(REVISED)
Preliminary attempt incorporating oceanographic conditions into CPUE standardization using HSI (Habitat Suitability Index)

- *Case study using yellowfin tuna CPUE from Japanese tuna longline fisheries in the Indian Ocean* -

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Abstract

IOTC CPUE workshop (2013) recommended that when environmental covariates are incorporated in CPUE standardization, it should be conducted in sub-area where variability pattern of the environmental signature is well identified. We attempted to implement this recommendation with one case study (Indian Ocean yellowfin tuna) incorporating oceanographic variables into CPUE standardization using HSI (Habitat Suitability Index). We used four oceanographic variables affecting YFT habitat, i.e., depth-specific sea temperature, salinity and vertical shear currents and thermocline depth.

Then SI (Suitable Index) was estimated for each oceanographic variable through spatial correlations with YFT nominal CPUE. SI is % frequency distribution representing the most suitable sea temperature range for YFT (for example) as 1 then for other ranges, proportional scales (between 0 and 1) are assigned. Then, HSI integrated four SI using geometric means and was represented as one scale from 0 (worst habitat)-1 (best habitat). As SI is based on CPUE, we cannot use it in GLM due to violation of the assumption of GLM (CPUE should not be in both sides). Thus, we changed to operation-based SI as the proxy CPUE-based SI.

We attempted CPUE standardization in sub-area (higher HSI score areas instead of the whole area) as recommended by the CPUE workshop. Then effectiveness of HSI was tested by GLM with and without HSI in that sub-area. The results showed that HSI effect was the highest significant term when it was incorporated, although trends of STD_CPUE with and without HSI are not much different. As this is very preliminary study with only one case study, we cannot make any general conclusion. We need to explore more case studies using different areas, species and fleet to provide reliable conclusions in the future. In addition, it is the critical point that we need to verify whether operation-based SI is the proxy of CPUE-based SI. Otherwise, we cannot use this approach.

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1. Introduction

In CPUE standardization for tuna longline fisheries, various oceanographic variables as covariates have been incorporated in the past. However, problems have been pointed out by tuna RFMOs. These problems were well described in the IATTC workshop (2011) on "Using Oceanography for Fisheries Stock Assessment and Management "and in IOTC CPUE workshop (2013). The major problem is that apparent over-fitting of oceanographic data to nominal CPUE and it is difficult to know if they are really related. This is because both data are used for all areas (such as 1°x1°, 5°x5° area) which produce apparent correlations (i.e., oceanographic conditions significantly affecting nominal CPUE). Thus, it is not considered that using oceanographic data in the whole area is meaningful.

Because of this problem, in recent years less oceanographic data have been used than in the past. To improve this situation, IOTC CPUE workshop (2013) suggested as follows:

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 in order to test hypothesis on the ecological processes at stake.*

This preliminary study attempts to incorporate this suggestion using HSI (Habitat Suitability Index) instead of EOFs, which may be able to identify sub-areas where the ecological processes produce good habitat areas and we need to standardize nominal CPUE.

2. Case study

In the case study, we apply for Indian Ocean YFT in sub-area R2 (SW Indian Ocean) defined by SS3 (Fig. 1) (Langley, 2015). Due to the time constraint, we could conduct only this area for this time. In the future, we need to explore other areas (such tropical area for YFT), other species and other fleets to see the general situation.

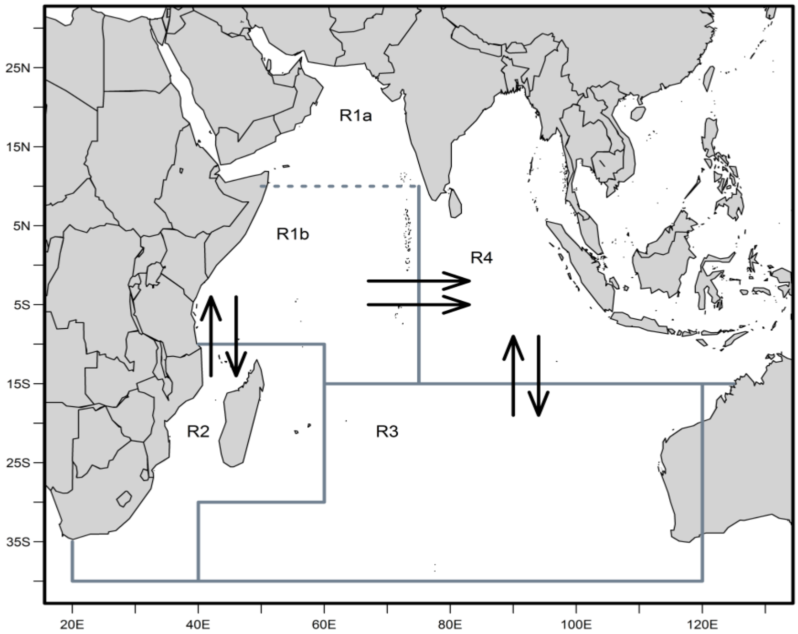


Fig 1. Case study area (R2) defined in YFT SS3 stock assessment (Langley, 2015)

3. Data

3.1 Fisheries data

Japanese tuna longline fisheries data (1980-2016) was used, which is the set by set data and represented by 1^ox1^o and month. Variables used are year, month, 1^ox1^o area, call signs (as skipper's effect), number of hooks per float (targeting correction factor), effort (number of hooks), catch (fish), catch (kg) and nominal CPUE (no of fish/1,000 hooks).

3.2 Oceanographic data

We used oceanographic data available in Global Ocean Data Assimilation System (GODAS) (http://cfs.ncep.noaa.gov/cfs/godas/monthly) in NCEP, NOAA, USA (1980-2016). The tempo-area resolution is (1/3) degrees in latitude x 1 degree in longitude and month.

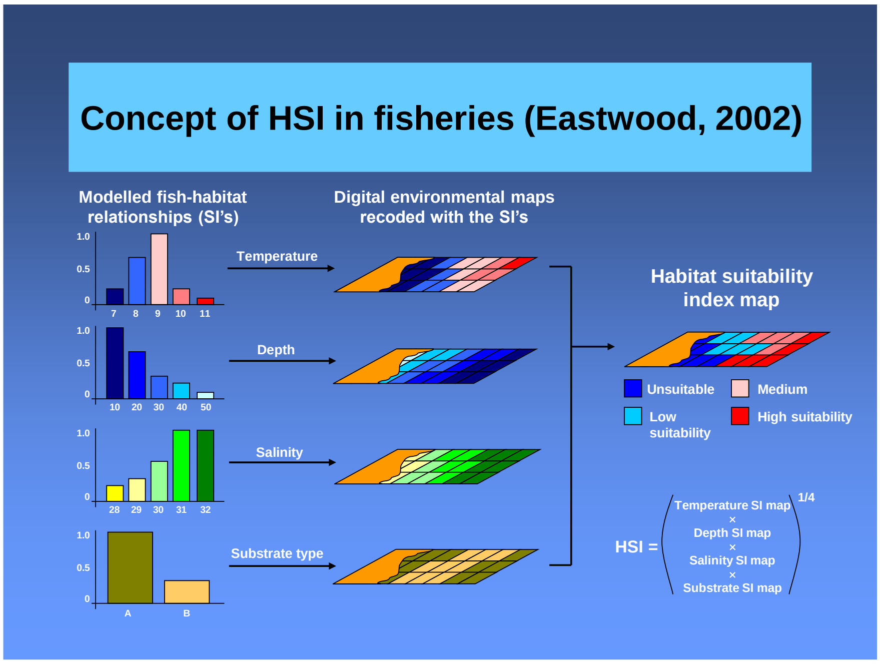
The GODAS data include temperature, salinity and current (u, v) digital data for 28 depth layers, i.e., every 10 m starting from 5m depth to 225m with extra 5 deeper depth layers, i.e., 5m, 15m, 25m, 35m, 45m, 55m ,65m, 75m, 85m, 95m, 105m, 115m, 125m, 135m, 145m, 155m, 165m, 175m, 185m, 195m, 205m, 215m, 225m, 238m, 262m, 303m, 366m and 459m. This data set was estimated by the spatial models developed by the NCEP and the estimation method is described in the above-mentioned web site. The GODAS data set has been validated. (Pentakota et al, 2016; Nishida et al, 2011).

