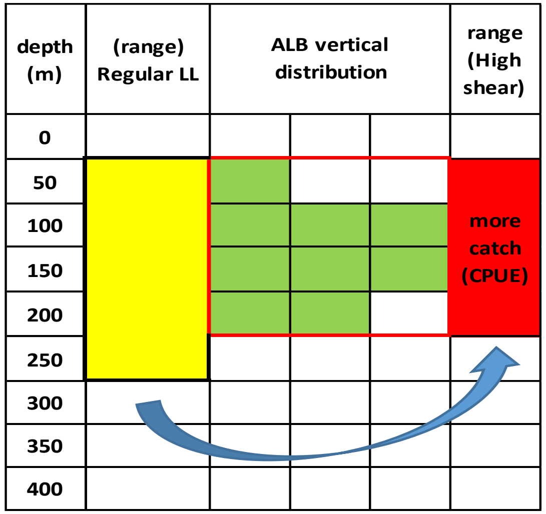
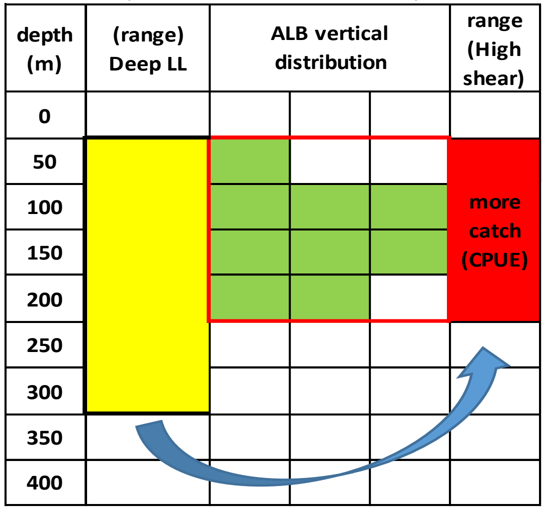
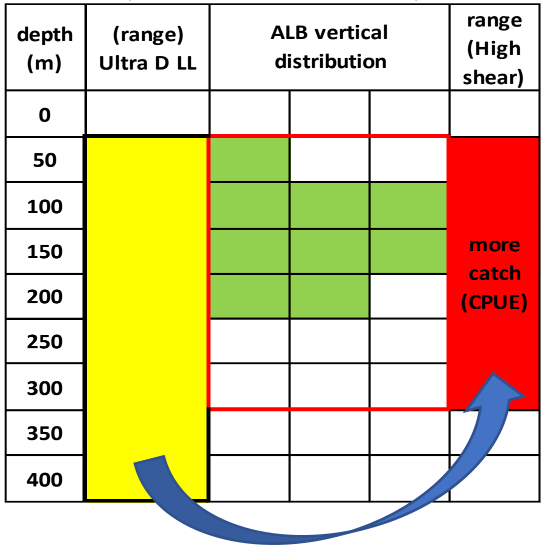


(Observed = Predicted)



BOX 3 Observed and **Expected** results on effects of vertical shear currents by three class (high, medium and low) to Japanese tuna LL nominal **ALB** nominal CPUE in the Indian Ocean (Shallow/Regular vs. Deep vs. Ultra-deep)

(For detail interpretations on legends and illustrations, please see page 8)

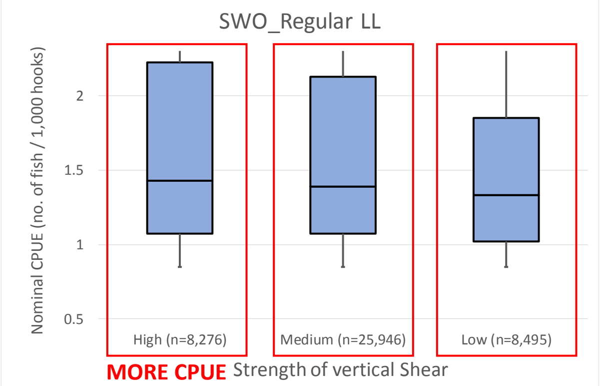
LL	Regular	Deep	Ultra-deep
OBSERVED			
PREDICTED	(Observed = Predicted) 	(Observed = Predicted) 	(Observed = Predicted) 

