Estimation of the Abundance Index (AI) of swordfish (*Xiphias gladius)* in the Indian Ocean based on the fine scale catch and effort data in the Japanese tuna longline fisheries (1980-2007)

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Abstract

We attempt to estimate of abundance indices of swordfish (SWO) in the Indian Ocean based on the fine scale catch and effort data in the Japanese "tuna longline fisheries" (LL) . Until last year we have been using 5x5 degree based catch and effort data. But we recognized that such resolution is not sensitive to fine scale environment ENV data such as sea temperature, salinity, shear currents and ocean fronts. In addition daily moon phase data is recommended to use in the last WPB6 in 2008. To match such ENV data we apply the daily based fine scale (1x1) catch and effort data.

GLM results suggested that AI rapidly increased from 1980 to 1988 afterwards AI decreased gradually until 2006 and AI jumped up largely in 2007. Using daily fine scale CPUE (set by set) data it was found that nominal CPUE are significantly affected by ENV factors such as "ocean fronts", "shear currents", "temperature & salinity at the depth SWO caught (45m)" and "moon phase (MP)". Such findings were not obtained when we used the coarse scale (5x5) nominal CPUE in the past. This demonstrates effectiveness of fine scale CPUE.

AI indices in NW shows the gradual decrease trends while AI in SW shows sharp decreasing trends and AI in East (NE and SE) shows the constant trend. Considering together with ocean currents driven by monsoons and also 2 spawning areas (around La Reunion and off south Java Island, Indonesia), there may be possible three hypothetical stocks, i.e., SW, NW and E stocks which are intermingled in the borders.

1. Introduction

We attempt to estimate of the abundance index of swordfish (*Xiphias gladius)* SWO (hereafter abbreviated as SWO) in the Indian Ocean based on the fine scale catch and effort data in the Japanese "tuna longline fisheries" (LL) (hereafter abbreviated as LL). Until last year we have been using 5x5 degree based catch and effort data. But we recognized that such resolution is not sensitive to the fine scale environment ENV (hereafter abbreviated as ENV) data such as sea temperature, salinity, shear currents and ocean fronts. In addition the daily moon phase data is recommended to use in the last WPB6 in 2008. To match such ENV data we apply the daily based fine scale catch and effort data.

2. Data

2.1 Catch and effort data

We used daily and 1x1 degree based catch and effort data (1980-2007) available in the database of the National Research Institute of Far Seas Fisheries, Fisheries Research Agency, Japan.

2.2 ENV data

(1) IOI (Indian Ocean Index)

Marsac (IRD, France) provided us the monthly IOI data from 1980-2007. IOI is the alternate indicator of SOI (El Nino and La Nina events) in the Indian Ocean, is the difference of the atmospherics pride between Mahe air port (Shackle) and Darwin (austere)

(2) MP (Moon phase)

Daily moon phase data (1980-2007) are downloaded from the web site of the Japan Metrological Agency. MP ranges from 0 (new moon) to 29.7 (full moon).

(3) Oceanographic conditions (NCEP data)

(Temperature, salinity, thermocline depths, ocean fronts and shear currents)

To make the above mentioned ENV data affecting SWO habitat we applied depth specific temperature, salinity and current data available the NCEP Global Ocean Data Assimilation System monthly data (GODAS; http://cfs.ncep.noaa.gov/cfs/godas/monthly).

The Original data include temperature, salinity and current (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.

These data are available globally for 28 years from 1980 - 2007 with the resolution of (1/3) degrees in latitude and 1 degree in longitude. These depth specific data were estimated by the spatial models developed by the NCEP. For details refer to the above mentioned web site.

Using these original NCEP data we made the following 1x1 and month based oceanographic condition data sets in the Indian Ocean for 28 years (1980-2007) used to estimate STD (standardized) CPUE. Now we explain how to make ENV data.

(a) T45 and T45 (temperature and salinity at the 45 m depth)

Instead of normally used the SST or salinity at surface we used T45 and S45. This is because Oliveira et al (2005) (submitted as the INFO paper in this WPB7 meeting) suggests that SWO are most frequently exploited by the LL at the depth range from 40-50m. Since salinity and temperature data at the 45 m in depth are available in the NCEP data set we directly used such INFO.