According to various references (see Appendix A), YFT habitats are influenced by temperature, salinity, thermocline depths and vertical shear currents. Thus, we use these 4 parameters to represent as oceanographic conditions. Thermocline depth were estimated using 20^{o}C (north of latitude S25^{o}), while 19.5^{o}C (south of S25^{o}) and vertical shear current was estimated by the model developed by Bigelow et al (2006). Resolution of oceanographic data were converted to 1^{o}x1^{o} and month data to match tuna longline fisheries data.

4. Methods

4.1 Concept of HSI (Habitat Suitability Index)

HSI have been used in the terrestrial ecological studies for many years. In recent years, HSI have been applied in fisheries for fishing ground forecasting, ecological and habitat studies. Fig. 2 shows the concept of HSI in fisheries. HSI uses various environmental factors represented as SI (Suitable Index) significantly affecting habitat (nominal CPUE) in small area (e.g. 1^{o}x1^{o} area). Then HSI is estimated by integrating SI using geometric means, statistical methods (GLM, GAM etc.), AI etc. HSI is scaled from 0 (worst habitat) to 1 (best habitat), so that levels of habitat suitability can be identify by HSI scores. This means that the area with higher HSI scores produce suitable habitat (high CPUE) areas which produce high q (catchability), consequently produce biased nominal CPUE. Thus, we need to standardize nominal CPUE using HSI.



Concept of HSI in fisheries (Eastwood, 2002)

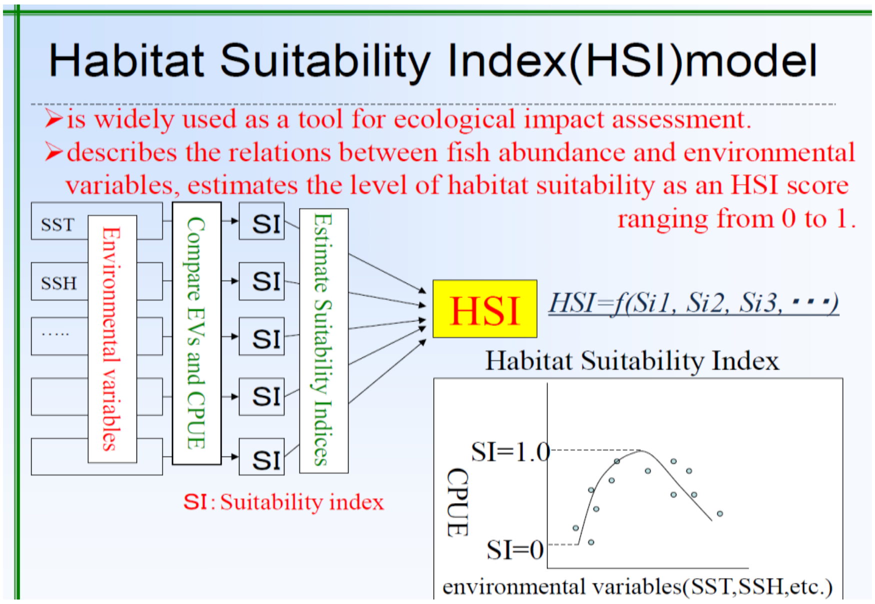
Modelled fish-habitat relationships (SI's)

Digital environmental maps recoded with the SI's

Habitat suitability index map

🟦 Unsuitable
🟥 Medium
🟦 Low suitability
🟥 High suitability

$$HSI = \left(\text{Temperature SI map} \times \text{Depth SI map} \times \text{Salinity SI map} \times \text{Substrate SI map}\right)^{1/4}$$



Habitat Suitability Index(HSI)model

➤is widely used as a tool for ecological impact assessment.
➤describes the relations between fish abundance and environmental variables, estimates the level of habitat suitability as an HSI score ranging from 0 to 1.

HSI=f(Si1, Si2, Si3, ･･･)

Habitat Suitability Index

SI: Suitability index

Fig. 2 Concept of HIS (above Eastwood, 2012 and below: Igarashi et al, 2014)

In CPUE standardization, HSI can be used as one integrated index to represent various levels of habitat. Thus, HSI can identify habitat area affecting nominal CPUE driven by ecological processes. Hence CPUE standardization by GLMs can be conducted in sub-areas where the variability pattern of the environmental signature is identified. Thus, HSI is considered as the appropriate method suggested by the IOTC CPUE workshop.

4.2 SI (Suitable Index)

We incorporate HSI into CPUE standardization using GLM. In GLM, normally nominal CPUE is response variable (in the left side equation such as log normal function). But if we use HSI as one of covariates (in the right equation), it will be a violation of the assumptions in GLM. This is because HSI is based on nominal CPUE, thus both nominal CPUE will be placed in both equations, which is a violation. Thus, we cannot use CPUE-based HSI.

To solve this problem, we attempt to use number of operations for nominal CPUE assuming they are proxy of SI (operation-based SI). But we need to verify whether operation-based SI are the proxy of CPUE-based SI. If it is verified, operation-based SI can be used to estimate HSI.

We attempted to use 4 types of oceanographic data as SI, i.e., sea temperature, salinity, vertical shear currents and thermocline depths. Tuna longline are deployed by different depth ranges according to number of hooks between floats (NHBF). Thus, we used 2 categories of depth ranges for sea temperature, salinity and vertical shear currents in corresponding depth (depth ranges) shown in Table 1.

As for thermocline depths, we used depths at 20°C (north of latitude S25°) and 19.5°C (south of S25°). This is because sea temperature in the southern area is cooler than in the northern part, thus if we use 20°C criteria, we will have a lot of missing values. Table 1 summarizes specification of four types of SI.