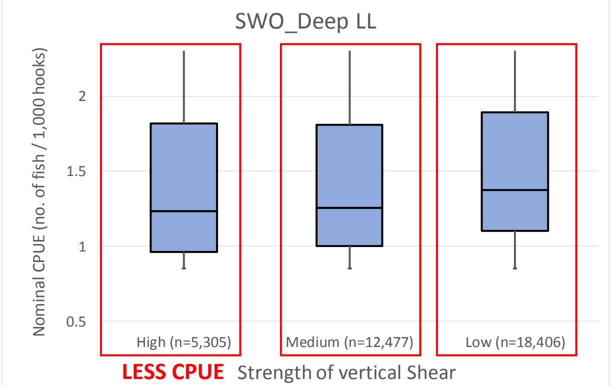
BOX 4 Observed and **Expected** results on effects of vertical shear currents by three class (high, medium and low) to Japanese tuna LL nominal **SWO** nominal CPUE in the Indian Ocean (Shallow/Regular vs. Deep vs. Ultra-deep)

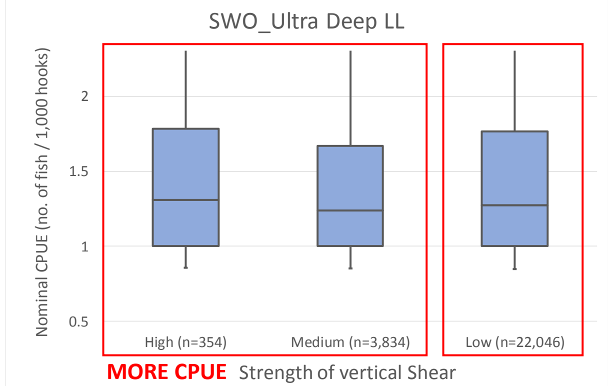
(For detail interpretations on legends and illustrations, please see page 8)

LL: Regular | Deep | Ultra-deep

OBSERVED

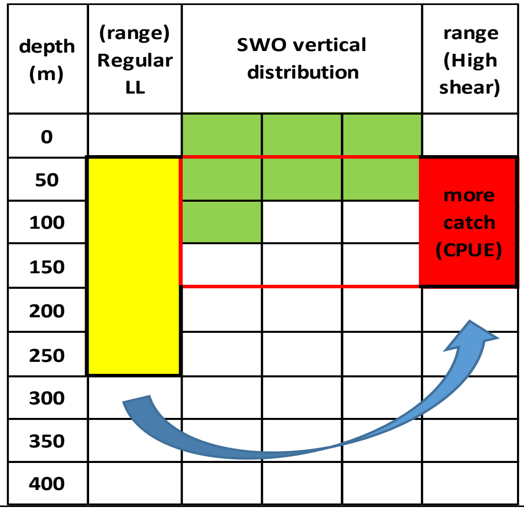




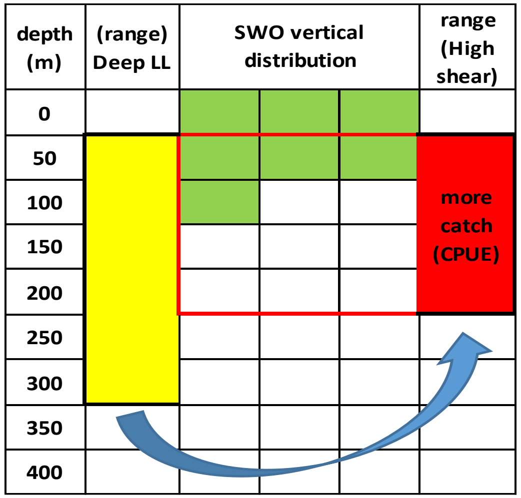


PREDICTED

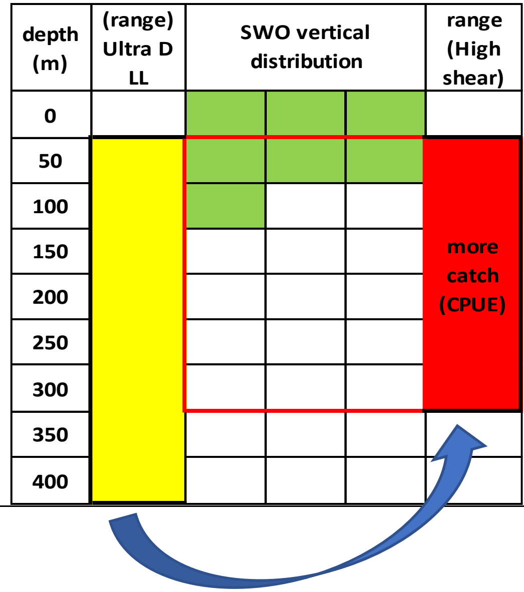
(Observed = Predicted)



(Observed ≠ Predicted)



(Observed = Predicted)



5. DISCUSSION

(1) Is time-area scale of vertical shear currents similar to LL (month/1°x1°) ? Critical question.

