Review of CPUE Issues for the 2011 Indian Ocean Swordfish Stock Assessment

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Introduction

In 2011, the IOTC Working Party on Billfish (WPB) has been tasked with revisiting the assessment and management advice for the swordfish sub-population of the southwest (SW) Indian Ocean:

> *"The Commission* ***requests*** *that the Scientific Committee provide clear advice outlining alternative management approaches which would provide effective protection of a possible southwest Indian Ocean swordfish stock."* (IOTC 2011).

The standardized longline CPUE series are the most important inputs to this assessment (along with total catches), as they provide the relative abundance trends that are required to quantify the impact of the fishery on the stock. Increasingly sophisticated analyses have been employed to standardize the Indian Ocean SWO CPUE time series in recent years. However, despite this steady progress, there a number of problems remain. Most of the issues are discussed in previous WPB reports (e.g. WPB 2010), including:

- There is uncertainty about the appropriate spatial units for the CPUE standardization.
- Trends in standardized CPUE differ considerably among fleets that operate in the same area.
- The steep decline in Japanese CPUE in the 1990s may exaggerate the perception of population decline in the SW region.
- The spatial distribution of effort has changed substantially for all of the main LL fleets.
- Methods of gear deployment have changed.
- Target species have changed.
- The effects of oceanographic variability on the species distribution/catchability are not well understood.
- Model selection criteria tend to prefer over-parameterized models.

These (often inter-related) problems are reviewed briefly below in the context of the 2011 SWO assessment, and analyses are proposed which might help to advance our understanding of the issues. Many of the analyses could be conducted prior to the WPB 2011. However, some analyses are more extensive and also relevant to the main tuna species. A dedicated CPUE workshop, possibly coordinated under the IOTC Methods Working Group, might be an appropriate forum to coordinate further work.

P1 – Stock structure uncertainty

The following discussion assumes that the 4 region structure used in recent IO SWO assessments provides a pragmatic partitioning of the IO SWO population for purposes of CPUE standardization and stock assessment (Figure 1). These assumptions are worth revisiting, particularly after the results of the Indian Ocean Swordfish Stock Structure (IOSSS) project are delivered to the WPB (preliminary results expected in 2011, final results in 2012).

P2 – The CPUE series from the different LL fleets suggest very different abundance trends

The CPUE series for different fleets, operating in the same area, are sometimes very different (Figure 2). In general, the SWO CPUE series are very noisy. Ideally, we would like to be able to standardize the series to account for important sources of variability in catchability, so that consistent trends can be estimated across fleets. Failing that, it would be good to have a sound justification for choosing the most reliable series. Whether or not these goals can be achieved, it is important that the uncertainty in the relative abundance indices is recognized in the assessment and management advice.

The conflicts in the SW region represent a particular concern, because there is a perception that this region may be excessively depleted. The recent SW Japanese (JPN) CPUE is sharply increasing, while the SW Taiwanese (TWN) CPUE series is steeply decreasing. In contrast, the nominal CPUE series from Reunion and Spain (SPA) appeared to be relatively stable over the last few years (but as these series were not standardized for this time period, they were not included in the assessments). At least one of the JPN or TWN series must be grossly misleading (or the conventional error assumptions are completely inappropriate). There is a secondary issue in that the relative magnitude of the mean CPUE also differs substantially among areas for each of the JPN and TWN fleets. This may have implications for the merging of regional CPUE series into an aggregate IO series, but is probably a lower priority issue for 2011, since the focus is on the SW region.

Recommendations

- The Spanish CPUE should also be standardized and compared with JPN and TWN.

P3 – The Japanese CPUE decline in the 1990s may exaggerate the perception of swordfish depletion in the SW region

CPUE trends from several fleets suggest that there has been a population decline in the SW region. However, only the JPN series was used in the assessment for the period prior to 1997, and there are some characteristics of this series that raise doubt about the magnitude of the decline in this early period.

Figure 3 compares the standardized CPUE series from the JPN LL fleet in the SW region from the WPB 2009 (traditional GLM, Nishida and Wang 2009) and 2010 (core area, Nishida and Wang 2010, described in the following section). The trends are similar, with two obvious discrepancies: i) the trends are in opposite directions in the early 1980s (which may be related to the low effort in this period), and ii) the timing of the very steep decline (>50% drop in one year) in the 1990s differs. The traditional model (2009) identified the drop between 1994-95, while the core area identified the drop between 1990-91. The elevated catches in the SW region started in 1992 (e.g. TWN LL fleet catch increased from 616 t in 1991 to 6074 t in 1992).

The abrupt decline in the JPN CPUE in the early 1990s is the strongest signal in the assessment that drives the inference of very high depletion in the SW region. The drop is so steep that the assessment models can only explain it through a combination of fishery depletion and anomalous recruitment (Martell 2010, Kolody 2010). But the decline is a questionable indicator of (regional) depletion because it is too steep to be explained by the catches, and the timing is sensitive to the spatial assumptions. If the decline can be explained as a shift in catchability (due to spatial or other targeting effects discussed below), this could result in a very different perspective for the SW region. Methods for investigating this problem are discussed in the following sections.

P4 – The spatial distribution of effort has changed over time

The spatial distribution of effort has shifted substantially for the main LL fleets, though there are some areas, mostly offshore, that have been fished reasonably consistently (Figure 4). There is little overlap in the consistently fished areas of JPN and TWN in the southern regions, while the northern regions are similar. The shifting effort distributions are probably related to exploratory/learning behaviour, economic factors (e.g. targeting shifts in response to species value, catch rates changing due to depletion, fuel prices) and other logistical concerns (e.g. EEZ access, pirate activity). However, there has been no comprehensive quantitative explanation for the patterns.