Table 1 Summary of four oceanographic variables as YTF SI (Suitability Index) and their specifications

Depth range	Shallower	Deeper
NHBF	10 <= HFBF	11<=NFBF
LL type	Shallow or regular LL	Deep or ultra-deep LL
Oceanographic variables as YFT SI (Suitability Index)		
	Representative depth (depth ranges)	
(1) Sea temperature	105m	205m
(2) Salinity		
(3) Vertical shear currents (Bigelow et al, 2006)	105-205m	105-303m
	Geographical area	
(4) Thermocline depth	25°S and/or north	25°S or south
Criteria	at 20°C	at 19.5°C

4.3 Estimation of HSI

In this study, HSI is estimated by $\sqrt[4]{SI(T) * SI(S) * SI(VS) * SI(TD)}$ ------- (1)

, where

SI : Suitability Index (0-1)
T : Sea temperature
S : Salinity
VS : vertical shear currents
TD : Thermocline depth

4.4 Area definitions

Within our YFT study area R2, we define 3 sub-areas, i.e., LL operating area, minimum YFT habitat area and high YFT habitat area (Fig. 3). We need to define minimum YFT area as there are nearly 50% of 0 (zero) YFT if we use data in the whole LL operating area which makes GLM runs difficult. This is because the southern part of this area (R2) is fishing grounds for southern bluefin tuna. We define minimum YFT habitat area as 1°x1° area where at least one YFT was caught in 1980-2016. In addition, to develop plausible SI we need to use high YFT habitat area, which is defined as 1°x1° area where there are more than median levels of YFT catch (in number) in 1980-2016.

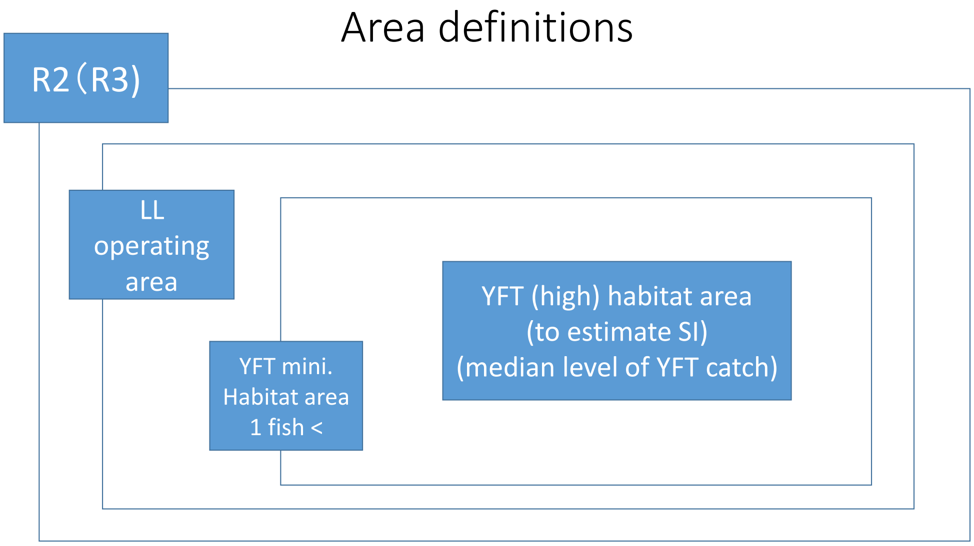


Fig. 3 Area defined in this study

4.5 Evaluation of HSI

(1) GLM

We will evaluate effectiveness of HSI in CPUE standardization through GLM, i.e., we simply test if HSI statistically significant by comparing following 2 GLMs.

- Log (nominal CPUE + n) =μ + YR + MO + target + Skipper + error
- Log (nominal CPUE + n) =μ + YR + MO + target + Skipper + HSI + error

, where
n : constant (10% of average nominal CPUE)
YR : year effect
MO : month (seasonal) effect
Target : targeting effect using number of hooks between floats (NFBF)

Range of NHBF	class	LL type
<= 7	1	shallow
8 <= NHBF <=10	2	regular
11<= NHBF <=13	3	deep
14<= NHBF <=16	4	deep
17<= NHBF <= 19	5	ultra-deep
20<= NHBF	6	ultra-deep

Skipper : Skipper's effect (Call sign)
HSI : Habitat Suitability Index
Error : Normal distribution

5. Results

5.1 SI

Fig. 4 and 5 shows resultant SI for 4 oceanographic parameters (frequency and % frequency respectively). It is clearly understood that all SI have unique ranges producing suitable YFT habitats.

5.2 HSI

HSI was computed using the equation (1) (page 7) by year, month and 1°x1° area. Fig. 6 shows the situation of average HSI by quartiles, i.e., HSI=0.58(25%tile), HSI=0.71 (50%tile/median) and HSI=0.71(75%tile). We use the red zone for GLM as these are high HSI area where the ecological processes produce good habitat areas.

5.3 Evaluation of HSI

BOX 1-2 show results of GLM with and without HSI term respectively. ANOVA tables in BOX 2 clearly indicates that HSI is the strongest term affecting nominal CPUE. Thus, HSI is likely the important factor in CPUE standardization in our case study. Fig. 7 shows the comparison of trends among nominal CPUE and STD_CPUE with and without HSI, which indicates both STD_CPUE smooth out nominal CPUE well. However, trends between STD_CPUE with and without HSI do not show much differences. This concludes that HSI is highly significant factor affecting nominal CPUE, but HSI did not change the trend of STD_CPUE without HSI.

One of possible reasons is that in this study, HSI is annual based, which may mask seasonal effects thus two trends are resulted in the similar outcome. SI are largely different by season in fishing ground forecasting in Pacific, season specific SI should be used (personal communication with Dr Itoh, Environment Simulation Laboratory, Japan).

Hence, it is not possible to evaluate on effectiveness of HSI in this case study. We need to do further investigation applying season-based SI in other areas, species and/or fleets.

<table>
<tr><td rowspan="2"></td><td colspan="2">Number of hooks between floats (baskets)</td></tr>
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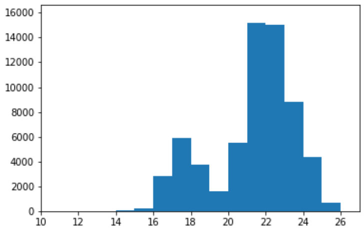
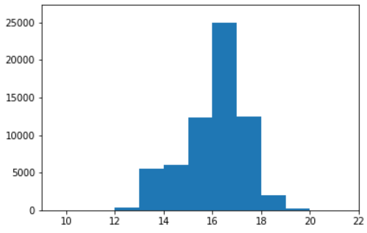
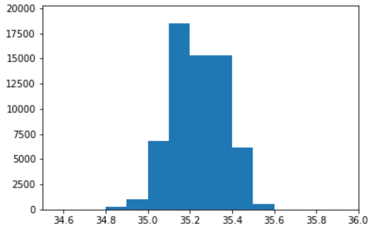
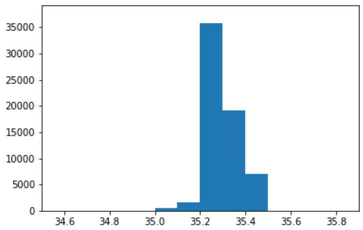
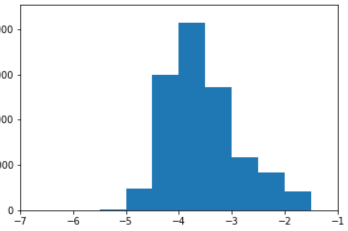
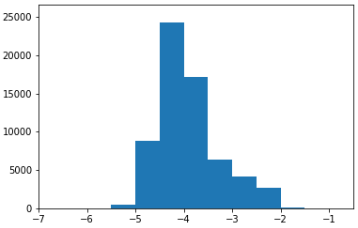
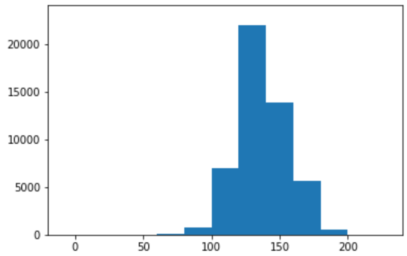
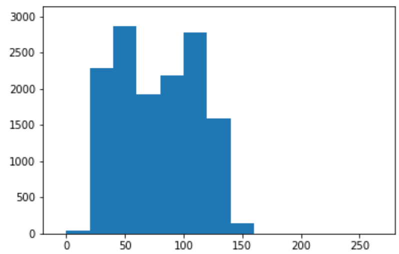
(shallow or regular LL)</td><td>11<=
(deep or ultra-dep LL)</td></tr>
<tr><td>Sea Temp</td><td>105m