It is unknown about the time-area scale of vertical shear currents. According to Dr Taneda (Seikai National Fisheries Research Institute, Nagsaki, Japan) and former Professor Murakami (Hokkaido University), vertical shear currents occur from very small time-area scale (a few days and a few 10 Km^2) to very large scale (a few months and a few hundred Km^2) (Fig. 3). However, frequncies of various time-area scales are unknown.

If majority of time-area scales of vertical shear currents data are larger than LL scale (a month and 1°x1°), results of this study will be more reliable as they well cover LL nominal CPUE scale, while the inverse situation, less reliable because time-area scales of LL data are much larger than those of vertical shear currents, which makes vertical shear currents effects on LL nominal CPUE very dull.

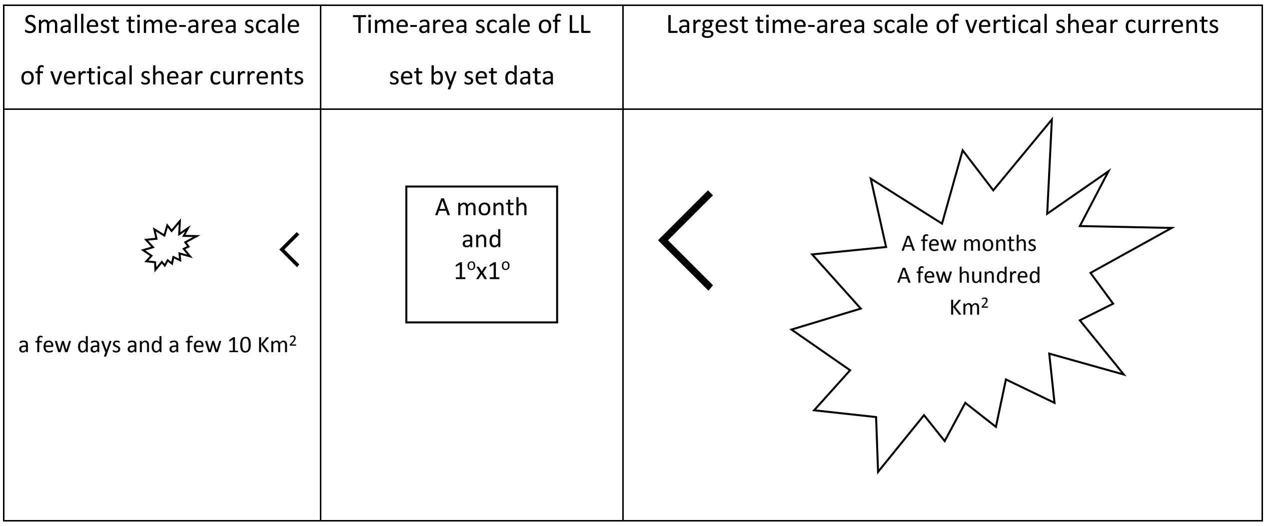


Fig. 3 Scematic images of time-area scales of vertical shear currents (left:smallest and right: largest) and LL set by set data time-area scale (middle)

(2) Uncertainties

There are a number of uncertainties in this study as listed below, thus results should be looked with caution.

- Shear currents data are based on the assumilations, which may not represent real situation;
- Actual LL depth range may be different from the predicted (average) sitaution based on past studies;
- Nominal CPUE may be affected by other environmetal factors, thus signals of nominal CPUE in this study may not be caused only by vertical shear currents;
- It is unknown about frequncies of time-area scales of vertical shear currents, which affect reliabilities of results as discussed in the previous section; and
- In this study, materials of main and branch lines are not incorporated. Effects of vertical shear currents on nominal CPUE are considered to be also affected by materials.

(3) Low frequencies (sample sizes) in high (strong) vertical shear currents

We defined three classes (degrees) of vertical shear current strength [unit: (m/s)/m] , i.e., High (strong) ([s] <=-4), Medium (-4< [s] <= -3) and Low (-3 <=[s]). Box 5 shows sample size (n=) of vertical shear currents and its percent frequencies by shear class (high, medium and low), LL type and species.

