# Estimation of the Abundance Index (AI) of swordfish (*Xiphias gladius)* in the Indian Ocean (IO) based on the fine scale catch and effort data in the Japanese tuna longline fisheries (1980-2008)

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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 2 years ago 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, i.e., sea temperature, salinity, shear currents and ocean fronts that were recommended by the Scientific Committees in the past. 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. The core fishing areas to be used for the standardized CPUE are identified. These areas could mitigate problems of spikes in STD-CPUE in some extent.

Base on the GLM analyses, the AI in general showed the decreasing trend the analyzed period (1980 to 2008) with several big bumps (ups and downs). Using daily fine scale CPUE (set by set) data it was found that nominal CPUE are significantly affected by the following factors (by order of statistical significance), i.e., “number of hooks between hooks”, “ENV (moon phases, ocean fronts, temperature & salinity at the depth where SWO caught (45m)” and “main factors (area and season)”. Such findings especially relating to ENV could not obtained when we used the coarse scale (5x5) nominal CPUE in the past. This demonstrates effectiveness of fine scale CPUE and ENV data. In addition it was also resulted that V (vessel) (used as a first time) significantly affect nominal CPUE which implied that there were different levels of catchability among vessels due to the skipper’s skills.

Resultant AI indices show the constant trends 1980-1998 except1985-1988 where AIs were much higher levels. After 1998 AI showed the decreasing trend until 2006 and in 2007-2008 AI increased. AI trends in recent years in NW, NE and SW showed sharp decreasing trends but they (sharp decrease) started different years,

# 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 2008 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 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 (1980-2008) 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 1980-2008. 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 (Seychelles) and Darwin (Australia)

(2) IODP index (Indian Ocean Dipole Index) (DMI)

Marsac (IRD, France) newly provided us the monthly DMI data from 1980-2008. DMI is the different anomaly of SST between two zone (Z1 and Z2) in the eastern and western IO, i.e., Z1 : 50°E-70°E / 10°N-10°S and Z2 : 90°E-110°E / 0°-10°S.

(3) MP (Moon phase)

Daily moon phase data (1980-2008) are downloaded from the web site of the Japan Metrological Agency. MP ranges from 0 (new moon) to 29.7 (full moon).

(4) 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.

(5) 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.

(6) 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$^{o}$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.

(7) 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.

(8) 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.

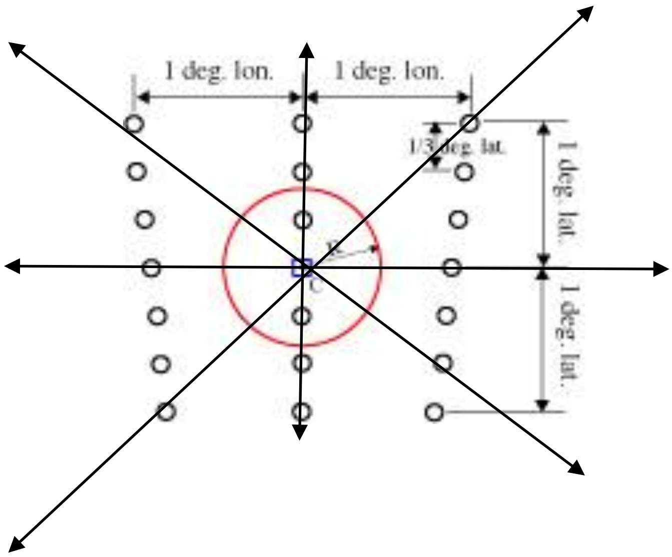



Fig. 1 Searching directions for TG and SG

(9) 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) |
| DMI | Different anomaly of SST between two zone (Z1 and Z2) in the eastern and western IO, i.e., Z1: 50°E-70°E / 10°N-10°S and Z2: 90°E-110°E / 0°-10°S. | Month | $^{o}$C | |
| 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 Model

As we have many 0(zero) catch, WPB7 recommended to used Delta log normal model (DLN). Then Wang and Nishida (2010) attempted to use the DLN for our data. It was resulted that GLM and DLN produced very similar results. Thus we decide to use the GLM again. We use the following model as in the past.