 </td><td>205m

 </td></tr>
<tr><td>salinity</td><td>105m

 </td><td>205m

 </td></tr>
<tr><td>Vertical shear currents</td><td>105-155m

 </td><td>105-303m

 </td></tr>
<tr><td colspan="3">Thermocline depth (m)</td></tr>
<tr><td colspan="2">Tropical-sub-tropical: North of S25°C (depth at 20°C)

 </td><td>Sub-tropical-temperate: South of S25°C (depth at 19.5 °C)

 </td></tr>
</table>

Fig. 4 SI (frequency distribution for number of operations) for 4 oceanographic parameters

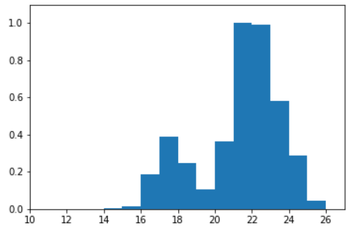
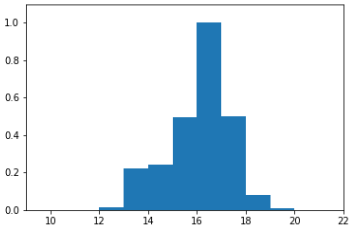
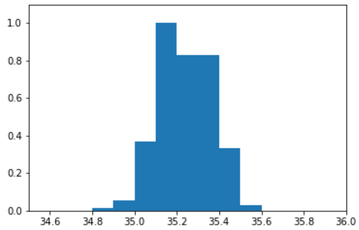
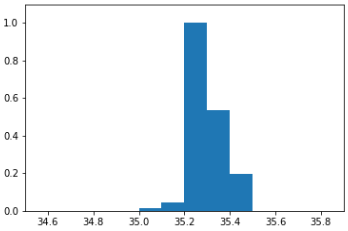
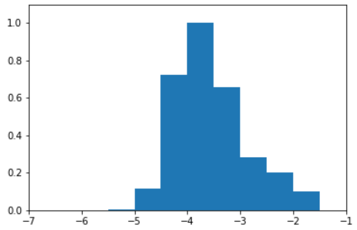
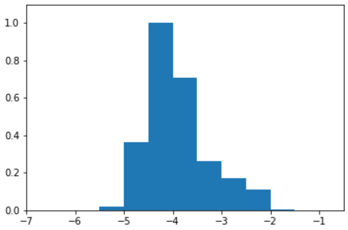
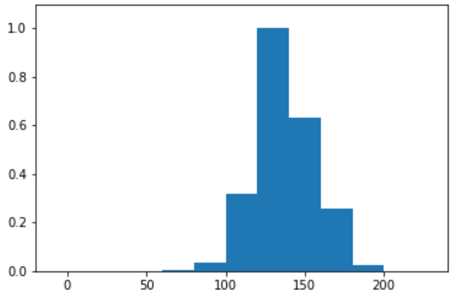
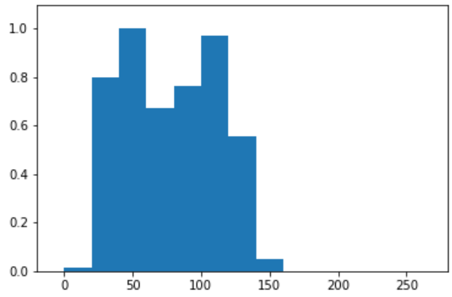
<table>
<tr><td rowspan="2"></td><td colspan="2">Number of hooks between floats (baskets)</td></tr>
<tr><td><=10
(shallow or regular LL)</td><td>11<=
(deep or ultra-dep LL)</td></tr>
<tr><td>Sea Temp</td><td>105m
 </td><td>205m
 </td></tr>
<tr><td>salinity</td><td>105m
 </td><td>205m
 </td></tr>
<tr><td>Vertical shear currents</td><td>105-205m
 </td><td>105-303m
 </td></tr>
<tr><td colspan="3">Thermocline depth (m)</td></tr>
<tr><td colspan="2">Tropical-sub-tropical: North of S25°C (depth at 20°C)
 </td><td>Sub-tropical-temperate: South of S25°C (depth at 19.5 °C)
 </td></tr>
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Fig. 5 SI (% frequency distribution for number of operations) for 4 oceanographic parameters.

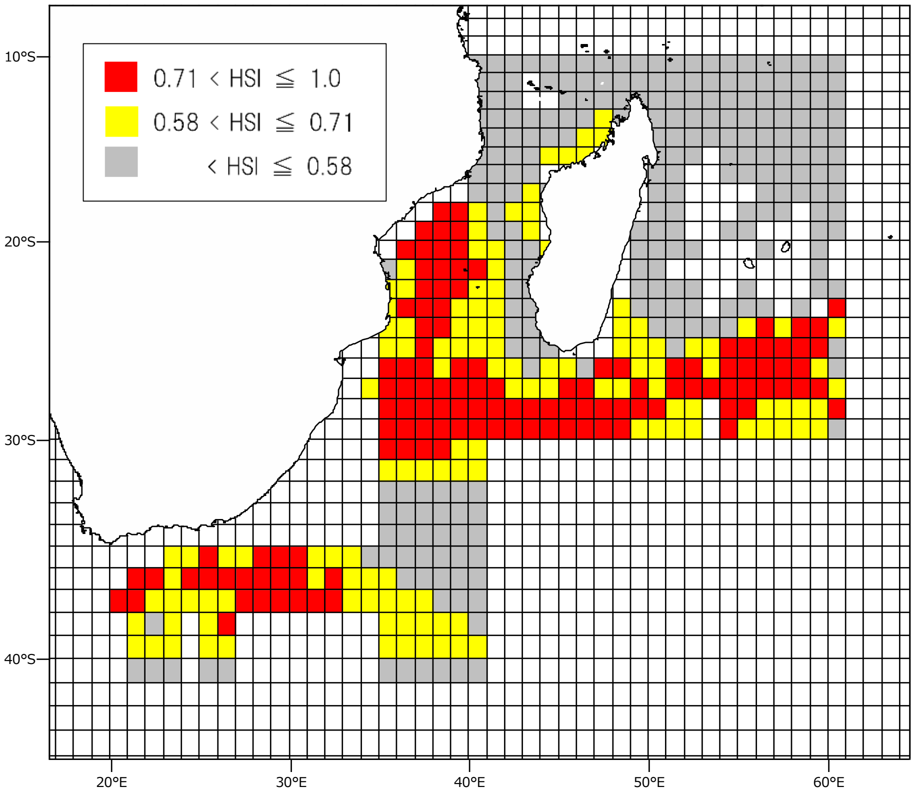


Fig. 6 Distribution of average HSI by quantile and 1ºx1º area
HSI=0.58(25%tile), HSI=0.71 (50%tile/median) and HSI=0.71(75%tile)