In general, sample sizes (frequncies) of "high shear class" in Ultra-deep LL (except ALB) are very low (Table 1). This means that high (strong) vertical shear currents do not occur so often. However, it depends on the definition of [s], i.e., in this study, we used [s] => 4 as the high (strong) vertical shear currents which have less sample sizes. Thus we may need to explore other definition such as [s] => 3, so that the results may be more relaible (?) as we may get more sample sizes (frequncies). This will be the future work.

Box 5 Sample size (n=) of vertical shear currents and its percent frequencies by species, shear class (high, medium and low) and LL type.

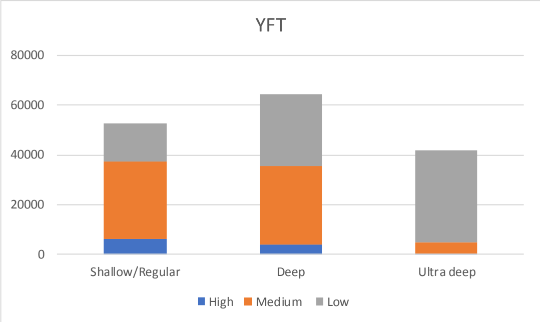
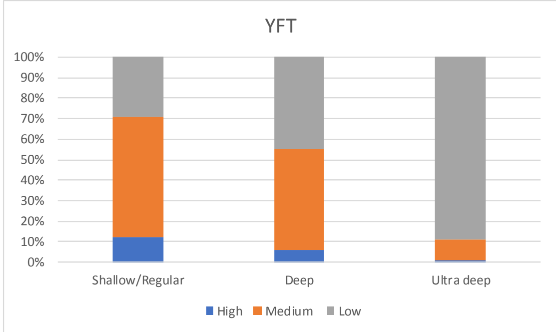
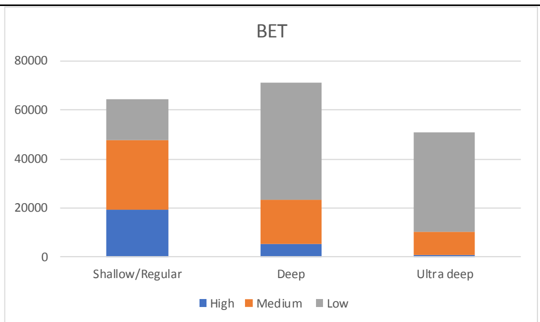
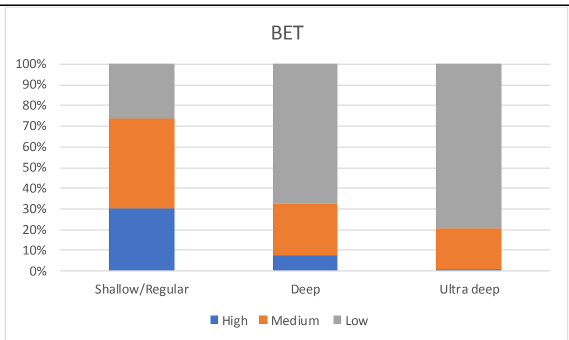
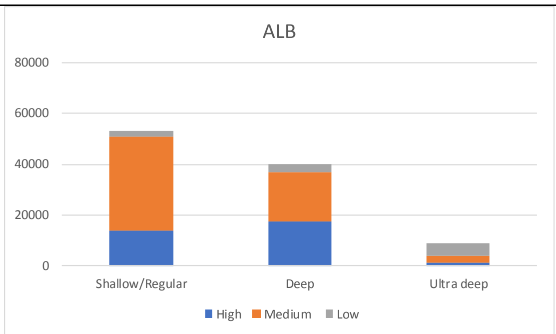
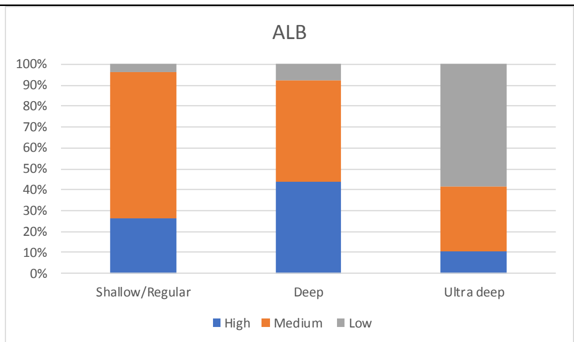
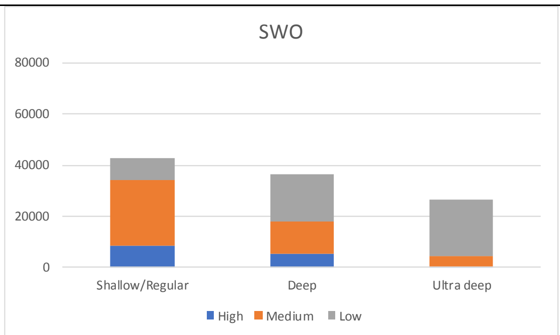
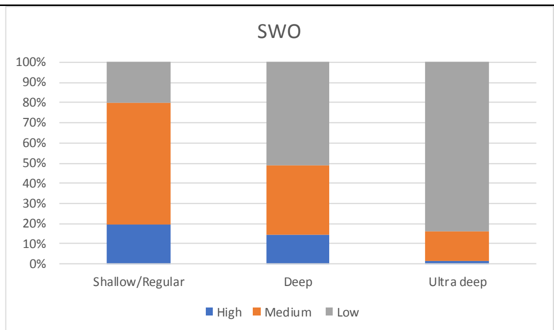
	Sample size (n=) by vertical shear current class, LL type and species	Percent frequncies of sample size (n=) by vertical shear current class, LL type and species
YFT		
BET		
ALB		
SWO		