(b) TD (Thermocline depth or Mixing layer depth)

Using the NCEP data we estimated TD at 20^{o}C (Mizuno, Marsac and many others). However we noticed that there are too many missing data in the SWO area hence we excluded TD data. This is because we lose about 20-30% of the whole data set in the GLM analyses due to these missing data, which likely produced biased results. These missing data are caused when there is no 20°C tempura especially in the coastal waters and/or cold waters. We will improve this situation in the future in order to utilize the TD data as one of the most important END data.

(c) Shear currents (SC) and its amplitude (AM)

The current shear, 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, u_n the zonal velocity component of layer n, v_n the meridional velocity component of layer n and z_n is the depth of layer n. vertical shear was estimated from the NCEP model by integrating from 5 to 205 m. Values found for this factor in the study area range between -4.65 and -0.09.

We also estimate the amplitude of the current in the water column where the shear is calculated. To do so, we calculate the difference between minimal and maximal current velocities found in the column sampled. This complements the shear current factor by providing a more direct value (in cm.s^{-1}) of the heterogeneity of current. Values found for this factor in the study area range between 0.31 and 168.9.

Following the original resolution of the NCEP model output selected, both shear current and amplitude are given by 1/3° latitude and 1° longitude box and month. Then 1x1 and month data set are created.

(d) Ocean fronts: TG and SG (temperature and salinity gradients)

Ocean fronts affect the SWO distributions and densities hence they affect the nominal CPUE (Bigelow). To represent the ocean currents we compute the maximum gradients per 100km in eight directions around each pixel (Fig. 1). After we select the maximum gradient per 100km we made average gradient by 1x1 and month at 5m depth data available in the NCEP data set.

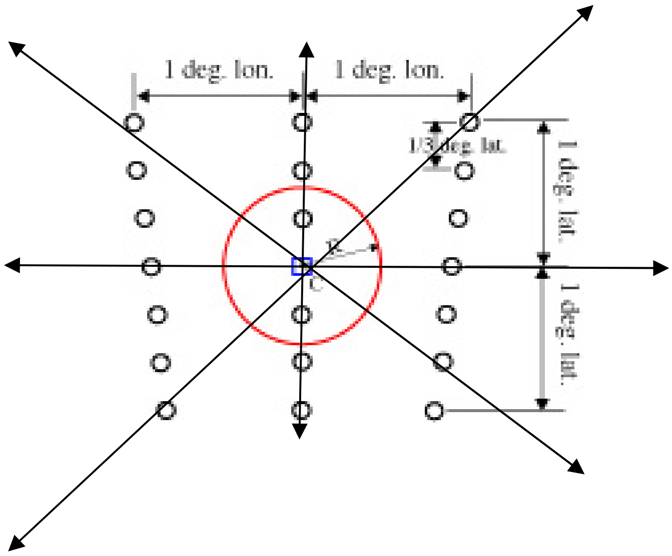


Fig. 1 8 searching directions for TG and SG

(5) Summary of the ENV data (Table 1)

Table 1 Summary of the ENV data

Code	Meanings	Resolution	Unit	Sources
IOI	Indian Ocean Index (difference of the atmospheric pressure between Mahe and Darwin)	Month	hPa（hect pascal）	Marsac (IRD, France)
MP	Moon Phase	Day	Index: 0 (new moon) & 29.7(full)	Japan Metrological Agency
T45	Temperature at 45 m depth	1x1 & month	^{o}C	NCEP
S45	Salinity at 45 m depth		PSU (Practical Salinity Unit)	
SC	Shear current (currents integrated from 5 to 205 m)		cm/second	
AM	Amplitudes of the SC (different between mini & max water column sampled)		cm/second (0.31 - 168.9)	
TG	Oceanic front (temperature gradient)		Max ^{o}C /100 km	
SG	Oceanic front (salinity gradient)		Max PSU /100 km	

3. GLM

3.1 Full model (1)

As a first step, we attempt the following full model:

Log (CPUE+ c)= [mean] +[Y]+ [Q]+ [A]+[NHBF]+ [MIKI]+[EDA]+ [ENV] + [INT] + [error term]

where,

c	*constant (10% of the nominal CPUE)*	
Y:	*year effect*	
Q:	*quarter effect*	
A:	*sub area effect (see Fig.2)*	
NHBF:	*number of hooks between floats*	
MIKI:	*material of MIKI (main line) 1: nylon 2: others*	
EDA:	*material of EDA (branch line) 1: nylon 2: others*	
[ENV]	*MP:*	*moon phase*
	SC:	*shear current*
	AM:	*amplitude of SC*
	S45:	*salinity at the 45 m depth*
	T45:	*temperature at the 45m depth*
	TG:	*temperature gradient*
	SG:	*salinity gradient*

[INT] interaction terms (*)

*Y*Q+ Y*A+ Q*A+Y*Q*A*
*+ MIKI+ MIKI*Q + MIKI*A + MIKI*Y*Q + MIKI*Y*A + MIKI*Q*A + MIKI*Y*Q*A*
*+ EDA+ EDA*Q + EDA*A + EDA*Y*Q + EDA*Y*A + EDA*Q*A + EDA*Y*Q*A*
*+MIKI*EDA +MIKI*EDA*Q + MIKI*EDA*A + MIKI*EDA*Y*Q +MIKI*EDA*Y*A*
*+ MIKI*EDA*Q*A + MIKI*EDA*Y*Q*A*
+ NHBF + MP + IOI + SC + AM + S45 + T45 + TG + SG
*+ A*NHBF+ A*MP+ A*IOI + A*SC+ A*AM+ A*S45+ A*T45+ A*TG+ A*SG*
*+ Q*NHBF+ Q*IOI + Q*SC+ Q*AM + Q*S45+ Q*T45+ Q*TG+ Q*SG*

*Note (*) Hinton and Maunder (2004) indicated that interactions with the year effect would invalidate the year effect as an index of abundance. For the interactions related to year effect, therefore, only the interactions among the effects of year, quarter and area are considered in the GLM, i.e., only Y*Q, Y*A and T*Q*A are included in the full GLM model.*

But with this full model we could not get convergence.

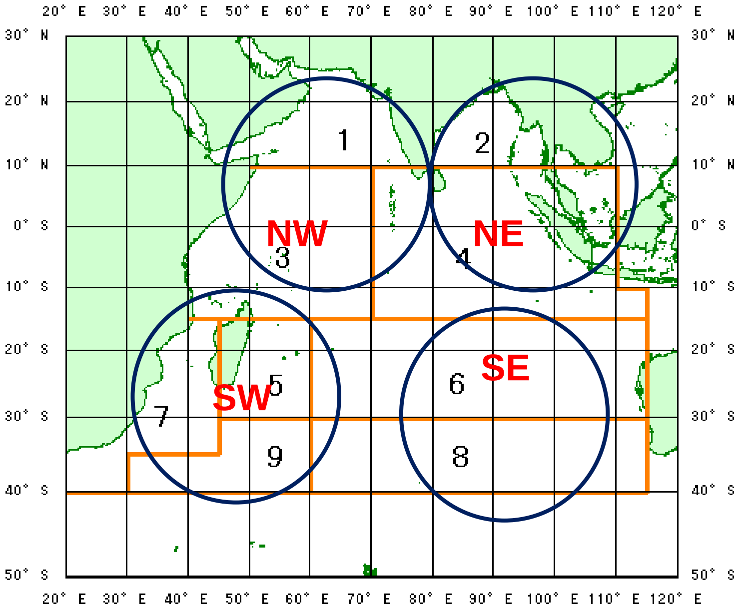


Fig 2 Nine sub areas (1-9) used in the past WPB5 (2006) and the new sub areas (NE, NW, SW and SE) used in last WPB 6 (2008) and also in this WPB7 (2009)

3.2 Full model (2)

As the next step, we searched the full model that can converge. After we explored the full model (1) by reducing terms, we found the following model that could converge.