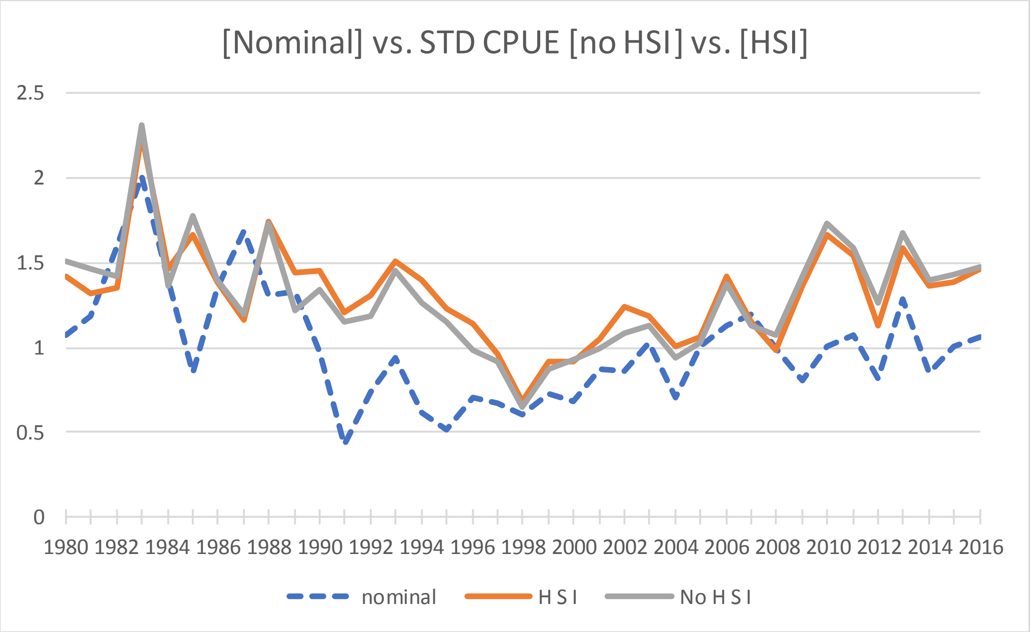
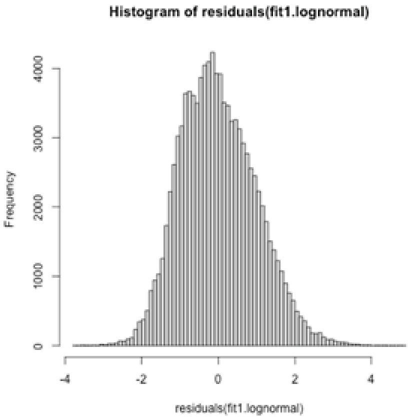


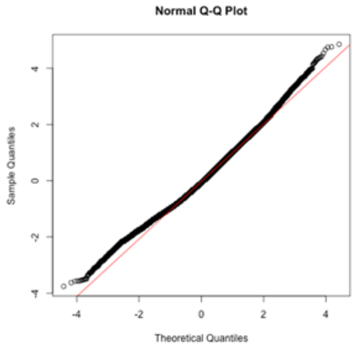
Fig. 7 Comparisons among nominal CPUE and STD_CPUE with and without HSI

BOX 1 Results of GLM: base case (without HSI)

Log (nominal CPUE + n) =μ + YR + MO + target + Call(Skipper)   + error

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)
NULL		100822	172578			
Year	36	17716.4	100786	154862	504.404	< 2.2e-16 ***
Month	11	29846.2	100775	125016	2781.011	< 2.2e-16 ***
Target	5	1813.6	100770	123202	371.763	< 2.2e-16 ***
Call	583	25454.7	100187	97747	44.751	< 2.2e-16 ***

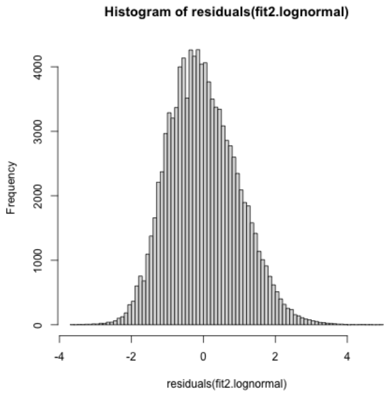


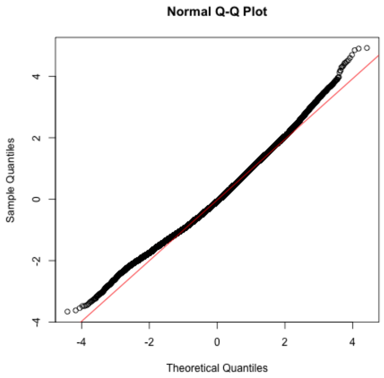


BOX 2 Results of GLM with HSI

Log (nominal CPUE + n) =μ + YR + MO + target + Call (Skipper) + HSI   + error

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)
NULL		100822	172578			
Year	36	17716.4	100786	154862	521.702	< 2.2e-16 ***
Month	11	29846.2	100775	125016	2876.383	< 2.2e-16 ***
Target	5	1813.6	100770	123202	384.512	< 2.2e-16 ***
Call	583	25454.7	100187	97747	46.286	< 2.2e-16 ***
HSI	1	3241.9	100186	94505	3436.814	< 2.2e-16 ***





6. Discussion

As this is the preliminary study with only one case study, it is not possible to provide any conclusions on the effectiveness of HSI in CPUE standardization. We will discuss issues to improve the situation.

(1) SI

In fisheries related studies, HSI are normally applied using CPUE (for example, fishing grounds forecasting study, habitat study, ecological study etc.). However, in our case, we cannot use CPUE-based HSI in CPUE standardization and we will have CPUE in both sides of GLM or other statistical methods, which is a fundamental violation of assumptions. Thus, we decided to use operation-based SI instead of CPUE-based SI.

However, we do not know if operation-based SI are valid to use because operation-based SI may be influenced by vessel aggregations due to nature of fishing operations but not driven by intrinsic YFT habitat. This is one of major reasons why we cannot make any conclusions. To mitigate this problem, we investigated (fisheries independent) SI through past literature (Appendix A). We found that some ranges of SI (oceanographic parameters) are very similar to those in our case study. However, we could not find the SI frequencies (degrees of suitability). Thus, the validity of SI is still unknown.

As a future work, we may be able to evaluate operation-based SI by comparing CPUE-based SI estimated in the same area, i.e., if both SI patterns are similar, operation-based SI is valid as proxy of CPUE-based SI (Fig. 8). Thus, we can use operation-based HSI in CPUE standardization.