Table 1 Percent frequencies of high (strog) shear currents in ultra deep LL by species.

% frequencies	YFT	BET	ALB	SWO
Ultra-deep LL	0.7%	1.1%	10.7%	1.3%

(4) Effects of vertical shear currents to nominal CPUE by species

Although there are a number of uncertainties, we could find some results closed to the predicted situation regarding effects of vertical shear currents on nominal CPUE by species as follows (refer to Boxes 1-4):

[YFT]

We expect that nominal YFT CPUE are largely affected by strong vertical shear currents, especially for Deep and Ultra deep LL (see illustration in expected results in Box 1, Page 9). This is because when strong vertical shear currents occur, LL (hooks) are lifted-up to shallower depth ranges, where there are major YFT habitat depths, hence higher YFT CPUE are expected. But, we could not get the expected results, i.e., only very small positive (expected) effects were found for Deep LL and the inverse effect for ultra-Deep LL. Possible reasons why we could not get the expected results are as follows: (a) actual LL depth range might be different from the predicted situation, which produce biases in results, (b) other environmental factors might affect more on nominal YFT CPUE, (c) there are very small sample sizes of high (strong) vertical shear currents in deep and ultra-deep LL and/or (d) materials of main and brach lines may affect results. But exact causes are not identified at this stage. As a result, it was suggested that vertical shear currents could not affect nominal YFT CPUE for deep and ultra-deep LL as predicted, while in case for Shallow/Regular LL, we could get results close to the predcited one.

[BET]

We expect that nominal BET CPUE are largely affected by strong vertical shear currents for all three types LL (see illustration for expected results in Box 2, Page 10). This is because when strong vertical shear currents occur, LL (hooks) are lifted-up to shallower depth ranges, where there are minor BET habitat depths, hence lower CPUE are expected. In fact, we could get results close to the predicted results (see Box 2), thus BET is the supporting example (observed=predicted) in this study.

[ALB]

We expect that nominal ALB CPUE are largely affected by strong vertical shear currents for three types LL (see illustration for expected case in Box 3, Page 11). This is because when strong vertical shear currents occur, LL (hooks) are lifted-up to shallower depth ranges, where there are major ALB habitat depths, hence higher CPUE are expected. In fact, we could get results close to the predicted ones (see Box 3), thus ALB is the supporting example (observed=expected) in this study.

[SWO]

We expect that nominal SWO CPUE are largely affected by strong vertical shear currents for all three LL types (see illustration for expected results in Box 4, Page 12). This is because when strong vertical shear currents occur, LL (hooks) are lifted-up to shallower depth ranges, where there are major SWO habitat depths, hence higher SWO CPUE are expected. But, we could not get the expected results, i.e., only very small positive effect for all three LL types. The possible reasons why we could not get the predicted results are as follow: (a) SWO habitat depth range may be too shallow to support the predicted scenario, (b) actual LL depth range might be different from the predicted situation, which produce biases (uncertainties) in results, (c) other environmental factors negatively affected on nominal SWO CPUE, (d) there are very small sample sizes of high (strong) vertical shear currents in ultra-deep LL and/or (f) materials of main and branch lines may affect results. However, exact causes are not identified at this stage. As a result, it was suggested that vertical shear currents could not affect nominal SWO CPUE as predicted.