Log (CPUE+ c)= [mean] +[Y]+ [Q]+ [A]+[NHBF]+ [MIKI]+[EDA]+ [ENV] + [INT] + [error term]

,where,

c — *constant (10% of the nominal CPUE)*
Y: — *year effect*
Q: — *quarter effect*
A: — *sub area effect (Fig. 2)*
NHBF: — *number of hooks between floats*
MIKI: — *material of MIKI (main line) 1: nylon 2: others*
EDA: — *material of EDA (branch line) 1: nylon 2: others*

[ENV]
MP: — *moon phase*
SC: — *shear current*
AM: — *amplitude of SC*
S45: — *salinity at the 45 m depth*
T45: — *temperature at the 45m depth*
TG: — *temperature gradient*
SG: — *salinity gradient*

[INT] interaction terms

*Y*Q+ Y*A+ Q*A+Y*Q*A*
*~~+ MIKI+ MIKI*Q +~~ MIKI*A + ~~MIKI*Y*Q + MIKI*Y*A + MIKI*Q*A + MIKI*Y*Q*A~~*
*+ EDA+ EDA*Q + EDA*A + ~~EDA*Y*Q + EDA*Y*A + EDA*Q*A + EDA*Y*Q*A~~*
*+MIKI*EDA +MIKI*EDA*Q + MIKI*EDA*A + ~~MIKI*EDA*Y*Q +MIKI*EDA*Y*A~~*
*~~+ MIKI*EDA*Q*A + MIKI*EDA*Y*Q*A~~*
+ NHBF + MP + IOI + SC + AM + S45 + T45 + TG + SG
*+ A*NHBF+ A*MP+ A*IOI + A*SC+ A*AM+ A*S45+ A*T45+ A*TG+ A*SG*
*+ Q*NHBF+ Q*IOI + Q*SC+ Q*AM + Q*S45+ Q*T45+ Q*TG+ Q*SG*
*~~+ MIKI*EDA*Q*A + MIKI*EDA*Y*Q*A~~*

3.3 Reduced model

After we ran the full mode (2), we found 5 statically non-significant terms (MIKI, MIKI*Q, EDA*Q, S45 and T45) and we excluded them then we made the following reduce model:

Log (CPUE+ c)= [mean] +[Y]+ [Q]+ [A]+[NHBF]+ [MIKI]+[EDA]+ [ENV] + [INT] + [error term]

,where,

c	*constant (10% of the nominal CPUE)(0.047)*
Y:	*year effect*
Q:	*quarter effect*
A:	*sub area effect*
NHBF:	*number of hooks between floats*
MIKI:	*material of MIKI (main line) 1: nylon 2: others*
EDA:	*material of EDA (branch line) 1: nylon 2: others*

[ENV]	*MP:*	*moon phase*
	SC:	*shear current*
	AM:	*amplitude of SC*
	S45:	*salinity at the 45 m depth*
	T45:	*temperature at the 45m depth*
	TG:	*temperature gradient*
	SG:	*salinity gradient*

[INT] interaction terms

*Y*Q+ Y*A+ Q*A+Y*Q*A*

*~~+ MIKI+ MIKI*Q +~~ MIKI*A + ~~MIKI*Y*Q + MIKI*Y*A + MIKI*Q*A + MIKI*Y*Q*A~~*

*+ EDA+ ~~EDA*Q~~ + ~~EDA*A~~ + ~~EDA*Y*Q + EDA*Y*A + EDA*Q*A + EDA*Y*Q*A~~*

*+MIKI*EDA +MIKI*EDA*Q + MIKI*EDA*A + ~~MIKI*EDA*Y*Q +MIKI*EDA*Y*A~~*

*~~+ MIKI*EDA*Q*A + MIKI*EDA*Y*Q*A~~*

+ NHBF + MP + IOI + SC + AM + ~~S45 + T45 +~~ TG + SG

*+ A*NHBF+ A*MP+ A*IOI + A*SC+ A*AM+ A*S45+ A*T45+ A*TG+ A*SG*

*+ Q*NHBF+ Q*IOI + Q*SC+ Q*AM + Q*S45+ Q*T45+ Q*TG+ Q*SG*

*~~+ MIKI*EDA*Q*A + MIKI*EDA*Y*Q*A~~*

Results of GLM run for the reduced model

Source	DF	SS	MSS	F	Pr > F
Model	528	278733	527.904	300.06	<.0001
Error	611174	1075267	1.759		
Corrected Total	611702	1354000			