The IO SWO assessment sub-regions probably do not have an internally homogeneous distribution of fish density, such that spatial shifts in effort could have a large effect on observed CPUE. The general problem is illustrated in Figure 5. e.g. Some coastal regions appear to have higher CPUE than offshore regions (note the Taiwanese CPUE in the region off north-western Australia). Clearly changes in the presence or absence of observations from a high density sub-region can affect the regional CPUE for reasons that are unrelated to changing abundance. This issue needs to be explicitly admitted in the analysis somehow.

The core area approach was one method proposed to reduce the problem of shifting effort distributions on the periphery of the fishery. The approach has been used historically for SBT (e.g. Laslett 2001) and was employed in the WPB in 2010 for the main LL fleets of JPN and TWN (Nishida and Wang 2010, Wang and Nishida 2010) and the smaller fleets of Reunion and the Seychelles (Kolody et al. 2010A,B). Figure 6 shows the regions that were identified as having the most consistent fishing effort over time. However, the core area approach does have its own problems, notably:

1) The core area model assumes that relative density in a small, consistently-fished area represents a much broader regional population. But the core area might not be representative for a number of reasons, e.g. incorrect stock structure assumptions, localized depletion due to slow mixing rates, or oceanographic effects on the population distribution. There may also be important heterogeneity within the core areas (e.g. fronts, seamounts). These issues represent a problem both for core area and traditional regional standardization approaches.

2) Core area sample sizes may be very small, which may lead to high variance of the indices. Visual inspection of Figure 2 and Figure 7 indicates that the interannual variability may be very high (more variable than can be explained by the population dynamics alone) in either the core area or traditional approach.

Figure 8 and Figure 9 compare the catch, effort and nominal CPUE in the SW region and the SW core area for JPN, TWN and SPA. The main features of the data are similar in both regions, but there are important differences. It might be argued that there is not enough effort in the core area for the indices to be useful for any fleet prior to the 1990s. Furthermore, the effort from the Taiwanese fleet since 2005 is very low, and this casts serious doubt on the reliability of the apparent population collapse observed in the recent TWN CPUE (Figure 2).

Recommendations

- The core area approach should be further developed, with possible modifications:
    - Seasonal constraints should be considered in addition to spatial constraints.
    - Years which do not meet minimum effort levels for the core area should be omitted from the analysis (and the relative abundance index). e.g. Figure 9.
    - Multiple (overlapping or non-overlapping) time series might be generated from different core areas within each sub-region (e.g. before 1991 and after 1995 for JPN).
- Traditional (non core-area) models should also be compared in which spatial factors at a resolution higher than the 4 area IO structure, should be incorporated into the GLMs to admit that each of the NW, NE, SW, SE regions is probably not internally homogeneous (e.g. for SBT, fixed longitudinal and latitudinal blocks are included, Hearn and Polacheck 1998).
- 'Back-filling' (spatial imputation) models could be used to try and account for the absence of observations in key areas/strata (e.g. Carruthers et al 2010).
- CCSBT provides several examples of more sophisticated models to try to account for changing effort distributions. These include various geo-statistical approaches (eg. Toscas et al 2001), and density-dependent 'habitat-basin' models that attempt to quantify range collapse (e.g. Hearn and Polacheck 1998, Campbell 2004).

P5 – Changes in operational characteristics

Changes in gear configurations arise as a result of changing target species and general technological advance. If all vessels change almost simultaneously, there can be a confounding of abundance and gear change that is difficult to interpret. The only operational data used in the Indian Ocean LL CPUE standardization are the Hooks-Between-Floats (HBF, e.g. Figure 10) and line material. While HBF is often interpreted as an index of depth that indicates bigeye vs yellowfin targeting, there is a confounding with the shift from traditional kuralon to monofilament nylon main lines. As depth characteristics have rarely been measured adequately, the interaction between HBF and main line type on depth of setting is not clear, and the observational contrast is not ideal for disentangling the effect with a GLM (WPTT 2010). The timing of the shift in HBF and mainline corresponds suspiciously to the timing of the large drop in JPN SWO CPUE in the SW (Figure 3).

The potential effects of the skill of the fishing master is often noted as a potentially important factor in the success of a vessel, and this may be especially important for core area analyses where fewer boats may be represented. This was found to be the case in the Seychelles semi-industrial fleet, but the dynamic nature of entry and exit to this fishery is not comparable with the other fleets (Kolody et al. 2010).

Recommendations

- If some operational data are only collected irregularly, analyses should be conducted on the subset of data from which it is available, to see if it is likely to be important.
- It may be worth splitting CPUE time series before ~1993 and after ~1995, including only the dominant gear configuration in each time series. Splitting time series admits that standardization cannot account for important gear changes in some circumstances (e.g. as applied in the Spanish LL fleet before and after adoption of 'American-style' gear; Mejuto et al. 2008).

P6 – Changes in species targeting

This problem is not mutually exclusive from the other problems described above (i.e. species targeting shifts can be achieved by shifting areas/seasons of operation, or changing gear configurations). However, effective targeting shifts can also be achieved by other means that may not be adequately quantified in the logbooks, e.g. by changing fine-scale spatial decisions (e.g. which side of a front to set on), set-times, bait-type, lightstick usage and hook-types, etc.

The SPA fleet offers an interesting contrast to the JPN and TWN fleets (Figure 5, Figure 8 and Figure 9). The SPA fleet is clearly targeting SWO (the CPUE is roughly 10X higher than that of JPN and TWN). Furthermore, the CPUE appears to be spatially very uniform compared with the other fleets (Figure 5). This could indicate that the SPA fleet is skilled at finding SWO concentrations within heterogenous regions, or that shifting targeting practices among the JPN and TWN fleets (within and among years) creates CPUE patterns that do not reflect abundance. The trend in SW SPA nominal CPUE is generally decreasing through the 1990s, but stable or increasing in the 2000s (unfortunately the shift in gear style in 2001 renders the two periods incomparable).