(5) Do we need vertical shear currents in CPUE standardization?

In the predicted situation, vertical shear current affects nominal CPUE differently by its strength, species (habitat depth range) and LL type (shallow/regular, deep and ultra-deep LL) as shown in the predicted results (Boxes 1-4). This study suggested that “observed” results for BET and ALB were close to the “predicted” results, while not for YFT and SWO. From this fact, vertical shear currents by GODAS (NCEP/NOAA, USA) likely affect nominal BET+ALB CPUE as expected, while not for YFT+SWO due to a number of uncertainties dicussed previously, which possibly disturbed predicted results.

Thus, it is worth to examine if vertical shear currents affect on BET and ALB CPUE standardization in the future (in Part II) and also for YFT and SWO to demonstrate that vertical shear currents will not affect their nominal CPUE. In such cases, other important envriornemtal factors need to be also incorporated because effects to nominal CPUE may be integratedly created by various environmental factros including vertical shear currents.

In addition, when we examine the CPUE standardization, we need to incorporate effects by different types of LL (Shallow/Regular, Deep and Ultra deep used in this study). This is because this sutudy suggested that vertical shear currents effects on nominal CPUE among three types are statistically significant except 2 cases (ultra deep in YFT and SWO) (Boxes 1-4). In fact, in CPUE standardization for Japanese tuna LL fishereis data, 5-6 categories of number of hooks between floats have been applied routienly (for example, Nishida and Wang , 2014).

In addition, we need to keep in mind following suggestions made by the First IOTC CPUE workshop (2013):

Environmental data would be useful to consider in relation to standardization approaches. However, the way it is usually performed in GLMs, where an environmental covariate is associated to each observation (in regular 1°, 5° or even 10° grids), may not be the most pertinent as it does not allow to identify the ecological processes which may affect CPUE. Alternatively, GLMs could be performed in sub-areas where the variability pattern of the environmental signature is well identified (using spatial EOFs to delineate those sub-areas). In such sub-areas, GLMs could be designed with and without environmental covariates to understand the potential effect of the environment. Environmental covariates should be in limited numbers (the lesser the better) and selected to test hypothesis on the ecological processes at stake.

Thus, the future study will be a good opportunity to examine this suggestion in sub-areas within major fishing ground by species, where particilar environmetal factors including vertical shear currents affect nominal LL CPUE significantly.

6. SUMAMRY

- There are a number of uncertainties in this study, thus results should be looked with caution;

- Four major uncertainties are (a) vertical shear currents data are derived by assimilations, (b) time-area scales of vertical shear currents are unknown, (c) actual LL depth ranges may be different from predicted ones and (d) materials of main and branch lines,which were not usedin this study;

- Ranges of vertical shear current categories, especially for “high (strong)”, need to be examined because sample sizes of high (strong) currents are too small (about 1% except ALB, 10%), which may affect results to some extents;

- Although there are a number of uncertainties, we could get results very close to predicted ones in case for BET and ALB, while not for YFT and SWO, which particularly disturbed by uncertainties, (c) and (d);

- It will be worth to attempt CPUE standardization incorporating vertical shear currents and line materials in the future (Part II). In such case, we also need to use other influential environemtal factors becasue effects on nominal CPUE may be integratedly created; and

- The IOTC First CPUE workshop (2013) suggested that CPUE standardization should be conducted in specific areas (not whole Indian Ocean), where the variability pattern of the environmental signature is well identified. Thus, the future study may be a good opportunity to examine this suggestion.

ACKNOWLEDGEMENTS

We sincerely thanks to following experts to provide technical assistances: Professor Teruhisa Komatsu (Tokyo University, Japan), Dr Makoto Okazaki (National Research Institute of Far Seas Fisheries, Japan), Dr Francis Marsac (IRD, France), Dr Hiroki Yokoi (National Research Institute of Far Seas Fisheries, Japan), Former Professor Takashi Murakami (Hokkaido University) and Dr Kiyoshi Itoh (Environment Simulation Laboratory, Japan).

REFERENCES

Bach, N., Dargon, L., Bertrand, A., Josse, E., and Misselis, C. (2003). Acoustic telemetry versus monitored longline fishing for studying the vertical distribution of pelagic fish: bigeye tuna (*Thunnus obesus*) in French Polynesia, Fish Res. 60, 281-292.