R2	CV	SSE (error)	mean (lcpue)
0.205859	-68.76483	1.326404	-1.928898

factor	DF	Type III SS	MS	F	Pr > F
Y	27	10317.59082	382.13299	217.20	<.0001
Q	3	2240.87505	746.95835	424.57	<.0001
A	3	1899.79011	633.26337	359.94	<.0001
Y*Q	81	6296.50510	77.73463	44.18	<.0001
Y*A	81	11441.15477	141.24882	80.28	<.0001
Q*A	9	4084.42527	453.82503	257.95	<.0001
Y*Q*A	243	9845.88415	40.51804	23.03	<.0001
A*MIKI	3	574.08011	191.36004	108.77	<.0001
EDA	1	69.42707	69.42707	39.46	<.0001
A*EDA	3	48.89330	16.29777	9.26	<.0001
MIKI*EDA	1	181.15495	181.15495	102.97	<.0001
Q*MIKI*EDA	9	108.44965	12.04996	6.85	<.0001
A*MIKI*EDA	3	553.51911	184.50637	104.87	<.0001
NHBF	1	828.33192	828.33192	470.82	<.0001
MP	1	1290.63466	1290.63466	733.59	<.0001
IOI	1	183.62028	183.62028	104.37	<.0001
SC	1	585.81601	585.81601	332.97	<.0001
AM	1	549.87339	549.87339	312.54	<.0001
TG	1	122.45869	122.45869	69.60	<.0001
SG	1	1758.50055	1758.50055	999.52	<.0001
NHBF*A	3	854.38502	284.79501	161.88	<.0001
MP*A	3	453.99843	151.33281	86.02	<.0001
IOI*A	3	321.14081	107.04694	60.84	<.0001
SC*A	3	803.37019	267.79006	152.21	<.0001
AM*A	3	840.54530	280.18177	159.25	<.0001
S45*A	3	1712.16612	570.72204	324.39	<.0001
T45*A	3	423.96602	141.32201	80.33	<.0001
TG*A	3	5221.67991	1740.55997	989.32	<.0001
SG*A	3	1755.12012	585.04004	332.53	<.0001
NHBF*Q	3	536.81244	178.93748	101.71	<.0001
IOI*Q	3	1010.40029	336.80010	191.43	<.0001
SC*Q	3	401.80339	133.93446	76.13	<.0001
AM*Q	3	394.21787	131.40596	74.69	<.0001
S45*Q	3	1947.91739	649.30580	369.06	<.0001
T45*Q	3	1712.99068	570.99689	324.55	<.0001
TG*Q	3	75.33022	25.11007	14.27	<.0001
SG*Q	3	395.29309	131.76436	74.89	<.0001

3.4 Factors affecting annual nominal CPUE

GLM analyses suggests that STD CPUE by daily fine scale (set by set) data are very sensitive for ENV such as ocean fronts (TG & SG: temp & salinity gradient), shear current (SC and AM), ENV at the catch depth (45m) (T45 and S45) and moon phase (MP) as well as main factors (Y, Q and A), targeting (NHBF: number of hooks between floats) and line materials (nylon or rope) (Fig. 3). We could not get such results last year as we used the coarse (5x5) data.