The core area approach may have some capacity to reduce the influence of species targeting shifts even if they are not due solely to spatial effects. e.g. In some fisheries, the effect of gear configuration on catchability might be more important than the spatial effect, but the core area standardization might account for the gear effect if the two factors are closely coupled. However, the conflicting trends in Figure 9 suggest that the core area alone is not sufficient for standardization.

Figure 10 illustrates the nominal CPUE for the main commercial species in the SW region for the JPN and TWN fleets. The series are very noisy, but there are some patterns that are strongly suggestive of targeting shifts, e.g. particularly for the TWN fleet:

- There is a very steep increase in TWN SWO CPUE (and catch) between 1991-92, which is not observed in the JPN fleet. This is known to be a shift toward targeting SWO.
- From about 1985-95 there is a steady increase in BET CPUE. It is likely that some of the steep decline in TWN SWO CPUE since 1992 has been due to increased targeting of BET.

- From ~1987-93, there is a strong consistent decline in TWN ALB CPUE, which roughly coincides with the increase in BET (and SWO).
- There is a sharp increase in TWN SBT CPUE 2003-7, which corresponds to the period of most recent decline of SWO CPUE.

It is not clear how the targeting shifts affect CPUE, or whether these shifts can be explained by spatial and gear effects (e.g. the effect may operate at a very fine spatial scale, as when fishers report targeting different species on opposite sides of the same front). There is a temptation to include species other than the one of interest as a GLM covariate (e.g. as a species composition ratio) to quantify targeting effects. This has been criticized for a couple reasons: i) including the species composition ratio introduces the species of interest to both sides of the GLM equation (which can lead to spurious statistical relationships), and ii) the abundance of the other species probably changes over time, such that the covariate reflects both targeting and abundance. While these represent real problems, it is unclear whether these errors are likely to be greater than those arising from ignoring information from other species altogether.

Recommendations:

- Compare models with/without species targeting as a proportion (adjust for non-SWO abundance changes from other species assessments if possible).
- Eliminate sets with >X% of non-SWO species, compare sensitivity of X
- Split time series when obvious targeting shifts occur.
- Use multi-variate techniques to categorize set-types (e.g. Bigelow and Hoyle 2009 used cluster analyses)
- Multiple time series (e.g. with/without targeting effects) may be plausible and should be carried forward into the assessment to represent uncertainty associated with alternative interpretations.

P7 – There is uncertainty about how oceanographic variability affects species distributions and catchability

Undoubtedly oceanographic variability will influence the catchability of the population by changing fish behaviour (e.g. vertical and horizontal distributions) and the effectiveness of the gear. However, the mechanisms and interactions of the oceanographic effects can be difficult to quantify, especially if effort distributions change in response to changing oceanography.

Most (or all) of the oceanographic indices employed in the Indian Ocean CPUE analyses in recent years are derived from physical models which may include a large degree of error. These model-derived oceanographic fields may be inappropriate for describing relevant fine scale features such as fronts, but might be useful for describing basin-scale events like the Indian Ocean dipole.

Oceanographic data tend to be highly correlated in space and time, as do CPUE observations, which probably undermines the standard statistical assumptions of independence. To examine the chances of identifying spurious oceanographic co-variates in a GLM analysis, some simple tests were conducted on the Seychelles industrial fleet CPUE in 2010 (described in attachment A). Two relevant results were observed:

1) Highly significant relationships were identified even when the environmental indices were intentionally displaced in space (i.e. 30° in latitude and longitude) and time (20 years). This suggests that spurious relationships are likely to be identified.

2) Fixed spatial covariates (5x5°) explained more variance than the combined effects of the environmental covariates. This suggests that the environmental indices may not be providing much information on relevant dynamic oceanographic processes, but rather may simply be indexing spatial patterns that do not necessarily vary much from year to year.

These results indicate that one needs to be careful in using the environmental co-variates. As an example of how the environmental indices can be very misleading, consider the hypothetical effect of climate change. If SST has been rising steadily for 10 years, and CPUE has been falling steadily for 10 years, the traditional CPUE standardization may attribute all of the CPUE decline to a declining catchability effect of SST (and conclude that abundance is stable). But the SST could be having a negative impact on recruitment rather than catchability. Alternatively, SST may have no effect on either catchability or recruitment, but may be spuriously correlated with an abundance decline that is caused by a “one-way-trip” fishery. The alternative interpretations of the data need to be considered carefully.

Recommendations

- It is worth comparing the results when oceanographic anomalies (deviations from mean seasonal effects) are applied as covariates vs: directly using the oceanographic indices themselves vs: using finer-scale fixed spatial effects.
- Compare analyses based on model-derived and remote-sensing derived oceanographic indices when available to examine the effect of errors in the oceanographic models.
- The mechanisms of the oceanographic effects should be examined for plausibility. Co-efficients from different analyses conducted in different areas and among different fleets should be compared for consistency.
- The practical importance of the magnitude of the effect should be considered (and diagnostics should be examined to see whether the effects are sensitive to a small numbers of observations with high leverage).
- Functions other than linear responses might be required to describe some interactions (e.g. break the continuous variables into a series of categorical variables or use GAMs).
- In the longer term, simulation studies would be useful to see how often spurious effects are likely to be identified as significant model contributors.

P8. Alternative Statistical Models

In additional to the traditional GLMs, several other methods have been applied to the problem of CPUE standardization, including GAMs, regression trees, and neural networks. It has often been found that the broad features of the CPUE series remain unchanged when these approaches are used. And these methods do not add any special insight into the investigation of the hard problems e.g. how to account for catchability effects due to processes that are not easily observed (subtle targeting effects, changing spatial distributions of effort).

There has also been work to test alternative error structures of the CPUE models. For swordfish, some simple comparisons of lognormal and delta-lognormal models were undertaken (to better quantify the processes that lead to true zero CPUE observations) in 2010 with the TWN, Seychchelles and Reunion SWO CPUE data. No substantive differences were observed in the time series (WPB 2010). Efforts to consider the auto-correlation inherent in CPUE observations suggested that this might have very little influence on point estimates (e.g. Nishida and Chen 2004), but might make the variance estimates more realistic (implications for model selection criteria should also be considered).