Bigelow, K. A., J. Hampton, and N. Miyabe. (2002) Application of the habitat-based model to estimate effective longline effort and relative abundance of Pacific bigeye tuna (*Thunnus obesus*). Fish. Ocean. 11: 143–155.

Bigelow, K. A., M. N. Maunder, and M. G. Hinton. (2003). Comparison of deterministic and statistical habitat-based models to estimate effective longline effort and standardized CPUE for bigeye and yellowfin tuna. Standing Committee on Tuna and Billfish 16 RG−3. 19 p.

Bigelow, K, Musyl M. K., Poisson F., Kleiber P. (2006) Pelagic longline gear depth and shoaling. Fish. Res., 77, 173-183.

Bigelow, K.A. and Maunder, M.N. (2007). Does habitat or depth influence catch rates of pelagic species? Can. J. Fish. Aqu. Sci. 64:1581−1594.

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

Brill, R.W., Block, B.A., Boggs, C.H., Bigelow, K.A., Freund, E.V. and Marcinek, D.J. (1999) Horizontal movements and depth distribution of large adult yellowfin tuna (Thunnus albacares) near the Hawaiian Islands, recorded using ultrasonic telemetry: implications for the physiological ecology of pelagic fishes. Mar. Biol. 133:395–408.

Brill, R.W., Lutcavage, M.E., (2001). Understanding environmental influences on movements and depth distributions of tunas and billfishes can significantly improve population assessments. In: Sedberry, G. (Ed.), Island in the Stream: Oceanography and Fisheries of the Charleston Bump. Proceedings of the American Fisheries Society Symposium 25. Bethesda, MD, pp. 179–198.

Carton, H., G. Chepurin, and X. Cao. (2000a). A simple ocean data assimilation analysis of the global upper ocean 1950–95. Part I: Methodology. J. Phys. Ocean. 30: 294–309.

Dagorn, L., Bach, P. and Josse, E. (2000) Movement patterns of large bigeye tuna (*Thunnus obesus*) in the open ocean, determined using ultrasonic telemetry, Mar. Biol. 136: 361-371.

Gong, Y., Lee, J-U., Kim, Y-S and Yang, W-S., (1989) Fishing efficiency of Korean regular and deep longline gears and vertical distribution of tunas in the Indian Ocean. Bull. Korean Fish. Soc. 22, 86–94.

Goodyear, C. P., D. Die, D. W. Kerstetter, D. B. Olson, E. Prince, and G. P. Scott. (2003) Habitat standardization of CPUE indices: research needs. Pages 613–623 in ICCAT collective volume of scientific papers 55.

Hampton, J., Bigelow, K. and Labelle, M. (1998) Effect of longline fishing depth, water temperature and dissolved oxygen on bigeye tuna (Thunnus obesus) abundance indices. Working Paper 17, Eleventh Meeting of the Standing Committee on Tuna and Billfish, Honolulu, Hawaii, USA, 28 May - 6 June (1998), 18 p.

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.

Holland, K.N., Brill, R.W. and Chang, R.K.C. (1990) Horizontal and vertical movements of yellowfin and bigeye tuna associated with fish aggregating devices. Fish. Bull. U.S. 88:493–507.

IOTC (2013) Report of the IOTC CPUE Workshop. San Sebastian, Spain, 21-22 October 2013.

Kanaiwa, M., Bigelow, K. and Yokawa, K. (2008) A comparison of observed catenary angles and estimated angles with a statistical habitat-based standardization model with a multiple species approach. ISC/08/BILLWG−1/04 17p.

Langley, A., K. Bigelow, M. N. Maunder, and N. Miyabe. (2005) Longline CPUE indices for bigeye and yellowfin in the Pacific Ocean using GLM and statistical habitat standardization methods. Western and Central Pacific Fisheries Commission Science Committee 1 Stock Assessment Working Paper 8. 40 p.

Lee, J. H., Lee, C.W., Cha, B. J. (2005) Dynamic simulation of tuna longline gear using numerical methods. Fisheries Science, 71: 1287–1294.

Marsac, F. (2016) Outline of climate and oceanographic conditions in the Indian Ocean: an update to August 2016 (Marsac F) IOTC–2016–WPTT18–09.

Matsumoto, T., Uozumi Y., Uosaki K., and Okazaki M. (2001) Preliminary review of billfish hooking depth measured by small bathythermograph systems attached to longline gear. ICCAT Col. Vol. of Sci. Pap., 53, 337-344.