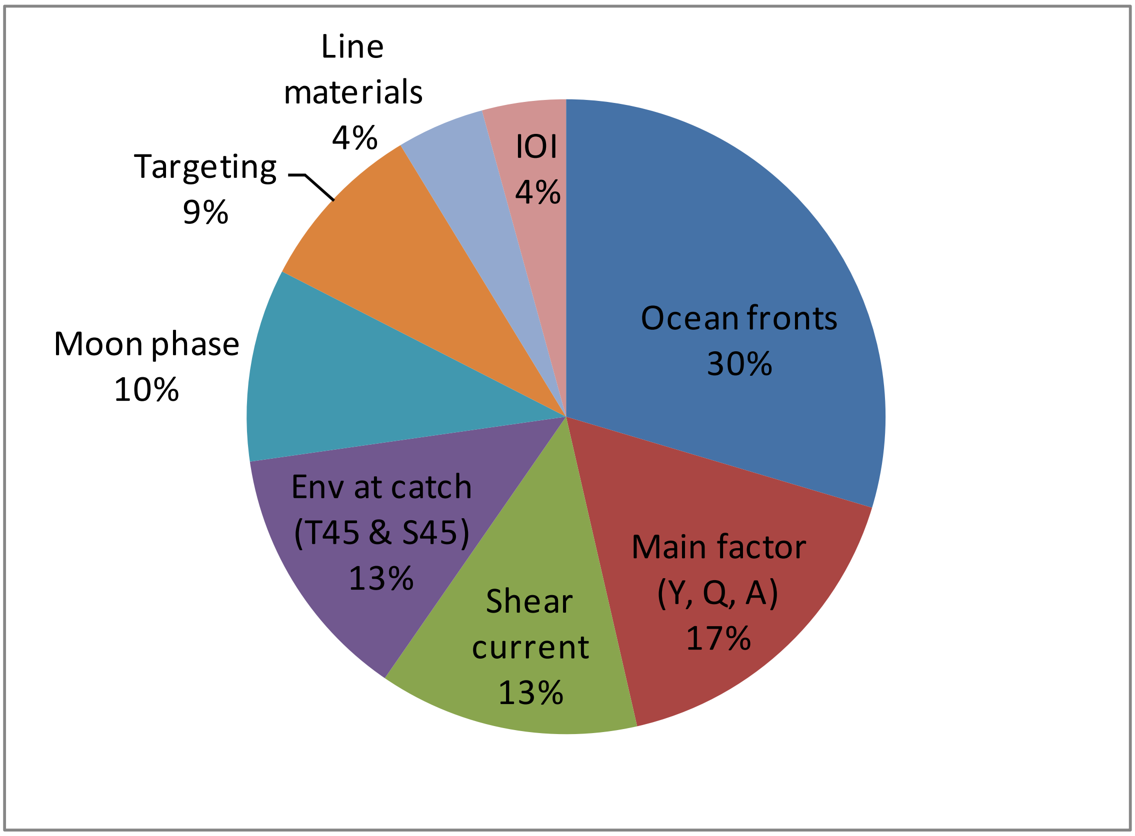


Fig. 3 Factors affecting the SWO nominal CPUE (in terms of compositions of standardized F statistics)

4. Estimation of the AI (abundance index)

The estimation of annual nominal and standardized CPUE is calculated from the weighted average of the area indices (Punt et al., 2000).

$$U_y = \sum_a S_a U_{y,a}$$

where U_y is CPUE for year y,

$U_{y,a}$ is CPUE for year y and area a,

S_a is the relative size of the area a to the four new areas as below.

NE	NW	SE	SW
0.2577	0.24775	0.3307	0.1638

The relative sizes of nine IOTC statistics areas for swordfish in the Indian Ocean (Nishida and Wang et al., 2006) were used to be aggregated into four new areas used in this study. Fig. 4-6 shows the estimated AI by Y, A*Y and Y*Q.

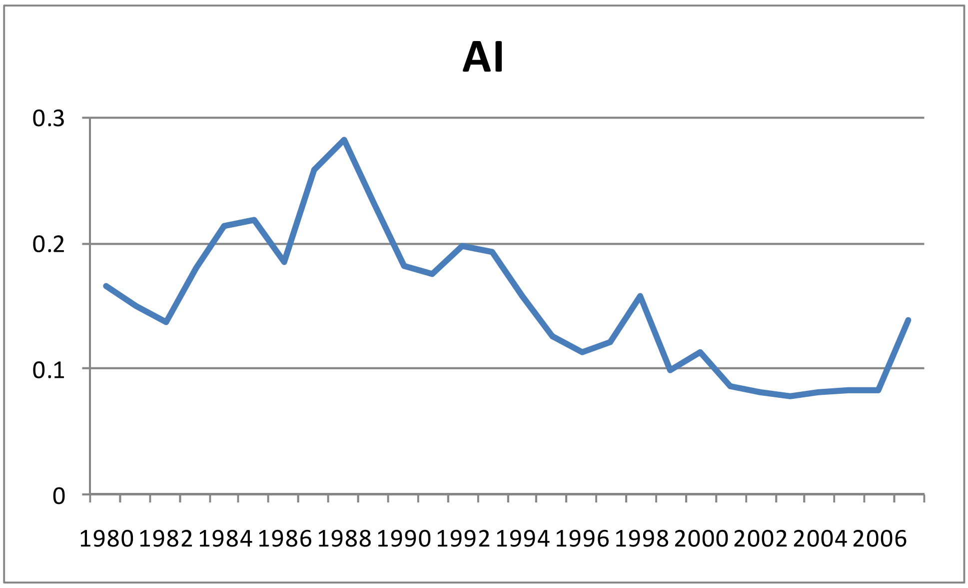


Fig. 4 Estimated Abundance index (Japan)