Recommendations

- In the short term, it seems that revising the core statistical assumptions is a lower priority than trying to account for the troublesome issues of spatiotemporal changes in effort, heterogeneity of spatial distributions, and other factors that influence the interannual variability in catchability. If appropriate mechanisms to account for changing catchability cannot be identified for this fishery, the statistically responsible approach may be to admit that the conflicting CPUE series can only be reconciled through a very high variance and strong temporal structure in the errors. This may lead to the conclusion that CPUE is telling us very little abundance.

P9. Model Selection

CPUE GLM models often identify a large number of statistically significant interactions and covariates. This is at least in part related to the very large number of observations and the spatial and temporal correlation among them (P7,P8 above). Simulations by Carruthers et al. (2010) demonstrated that standard model selection criteria (AIC) tended to select over-parameterized models, and this would be expected to be broadly relevant.

Recommendations

- Analysts should introduce covariates and interaction terms sparingly.
- The magnitude of the effects should be examined, and co-efficients lacking practical importance should be dismissed.
- Mechanisms of effect should be examined among areas and fleets, and over different time windows to check consistency.
- If two (or more) models are plausible and have very different trends, they might need to both be admitted into the stock assessment as alternatives.
- Further simulations should be undertaken to provide guidance on model selection criteria.

Conclusions:

A number of concerns have been highlighted in the analysis and interpretation of Indian Ocean SWO CPUE. Several analyses have been proposed which can easily be conducted prior to the WPB 2011, potentially at an informal meeting in the days immediately prior to the meeting. A number of useful analyses would require more intersessional work and may benefit from a dedicated CPUE workshop, perhaps coordinated by the IOTC MWG. Furthermore, arrangements for collaborative access to the operational data of the LL fleets might be very productive, (e.g. noting that there is a precedent for non-Japanese scientists to access the high resolution data in Shimizu under suitable confidentiality arrangements, Hoyle et al. 2010). As many of these problems are ubiquitous, such a workshop should include the other main tuna species, and may be relevant for all of the t-RFMOs.

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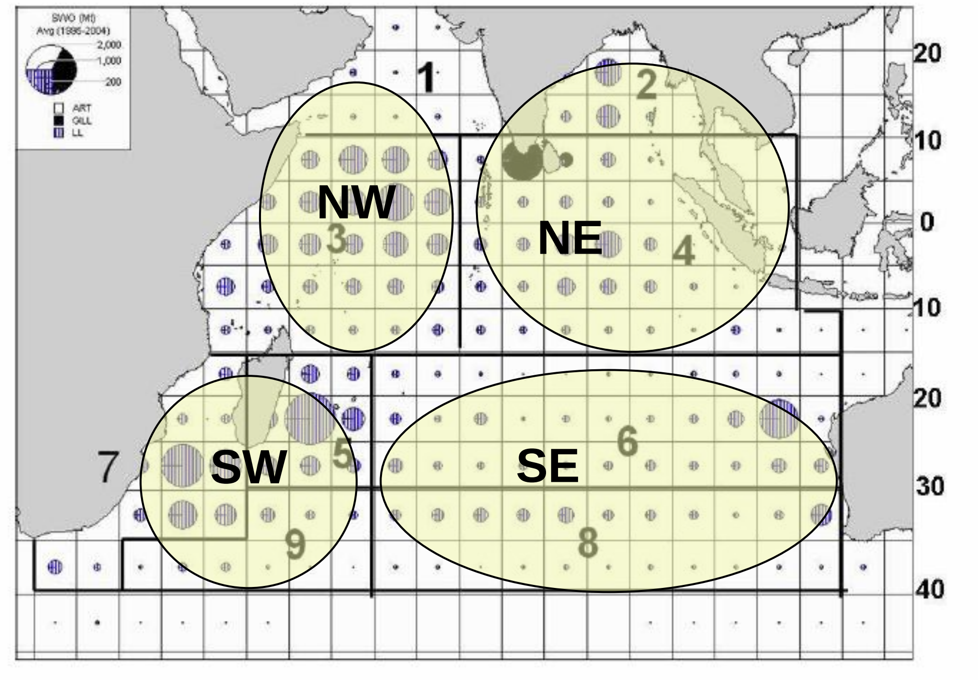
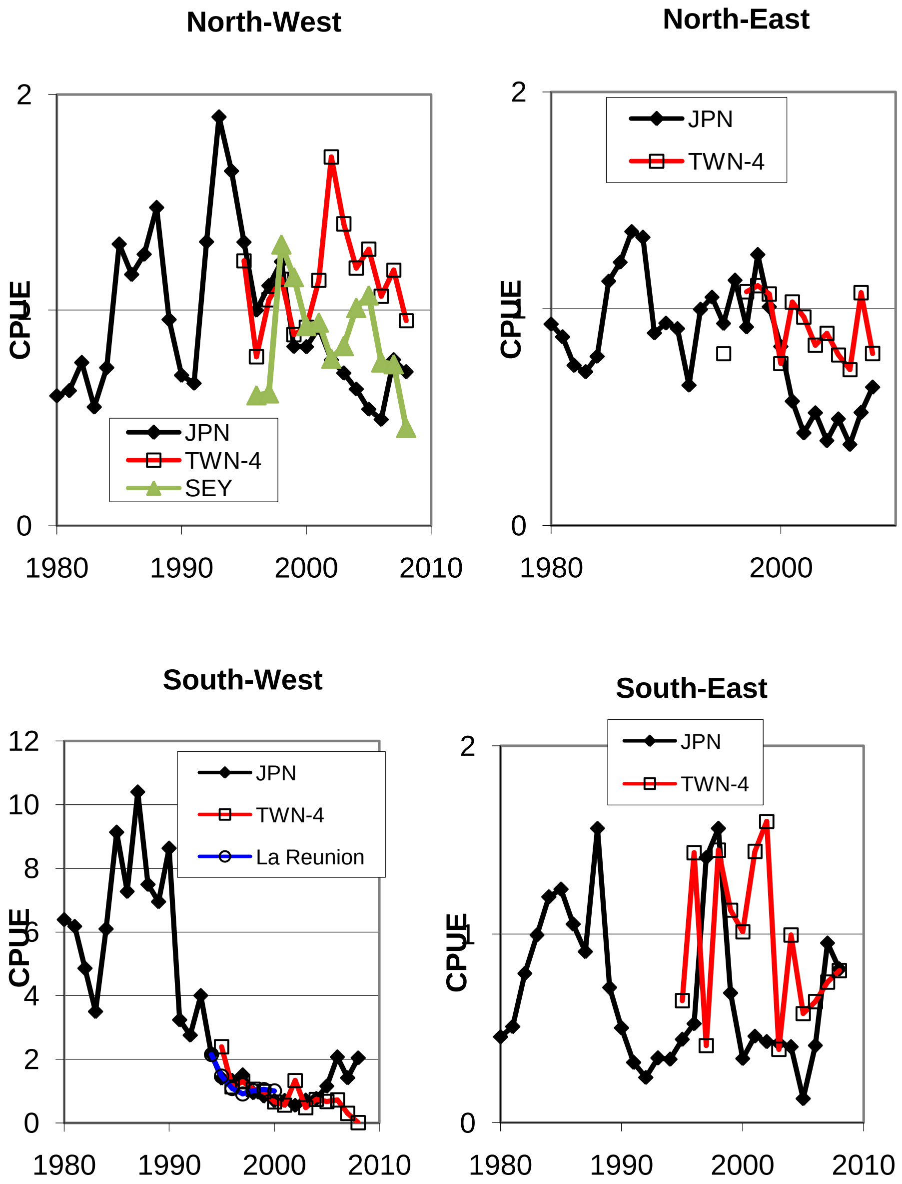