Miyamoto, Y., Uchida, K., Orii, R., Wen, Z., Shiode, D., and Kakihara, T. (2006) Three-dimensional underwater shape measurement of tuna longline using ultrasonic positioning system and ORBCOMM buoy. Fish. Sci., 72: 63-68.

Mizuno, K., Okazaki M., and Miyabe N. (1998) Fluctuation of longline shortening rate and its effect on underwater longline shape. Bull. Nat. Res. Inst. Far Seas Fish., 35, 155-164.

Mizuno, K., Okazaki, M., Nakano, H. and Okamura, H. (1999) Estimating the underwater shape of tuna longlines with micro-bathythermographs. Inter-Am. Trop. Tuna Comm., Special Report 10, pp. 35.

Nakano, H., Okazaki, M. and Okamoto. H., (1997) Analysis of catch depth by species for tuna longline fishery based on catch by branch lines. Bull. Nat. Res. Inst. Far Seas Fish. 34, 43–62.

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. Off coast Inc., (1997). Modeling gear configuration of longlines. Report No: OCI-97-202, 201 Hamakua Drive, Suite C-107, Kailua, HI 96734, USA, p. 7.

Nishida, T., Matsuura, H. and Marsac, F. (2008) New environmental information (NCEP) applied for standardized swordfish CPUE of tuna longline fisheries (Japan and Taiwan) in the IOTC WPB6, IOTC-2008-WPB-11.

Nishida, T. and Wang, S-P. (2014) CPUE standardization of swordfish (Xiphias gladius) of Japanese tuna longline fishery in the Indian Ocean using cluster analysis for targeting effect (Nishida T & Wang S-P) IOTC–2014–WPB12–21

Saito, S., Ishii, K., Yoneta, K., (1970) Swimming depths of large sized albacore in the South Pacific Ocean. 1. Fishing of albacore by newly designed vertical longline. Bull. Jpn. Soc. Sci. Fish. 36, 578–584.

Saito, S., (1973). Studies on fishing of albacore, *Thunnus alalunga* (Bonnaterre) by experimental deep-sea tuna long-line. Mem. Fac. Fish. Hokkaido Univ. 21, 107–185.

Saito, S., (1975). On the depth of capture of bigeye tuna by further improved vertical long-line in the tropical Pacific. Bull. Jpn. Soc. Sci. Fish. 41, 831–841.

Saito, S., (1992). Tuna longline fishery and tuna's swimming layers (Maguro no yu-eisou to haenawa gyohou). Seizando, Tokyo, pp. 1-18 (in Japanese).

Shiode, D., Hu, F., Shiga, M., Yokota, K., and Tokai, T. (2005) Midwater float system for standardizing hook depths on tuna longlines to reduce sea turtle by-catch, Fish. Sci. 71, 1182-1184.

Song, L.M., Zhou, J., Zhou, Y.Q. (2002) Environmental preferences of longlining for bigeye tuna (Thunnus obesus) in the tropical high seas of the Indian Ocean. IOTC-2006-WPTT-14. Wan, R., Hu, F.X., Tokai, T., et. al. A method for analyzing the static response of submerged rope systems based on a finite element method. Fisheries Science, 68: 65–70.

Suzuki, Z., Warashina, Y. and Kishida, M. (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.

Uozumi, Y. and Okamoto, H. (1997) Research on the hook depth of longline gear in the 1995 research cruise of the R/V Shoyo Maru. Working Paper 3, 7th Meeting of the Western Pacific Yellowfin Research Group, 18–20 June, Nadi, Fiji, pp.20.

Wan, R., Song, X. F., Tang, Y. L. (2004) A method for measuring 3D geometry of fishing gear models in the flume tank based on video image analysis. J of Fisheries of China, 28:443-449 (In Chinese).

Ward, P. and R. A. Myers. (2005) Inferring the depth distribution of catchability for pelagic fishes and correcting for variations in the depth of longline fishing gear. Can. J. Fish. Aquat. Sci. 62: 1130–1142.

Yano, K. and Abe, O. (1998) Depth measurements of tuna longline by using time-depth recorder. Nippon Suisan Gakkaishi (in Japanese, with English abstract) 64:178–188.

Yokawa, K., Saito H., and Shono H., (2003) Preliminary Result of Vertical distribution pattern between Atlantic blue marlin and its CPUE. 15th SCTB BBRG-13, 10pp.

Yoshihara, T., (1954) Distribution of catch of tuna longline. IV. On the relation between K and ϕ0 with a table and diagram. Bull. Japan Soc. Sci. Fish. 19, 1012–10