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

*where,*

| | | |
|---|---|---|
| *c* | *constant (10% of the nominal CPUE)* | |
| *Y:* | *year effect* | |
| *Q:* | *quarter effect* | |
| *A:* | *sub area (core fishing 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* |
| | *TG*A* | |

*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*A are included in the GLM model.*

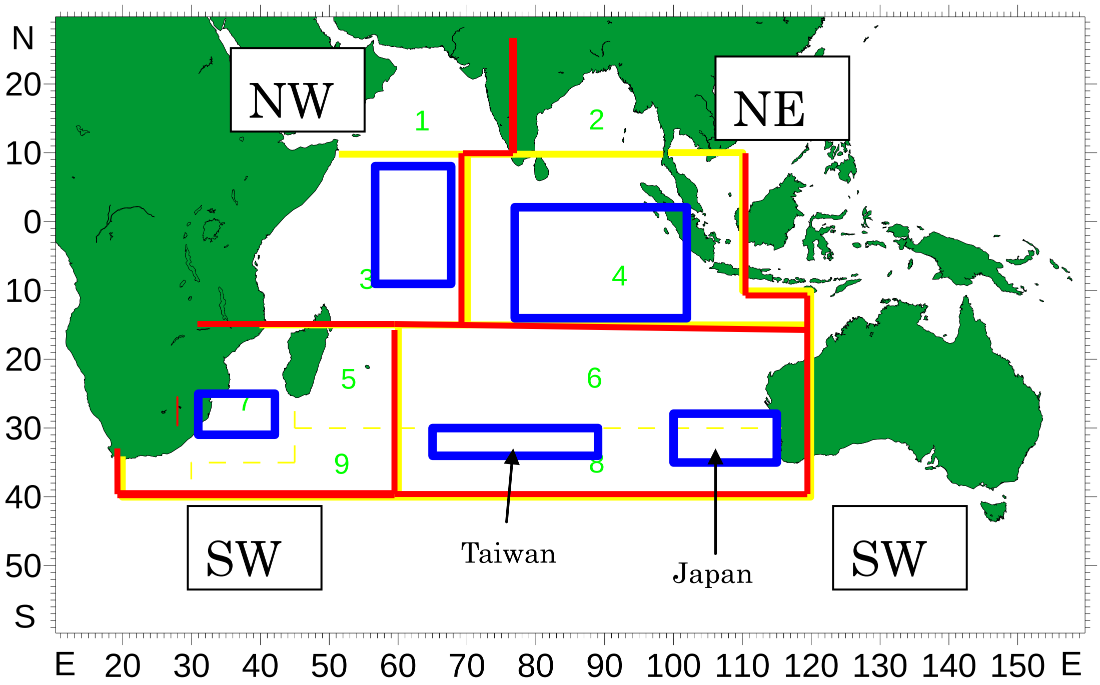



Fig 2. Evolution of sub areas for the SWO STD (standardized)-CPUE in the past.

Sub areas 1-9 were used to 2007. Then in 2008, 4 sub areas were used combining these 9 sub-areas i.e., NW(1 and 3), NE(2 and 4), SW (5,7 and 9) and SE(6 and 8).

However it was recognized that there are still unstable STD-CPUE problems (such as spikes and sudden sharp decrease) in with these 4 larger sub areas.

Then in 2010, ***core fishing areas*** within 4 sub areas were defined to mitigate such unstable situation, i.e., more frequent years fished areas were defined within each sub area as shown in the above map. Then data such FG are used to get the stable N-CPUE and STD-CPUE. Please note that in SW area, Japan and Taiwan have different two core areas.

Table 2 shows 9 scenarios for the STD-CPUE. As a result, scenario 7 was rated as the best.

Table 2 Nine scenarios for the STD-CPUE.

| GLM Model | BIC | R2 | |
|---|---|---|---|
| (1) Y+Q+A+YA | 287209 | 13.4 | |
| (2) Y+Q+A+YA+HBF | 286908 | 13.6 | |
| (3) Y+Q+A+YA+HBF+V | 283683 | 20.9 | 3rd |
| (4) Y+Q+A+YA+ENV | 286394 | 14.1 | |
| (5) Y+Q+A+YA+HBF+ENV | 286083 | 14.3 | |
| (6) Y+Q+A+YA+HBF+ENV+V | 283107 | 21.4 | 2nd |
| (7) Y+Q+A+YA+HBF+ENV+V+TG*A | 282775 | 21.7 | best |
| (8) Y+Q+A+YA+HBF+ML | 297437 | 4.5 | NG |
| (9) Y+Q+A+YA+HBF*ML | 297767 | 4.1 | NG |

- ENV (no INT) to reduce apparent good fits (9 vs 30)
- V : contributes a lot
- TG*A (best factor last) Area specific TG(ocean fronts)
- ENV contribute to smooth trends

### 3.4 Factors affecting annual nominal CPUE

Table 3 shows the resultant ANOVA for the scenario 7 in the GLM run. It was found that nominal CPUE are significantly affected by the following factors (by order of statistical significance), i.e., “number of hooks between hooks”, “ENV (moon phases, ocean fronts, temperature & salinity at the depth where SWO caught (45m)” and “main factors (area and season)”.