Figure 1. Spatial structure showing the 4 areas used in the model, superimposed on the IOTC statistical areas, and the swordfish catch distribution aggregated over 1995-2004.



North-West

North-East

South-West

South-East

Figure 2. Core-area Standardized CPUE by area for Japanese, Taiwanese, La Reunion and Seychelles semi-industrial longline fleets from WPB 2010. All series have been rescaled to have a mean of 1 over the interval 1997-2000 (note that this re-scaling is undertaken for the purposes of comparing trends among fleets within each area, and does not reflect the relative weighting across areas that is used in the assessment).

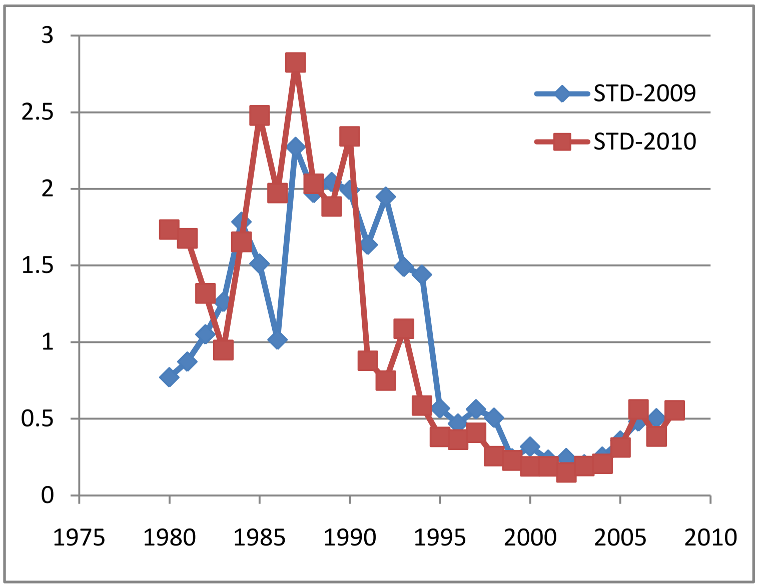


Figure 3. Comparison of standardized JPN CPUE in the SW region based on the analyses conducted in 2009 and 2010 (rescaled relative to the 1980-2007 mean).