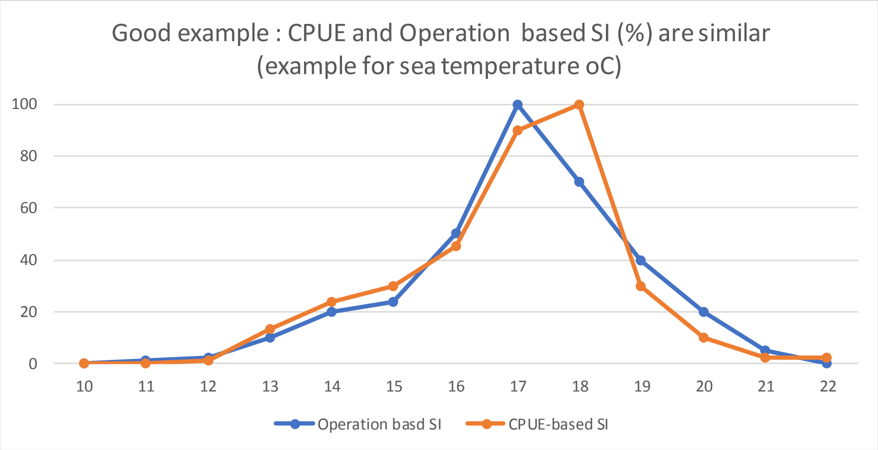


Fig. 8 Possible evaluation method if the operation-based SI is valid by comparing to CPUE-based SI. If both are similar patterns as in this graph, then operation-based SI is the proxy for CPUE-based SI. Then HSI can be estimated and incorporated to CPUE standardization.

(2) Other issues

Even if operation-based SI is validated by the method explained in the previous section, we need to work three more issues to obtain reliable HSI.

- **Seasonal effects**

In this preliminary study, we developed annual based SI. However, YFT SI changes by season, we need to develop seasonal-based SI and HSI in the future. This is because YFT distributions (fishing grounds) vary by season.

- **Sensitivity analyses**

In this preliminary study, we set up arbitrary definitions such as depths for oceanographic data (105m and 205m), areas (boundaries) (Fig. 3, page 8), HSI area for CPUE standardization (Fig.7, page12), classes intervals of SI (Fig. 4-5, page 10-11) (HSI values are influenced by intervals, personal communication with Dr Itoh, Environment Simulation Laboratory) etc. We may need sensitivity analyses to seek optimum definitions that can estimate reliable HSI.

- **Additional case studies**

As we have conducted only one case study, we cannot make any general conclusions. We need to expand case studies further to cover other arears, species and fleets.

(3) Alternative approaches using climate index (DMI and IOI)

For this time, we applied DMI (Dipole Mode Index) and IOI (Indian Ocean Index) as the alternative parameters in our case study area (temperate area) if operation-based SI is not validated. This is because that DMI and IOI influence oceanographic conditions such as sea temperature, salinity, vertical shear currents and thermocline depths. DMI and IOI data were provided by Dr Francis Marsac (IRD, France).

Similar GLM analyses were conducted and results are presented in Appendix B. It was concluded that DMI and IOI are not significant in CPUE standardization at all. The possible reason is that these indices are based on the tropical areas, thus they will not contribute significantly to CPUE standardization. Thus, we need to apply and test these indices in the tropical areas.

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We sincerely appreciate Dr Kiyoshi Itoh (Environment Simulation Laboratory) for the constructive suggestions. We also thanks to Dr Francis Marsac (IRD, France) for providing IOI (Indian Ocean Index) and DMI (Dipole Mode Index) data. We also appreciate Ms Jun Sato (Technical assistant, National Research Institute of Far Seas Fisheries) investigating references on oceanographic data affecting YFT habitat.

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Appendix A References on SI (Suitable Index) for YFT

This Appendix lists relevant references on SI for YFT (oceanographic variables) to examine if operation-based SI used in this study are similar to those available SI related information, especially fisheries independent data based on tagging experiments. Three types SI used in this study are investigated from three Oceans (Pacific, Indian and Atlantic), i.e., salinity, sea temperature and depth related data.

YFT SI: Salinity

Yellowfin Tuna Habitat - Salinity

Area	**Salinity**	**Note**	**Title of source**	**Author(s)**	**Year**	
Indian Ocean	**35.2 psu**	**50-200m**	**FACTORS AFFECTING DISTRIBUTION OF ADULT YELLOWFIN TUNA (THUNNUS ALBACARES) AND ITS REPRODUCTIVE ECOLOGY IN THE INDIAN OCEAN BASED ON JAPANESE TUNA LONGLINE FISHERIES AND SURVEY INFORMATION**	**Romena, November A**	**2001**	**IOTC-2001-WPTT-10**
Indian Ocean	**35.30-35.69 psu**	**closely correlated to CPUE**	**Environmental preferences of longlining for yellowfin tuna (Thunnus albacares) in the tropical high seas of the Indian Ocean**	**SONG Liming** **ZHANG Yu** ***XU Liuxiong** **JIANG Wenxin** **WANG Jiaqiao**	**2006**	**IOTC-2006-WPTT-13**
	35.40-35.49 psu	**more closely correlated to CPUE)**				
Area	**Salinity**	**Depth**	**Title of source**	**Author(s)**	**Year**	
Pacific Ocean (Central Pacific Ocean)	**34.22-35.25 psu**		**Using remote-sensing data to detect habitat suitability for yellowfin tuna in the Western and Central Pacific Ocean**	**KUO-WEI YEN,** **HSUEH-JUNG LU,** **YI CHANG and** **MING-AN LEE**	**2012**	

YFT SI: Thermocline depth

Yellowfin Tuna Habitat - TD

Area	Thermocline Depth	Note	Title of source	Author(s)	Year	
Indian Ocean (Arabian Sea) (Jan-Jun)	100.8-141.9m	the depth of the 20°C isotherm	INFLUENCE OF THE MARINE ENVIRONMENT VARIABILITY ON THE YELLOWFIN TUNA (THUNNUS ALBACARES) CATCH RATE BY THE TAIWANESE LONGLINE FISHERY IN THE ARABIAN SEA, WITH SPECIAL REFERENCE TO THE HIGH CATCH IN 2004	Kuo-Wei Lan, Tom Nishida, Ming-An Lee, Hsueh-Jung Lu, Hsiang-Wen Huang, Shui-Kai Chang, Yang-Chi Lan	2012	