Fig 5. STD CPUE by area and year (area weighting are not applied)

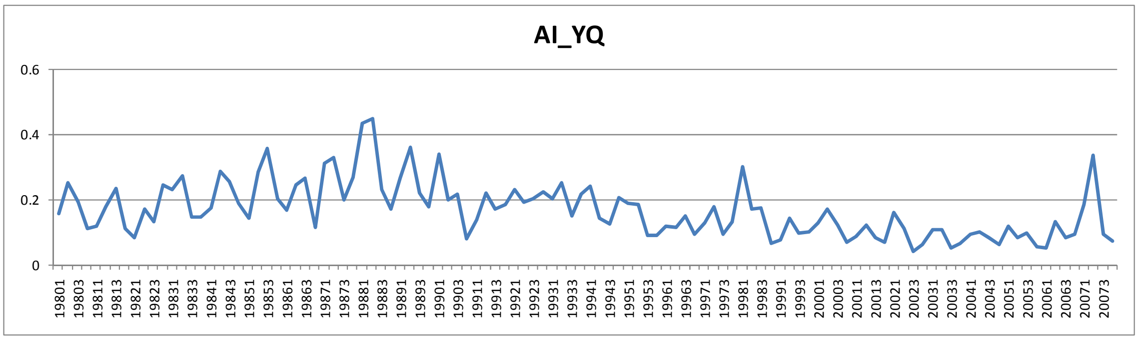


Fig. 6 AI by Q (1980-2007)

5. Discussion and conclusion

- Trends of the annual AI

GLM results suggested that AI rapidly increased from 1980 to 1988 afterwards AI decreased gradually until 2006 and AI jumped largely in 2007.

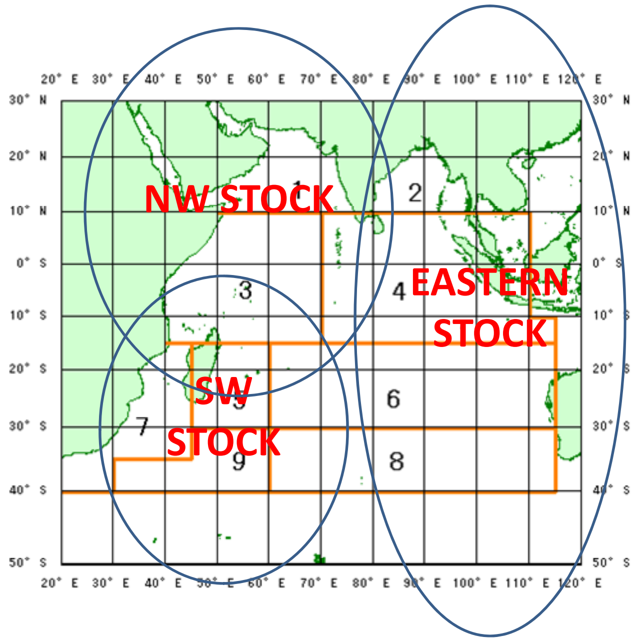
- Factor affecting annual nominal CPUE

Using daily fine scale CPUE (set by set) data it was found that nominal CPUE are significantly affected by ENV factors such as “ocean fronts”, “shear currents”, “temperature & salinity at the depth SWO caught (45m)” and “moon phase (MP)”. Such findings were not obtained when we used the coarse scale (5x5) nominal CPUE in the past. This demonstrates effectiveness of fine scale CPUE.

- AI by area and year and stock structure

AI indices in NW shows the gradual decrease trends while AI in SW shows sharp decreasing trends and AI in East (NE and SE) shows the constant trend. Considering together with ocean currents driven by monsoons and also 2 spawning areas (around La Reunion and off south Java Island, Indonesia), there may be possible three hypothetical stocks, i.e., SW, NW and E stocks which are intermingled in the borders.

Fig. 7
Hypothetical 3 stock structure of SWO in the Indian Ocean based on patterns of annual trends of AI (abundance index), patterns of ocean currents and 2 spawning areas i.e., NW, SW and E stocks which are likely intermingled in borders.



Acknowledgments

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References

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Other references are provided upon request to the authors.