| 要因 | 自由度 | Type III 平方和 | 平均平方 | F 値 | Pr > F |
|---|---|---|---|---|---|
| y | 28 | 5651.52777 | 201.84028 | 122.17 | <.0001 |
| q | 3 | 1005.54526 | 335.18175 | 202.87 | <.0001 |
| a | 3 | 1344.25631 | 448.08544 | 271.21 | <.0001 |
| y*a | 84 | 11187.51076 | 133.18465 | 80.61 | <.0001 |
| v | 1103 | 38475.17052 | 34.88229 | 21.11 | <.0001 |
| mh | 1 | 810.23556 | 810.23556 | 490.40 | <.0001 |
| t45 | 1 | 462.31569 | 462.31569 | 279.82 | <.0001 |
| s45 | 1 | 594.41298 | 594.41298 | 359.78 | <.0001 |
| ioi | 1 | 6.01640 | 6.01640 | 3.64 | 0.0564 |
| dpi | 1 | 39.75769 | 39.75769 | 24.06 | <.0001 |
| SG | 1 | 244.40886 | 244.40886 | 147.93 | <.0001 |
| TG | 1 | 456.05569 | 456.05569 | 276.03 | <.0001 |
| hpb | 1 | 1071.16215 | 1071.16215 | 648.33 | <.0001 |
| TG*a | 3 | 1469.46404 | 489.82135 | 296.47 | <.0001 |

V: not strong factors→ apparent good fit due to 1103 parameters
Limited ENV (9) (30 :last) to reduce apparent auto-correlations:
1st best factor affecting N-CPUE : HBF
2nd-4th ENV(moon phase, T45 and S45)

## 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). Fig. 4 shows the annual trends of AI and Fig. 5 shows AI by sub area. In these two Figures, trends estimated last year and this year are presented for comparison.

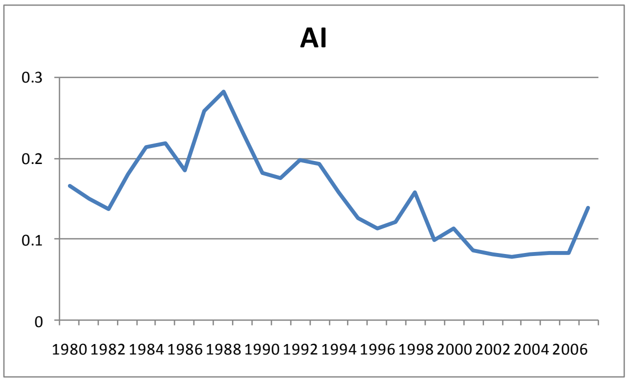
$$U_y = \sum_a S_a U_{y,a}$$

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 |



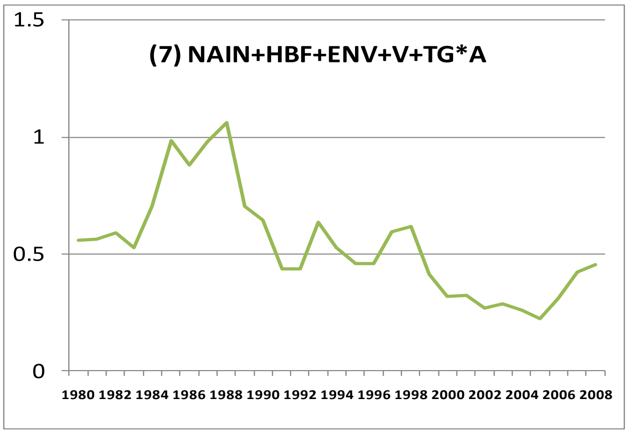




Fig. 4 Estimated Abundance index (Japan) above WPB7 (2009) and below this time (2010)