YFT SI: Sea temperature

Yellowfin Tuna Habitat - Temperature

Area	Temperature	Note	Title of source	Author(s)	Year	
Indian Ocean (Comoros Islands)	25-27℃ (day)	upper part of the thermocline	Behaviour of yellowfin tuna (Thunnus albacares) and skipjack tuna (Katsuwonus pelamis) around fish aggregating devices (FADs) in the Comoros Islands as determined by ultrasonic tagging	Patrice Cayré	1990	
	Above 27℃ (night)	warm mixed layer				
Indian Ocean	17-22℃	50-200m	FACTORS AFFECTING DISTRIBUTION OF ADULT YELLOWFIN TUNA (THUNNUS ALBACARES) AND ITS REPRODUCTIVE ECOLOGY IN THE INDIAN OCEAN BASED ON JAPANESE TUNA LONGLINE FISHERIES AND SURVEY INFORMATION	Romena, November A	2001	IOTC-2001-WPTT-10
Indian Ocean	14-17.9℃	closely correlated to CPUE	Environmental preferences of longlining for yellowfin tuna (Thunnus albacares) in the tropical high seas of the Indian Ocean	SONG Liming ZHANG Yu *XU Liuxiong JIANG Wenxin WANG Jiaqiao	2006	IOTC-2006-WPTT-13
	16.0-16.9℃	more closely correlated to CPUE				
Indian Ocean (Northeast Indian Ocean)	28-30 ℃	SST	Environmental preferences of yellow tuna (Thunnus albacores) in the northeast Indian Ocean: an application of remote sensing data to longline catches	Rajapaksha J.K. , Nishida T. and Samarakoon L.	2010	IOTC-2010-WPTT-43
Indian Ocean (Arabian Sea) （Jan-Jun）	25.1-29.3℃	SST	INFLUENCE OF THE MARINE ENVIRONMENT VARIABILITY ON THE YELLOWFIN TUNA (THUNNUS ALBACARES) CATCH RATE BY THE TAIWANESE LONGLINE FISHERY IN THE ARABIAN SEA, WITH SPECIAL REFERENCE TO THE HIGH CATCH IN 2004	Kuo-Wei Lan, Tom Nishida, Ming-An Lee, Hsueh-Jung Lu, Hsiang-Wen Huang, Shui-Kai Chang, Yang-Chi Lan	2012	
	21.7-23.4℃	ST/subsurface 105m				
Area	Temperature	Note	Title of source	Author(s)	Year	
Atlantic Ocean (Tropical Atlantic Ocean)	22-29℃	SST	Forecasting models for tuna fishery with aerospatial remote sensing	J.M. STRETTA	1991	
Atlantic Ocean (Gulf of Mexico)	14-29℃	Fish spent 99.5± 0.2% of their time	Habitat and behaviour of yellowfin tuna Thunnus albacares in the Gulf of Mexico determined using pop-up satellite archival tags	K. C. WENG, M. J. W. STOKESBURY, A. M. BOUSTANY, A. C. SEITZjj, S. L. H. TEO, S. K. MILLER B. A. BLOCK	2009	Weng et al. 2009
	22-29℃	※Nocturnal distribution is wamer →Night：90.7± 0.2% →Day：64.7±6.2%				
Atlantic Ocean (equatorial Atlantic Ocea)	above 24-25℃		Ocean variations associated with fishing conditions for yellowfin tuna (Thunnus albacares) in the equatorial Atlantic Ocean	Kuo-Wei Lan, Ming-An Lee, Hsueh-Jung Lu, Wei-Juan Shieh, Wei-Kuan Lin, Szu-Chia Kao	2011	
Area	Temperature	Note	Title of source	Author(s)	Year	
Pacific Ocean (California Bight)	17.5-20.5℃		Environmental preferences of yellow®n tuna (Thunnus albacares) at the northern extent of its range	B. A. Block J. E. Keen B. Castillo H. Dewar E. V. Freund D. J. Marcinek R. W. Brill á C. Farwell	1997	
Pacific Ocean (Hawaiian Island/eastern Pacific)	18-29℃	Fish spent >90% of their time in water above 22℃	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	R. W. Brill, B. A. Block, C. H. Boggs, K. A. Bigelow, E. V. Freund, D. J. Marcinek	1999	Brill et al. 1999
Pacific Ocean (Baja Califronia/Mexico)	16-29℃	SST	Movements, behavior, and habitat utilization of yellowfin tuna (Thunnus albacares) in the Pacific Ocean off Baja California, Mexico, determined from archival tag data analyses, including unscented Kalman filtering	Kurt M. Schaefer a, Daniel W. Fuller, Barbara A. Block	2011	Schaefer et al. 2011
Pacific Ocean (northeastern Pacific Ocean)	17-31	SST	Movements, behavior, and habitat utilization of yellowfin tuna (Thunnus albacares) in the northeastern Pacific Ocean, ascertained through archival tag data	Kurt M. Schaefer, Daniel W. Fuller, Barbara A. Block	2007	Schaefer et al. 2007
Pacific Ocean (Central Pacific Ocean)	29.8-30.5℃	SST	Using remote-sensing data to detect habitat suitability for yellowfin tuna in the Western and Central Pacific Ocean	KUO-WEI YEN, HSUEH-JUNG LU, YI CHANG and MING-AN LEE	2012	
Pacific Ocean (Tropical Pacific Ocean)	25-30℃	SST	Using Remote-Sensing Environmental and Fishery Data to Map Potential Yellowfin Tuna Habitats in the Tropical Pacific Ocean	Kuo-Wei Lan, Teruhisa Shimada, Ming-An Lee, Nan-Jay Su, Yi Chang	2017	

YFT SI: Depth related information

Yellowfin Tuna Habitat - Depth						
Area	Depth	NOTE	Title of source	Author(s)	Year	
Indian Ocean (Comoros Islands)	70-110m (Day) 40-70m (Night)		Behaviour of yellowfin tuna (Thunnus albacares) and skipjack tuna (Katsuwonus pelamis) around fish aggregating devices (FADs) in the Comoros Islands as determined by ultrasonic tagging	Patrice Cayré	1990	
Indian Ocean	50-200m	17-22℃	FACTORS AFFECTING DISTRIBUTION OF ADULT YELLOWFIN TUNA (THUNNUS ALBACARES) AND ITS REPRODUCTIVE ECOLOGY IN THE INDIAN OCEAN BASED ON JAPANESE TUNA LONGLINE FISHERIES AND SURVEY INFORMATION	Romena, November A	2001	IOTC-2001-WPTT-10
	75-130m					
Indian Ocean	100-179.9m	closely correlated to CPUE	Environmental preferences of longlining for yellowfin tuna (Thunnus albacares) in the tropical high seas of the Indian Ocean	SONG Liming ZHANG Yu *XU Liuxiong JIANG Wenxin WANG Jiaqiao	2006	IOTC-2006-WPTT-13
	120-139.9m	more closely correlated to CPUE				
Indian Ocean (Seychelles - WesternIndian Ocean)	0 - 75m	Fish spent 85% of their time	Deep diving behavior observed in yellowfin tuna (Thunnus albacares)	Laurent Dagorn, Kim N. Holland, Jean-Pierre Hallier, Marc Taquet, Gala Moreno, Gorka Sancho, David G. Itano, Riaz Aumeeruddy, Charlotte Girard, Julien Million Alain Fonteneau	2006	
Area	Depth		Title of source	Author(s)	Year	
Atlantic Ocean (Gulf of Mexico)	0 - 200m	Fish spent 93.4±2.0% of their time	Habitat and behaviour of yellowfin tuna Thunnus albacares in the Gulf of Mexico determined using pop-up satellite archival tags	K. C. WENG, M. J. W. STOKESBURY, A. M. BOUSTANY, A. C. SEITZjj, S. L. H. TEO, S. K. MILLER B. A. BLOCK	2009	Weng et al. 2009
	0 - 50m	Fish spent 72±5.0% of their time ※Depth distribution was shallower at night →NIght：84.9±4.6% →Day：59.3±6.1% (corresponds				
Atlantic Ocean (Gulf of Mexico)	0 - 100m	→Total time spent at night：99.8% →Total time spent during the day：90%	Vertical and Horizontal Movements of Yellowfin Tuna in the Gulf of Mexico	J. P. Hoolihan R. J. D. Wells J. Luo B. FaltermanA E. D. Prince J. R. Rooker	2014	
Area	水深		Title of source	Author(s)	Year	
Pacific Ocean (California Bight)	18 - 45m	(above the thermocline)	Environmental preferences of yellow®n tuna (Thunnus albacares) at the northern extent of its range	B. A. Block J. E. Keen B. Castillo H. Dewar E. V. Freund D. J. Marcinek R. W. Brill á C. Farwell	1997	
Pacific Ocean (Hawaiian Island/eastern Pacific)	0 - 100m	Fish spent 80% of their time (in or immediately below the relatively uniform temperature surface-layer)	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	R. W. Brill, B. A. Block, C. H. Boggs, K. A. Bigelow, E. V. Freund, D. J. Marcinek	1999	Brill et al. 1999