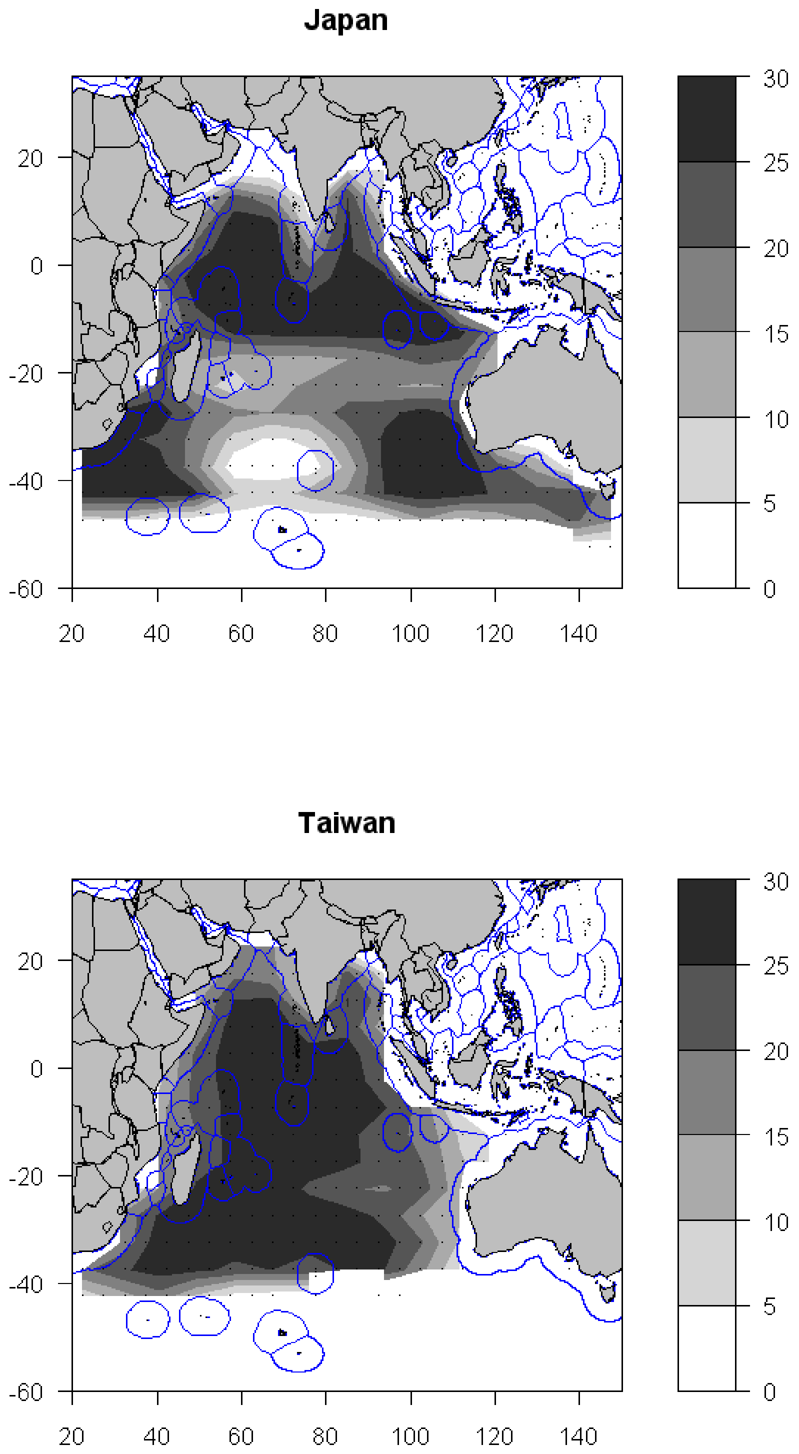


Figure 4. Contour plots indicating the number of years in which each 5x5° square was fished between 1980-2007 by the Japanese (top) and Taiwanese (bottom) longline fleets.

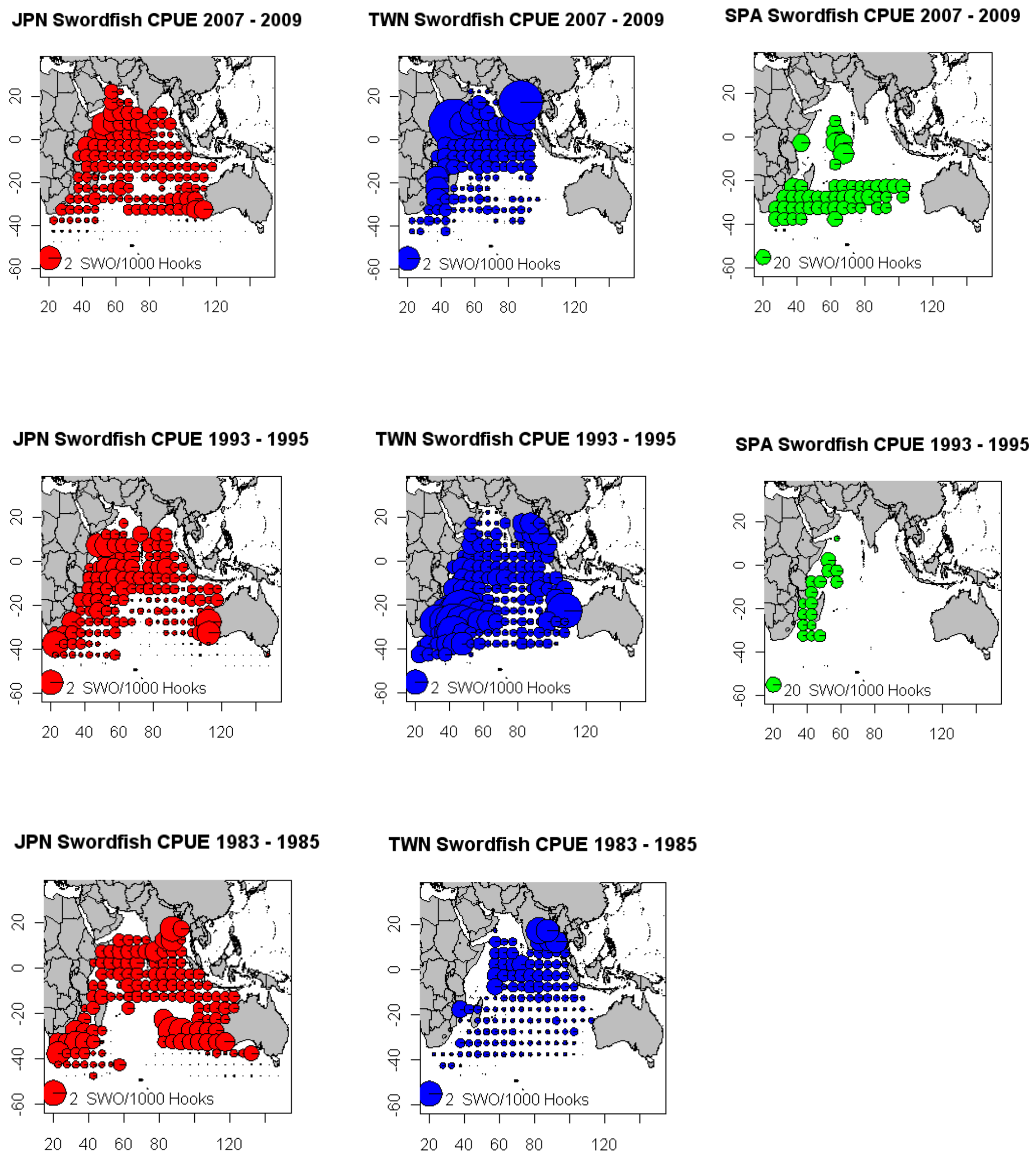


Figure 5. Distributions of JPN, TWN and SPA LL nominal (effort-weighted) SWO CPUE by time period.