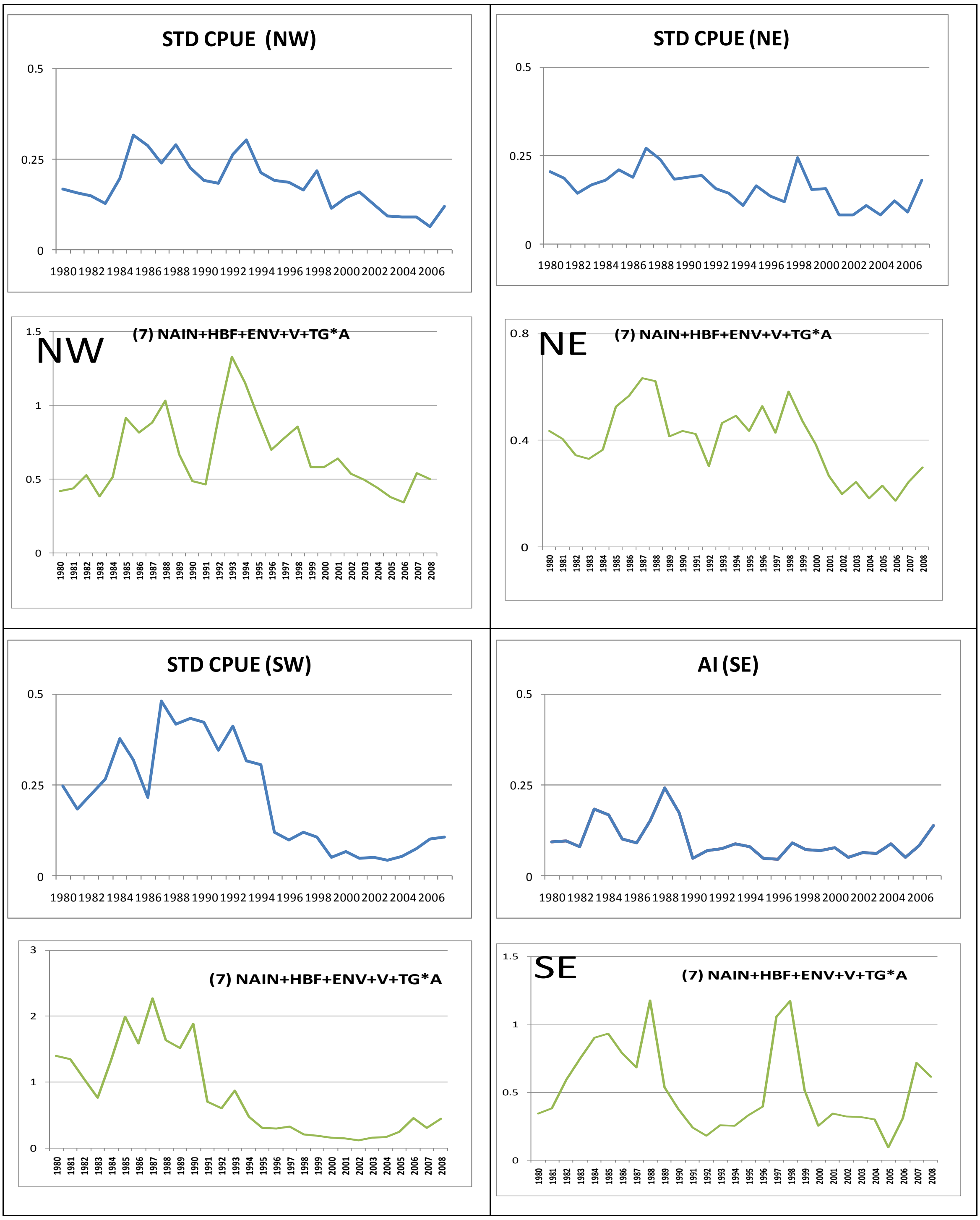



Fig 5. Annual trends of STD CPUE by sub-area

(above: results in WPB7 in 2009; below in WPB8 in 2010)

## 5. Discussion and conclusion

GLM results suggested that the abundance index (AI) rapidly increased from 1980 to 1988, then decreased until 2006, followed by increases in 2007-2008. Using daily fine scale CPUE (set by set) data it was found that nominal CPUE are significantly affected by the following factors (by order of statistical significance), i.e., “number of hooks between hooks”, “environmental data [moon phases, ocean fronts, temperature & salinity at the depth 45m depth where SWO primarily caught]” and “main factors (area and season)”. Such findings especially relating to environmental information could not obtained when the coarse scale (5x5) nominal CPUE were used in the past. This demonstrates effectiveness and importance of fine scale CPUE and environmental data. In addition it was also resulted that V (vessel) significantly affect nominal CPUE which implied that there were different levels of catchability among vessels due to the skipper’s skills.

The significant decline in AI in 1991 for the SW area and identified that this could be a consequence of various factors including the environmental heterogeneity of the area, targeting issues and specification of the model (*e.g*. interactions between environmental factors and spatial patterns in the fishery). Technological changes leading to an increase in tuna catch rates (*eg.* changes in longline fishing depth, number of hooks between floats) might have had a potential negative impact on swordfish catchability and CPUE.

## Acknowledgments

We thank Dr Kolody providing suggestions on the idea of core fishing grounds and also Dr Marsac (IRD, France) providing the IOI and IO dipole index data.

## References

Oliveira, Vasconcelos, Travassos, Garcia and Aldatz (2005): LENGTH-WEIGHT RELANTIONSHIPS AND LENGTH-LENGTH CONVERSIONS OF TUNAS AND SWORDFISH IN THE NORTHEAST OF BRAZIL, ICCAT/SCRS/2004/153 Col. Vol. Sci. Pap. ICCAT, 58(5): 1724-1728).

*Other references are provided upon request to the authors.*