Appendix B Effectiveness of climate indices (DMI+IOI) in CPUE standardization (as alternative of HSI)

At this stage we are not certain if operation-based SI is valid to estimate HSI. Hence, we attempted to incorporate alternative indices, i.e., the climate index such as DMI (Di-pole Mode Index) and IOI (Indian Ocean Index). They are temporal (monthly) indices and they will influence oceanographic conditions such as sea temperature, salinity, thermocline depth and vertical shear currents that we used in our case study. That is the reason why DMI and IOI can be the alternative indices for HSI. As they are not based on CPUE and independent covariates, we do not need to worry about the violation of assumptions in GLM. In the same way as for HSI, we compare the following 2 GLMs to evaluate effectiveness of IOI and DMI. As IOI and DMI do not have spatial elements, we do not need to worry about spatial problems such as oceanographic data, thus we use the YFT minimum habitat area for GLM (Fig. 3, page xx).

- Log (nominal CPUE + n) =μ + YR + MO + target + Skipper + error
- Log (nominal CPUE + n) =μ + YR + MO + target + Skipper + IOI + DMI + error

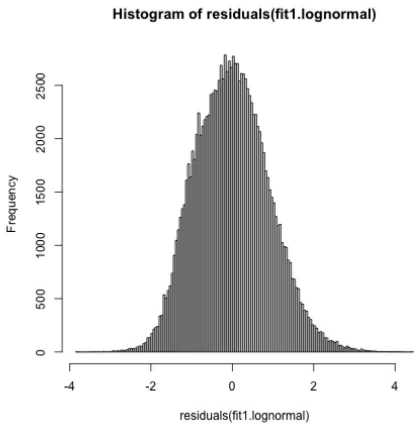
BOX 3-4 show results of GLM with and without DMI+IOI term respectively. ANOVA (BOX 4) clearly indicates that DMI+IOI produced very weak effects on nominal CPUE. Thus, DMI+IOI is unlikely the important factor in CPUE standardization. Fig. 9 shows the comparison among nominal CPUE and STD_CPUE with and without DMI+IOI, which indicates both STD_CPUE smooth out nominal CPUE well. However, trends between STD_CPUE with and without DMI+IOI are almost identical. This concludes that DMI+IOI is not significant factor affecting nominal CPUE.

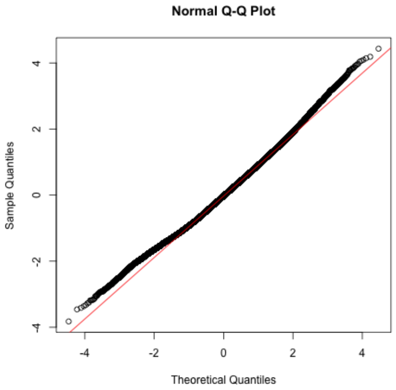
One of possible reasons why DMI+IOI are weak and not significant terms, is that they are based on the tropical areas, thus they will not affect nominal CPUE in the temperate area (our case study area).

BOX 3 Results of GLM: base case (without DMI+IOI)

Log (nominal CPUE + n) =μ + YR + MO + target + Call(Skipper) + error

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)
NULL		126274	168290			
Year	36	14833	126238	153457	498.129	< 2.2e-16 ***
Month	11	28649	126227	124808	3148.593	< 2.2e-16 ***
Target	5	1916	126222	122892	463.272	< 2.2e-16 ***
Call	565	18952	125657	103940	40.553	< 2.2e-16 ***

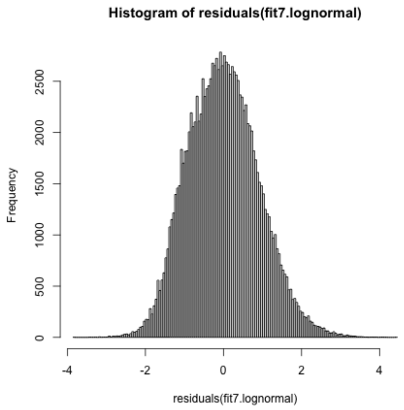


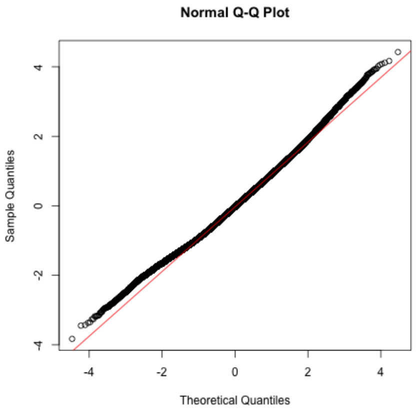


BOX 4 Results of GLM with DMI+IOI

Log (nominal CPUE + n) =μ + YR + MO + target + Call (Skipper) + DMI +IOI + error

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)
Year	36	14833.3	126238	153457	498.2075	< 2.2e-16 ***
Month	11	28648.6	126227	124808	3149.0888	< 2.2e-16 ***
Target	5	1916.0	126222	122892	463.3452	< 2.2e-16 ***
Call	565	18952.4	125657	103940	40.5594	< 2.2e-16 ***
DMI	1	11.8	125656	103928	14.2938	0.0001565
IOI	1	6.2	125655	103922	7.4723	0.0062664





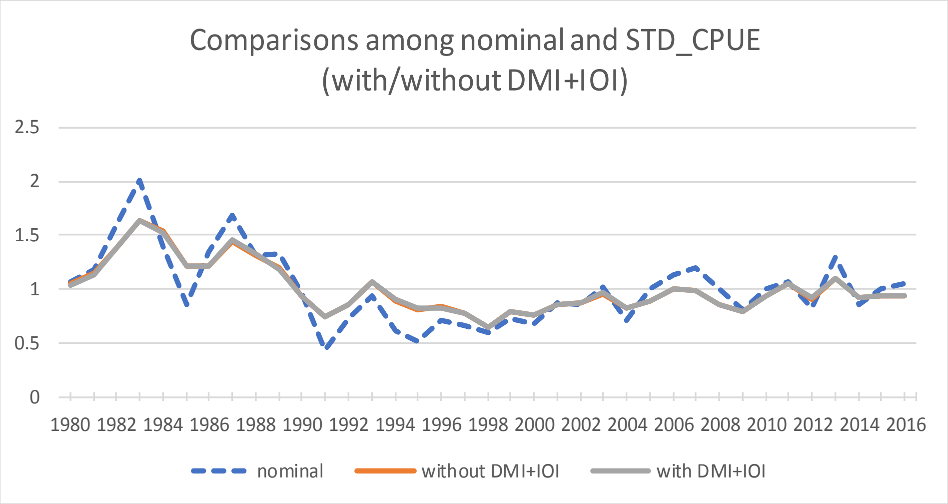


Fig. 9 Comparisons among nominal CPUE, STD_CPUE with and without climate indices (DMI+IOI)