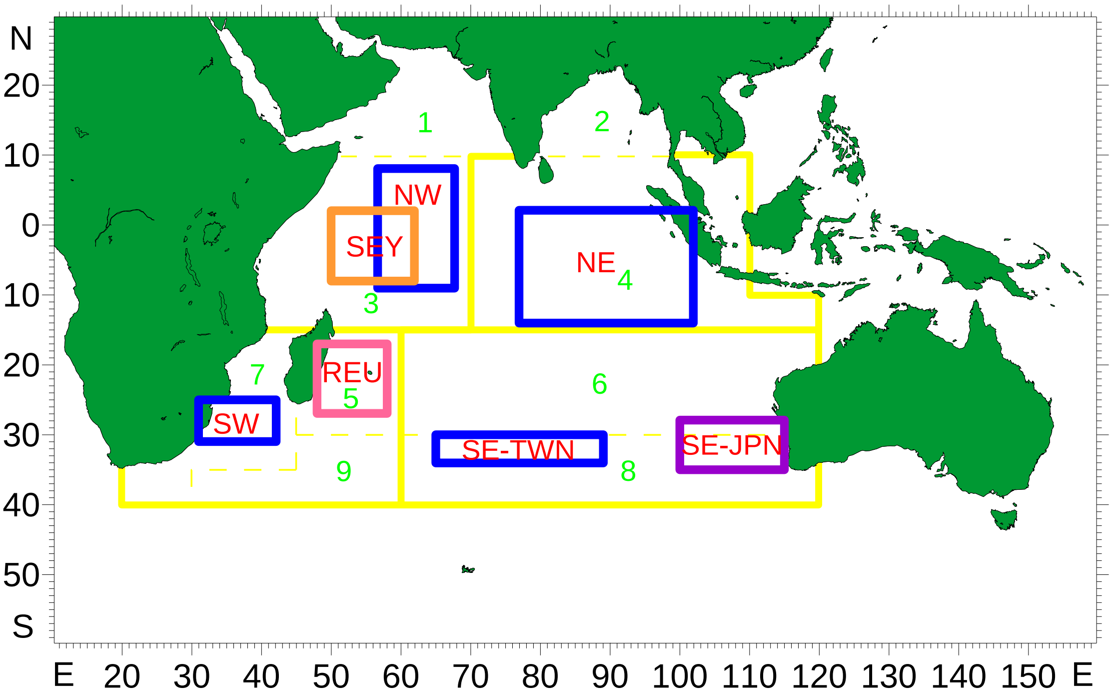


Figure 6. Map illustrating the core areas from which the 10 different standardized CPUE series were calculated in 2010 (courtesy of Dr. Sheng-Ping Wang, Taiwan). Each CPUE series was considered to be an abundance index for one of the 4 broader regions used in the assessment (roughly corresponding to the large yellow boxes). JPN and TWN used the same core area for the NW, NE and SW, but different areas for the SE. REU=La Reunion, SEY=Seychelles semi-industrial.

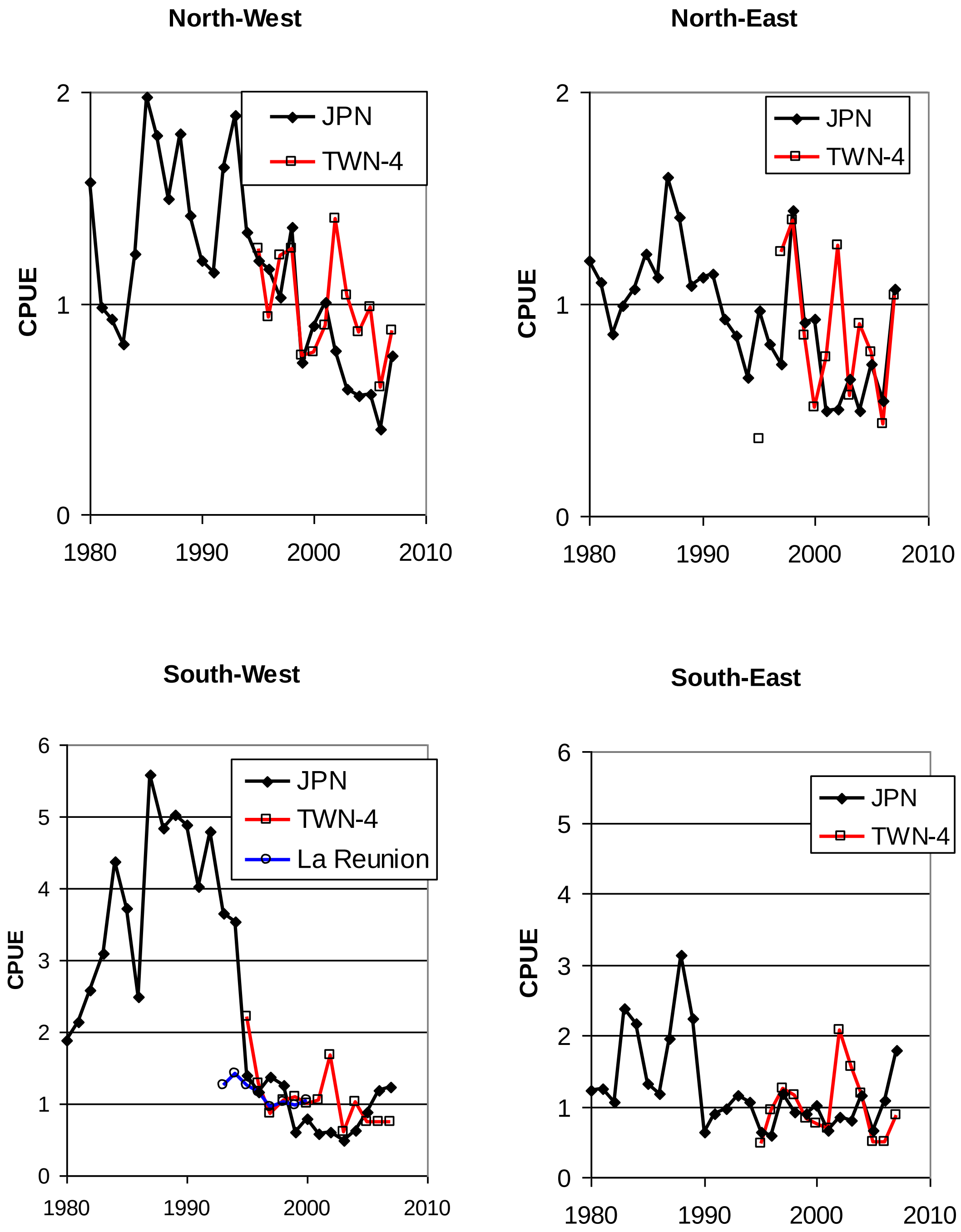


Figure 7. Standardized CPUE by area for Japanese, Taiwanese and La Reunion longline fleets from the 2009 (non-core area) analyses. All series have been rescaled to have a mean of 1 over the interval 1997-2000 (note that this re-scaling is undertaken for the purposes of comparing trends among fleets within each area, and does not reflect the relative weighting across areas that is used in the assessment).

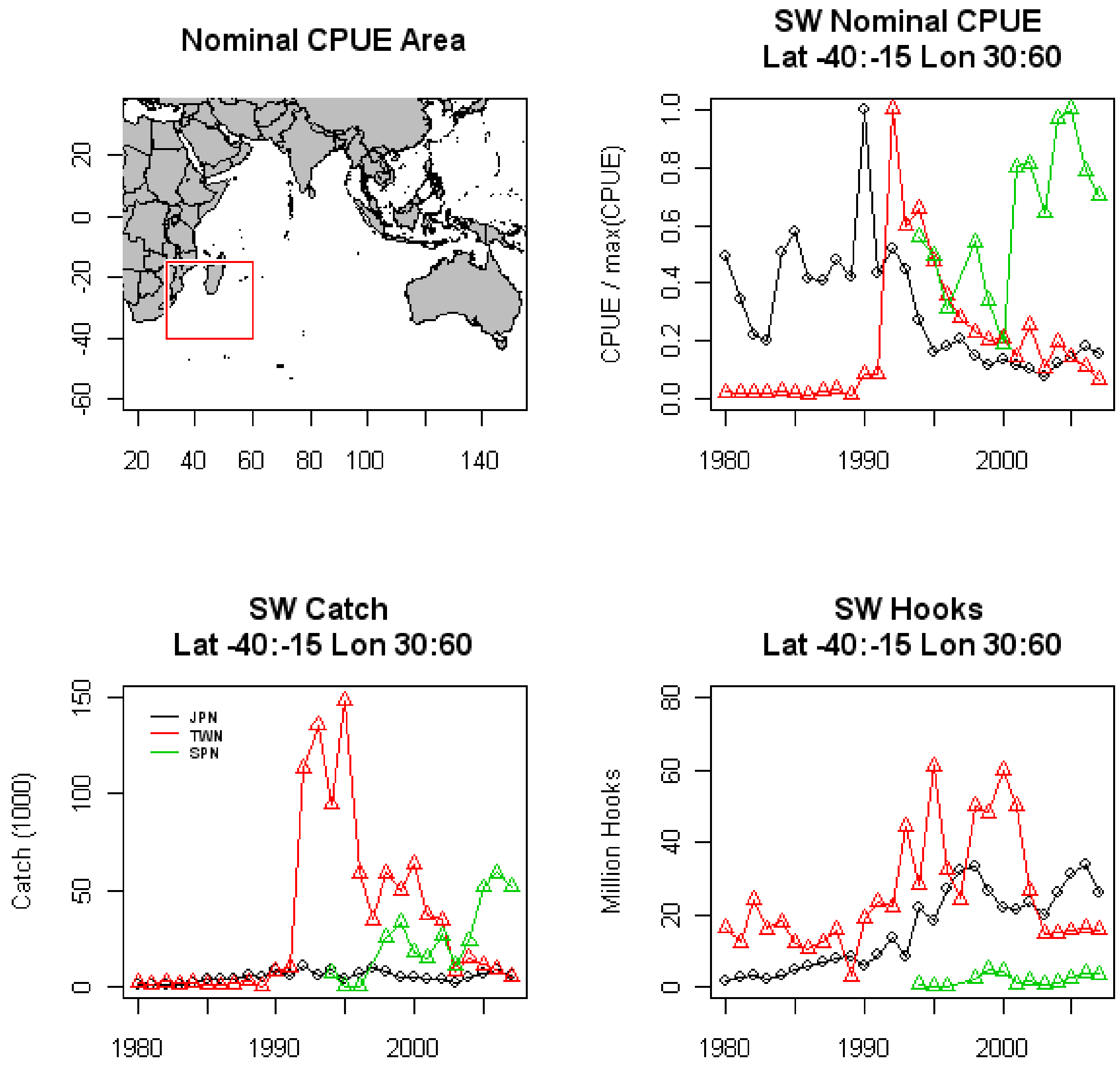


Figure 8. Time series of JPN and TWN longline swordfish Catch, Effort and Nominal CPUE (effort-weighted) in the South-West region.

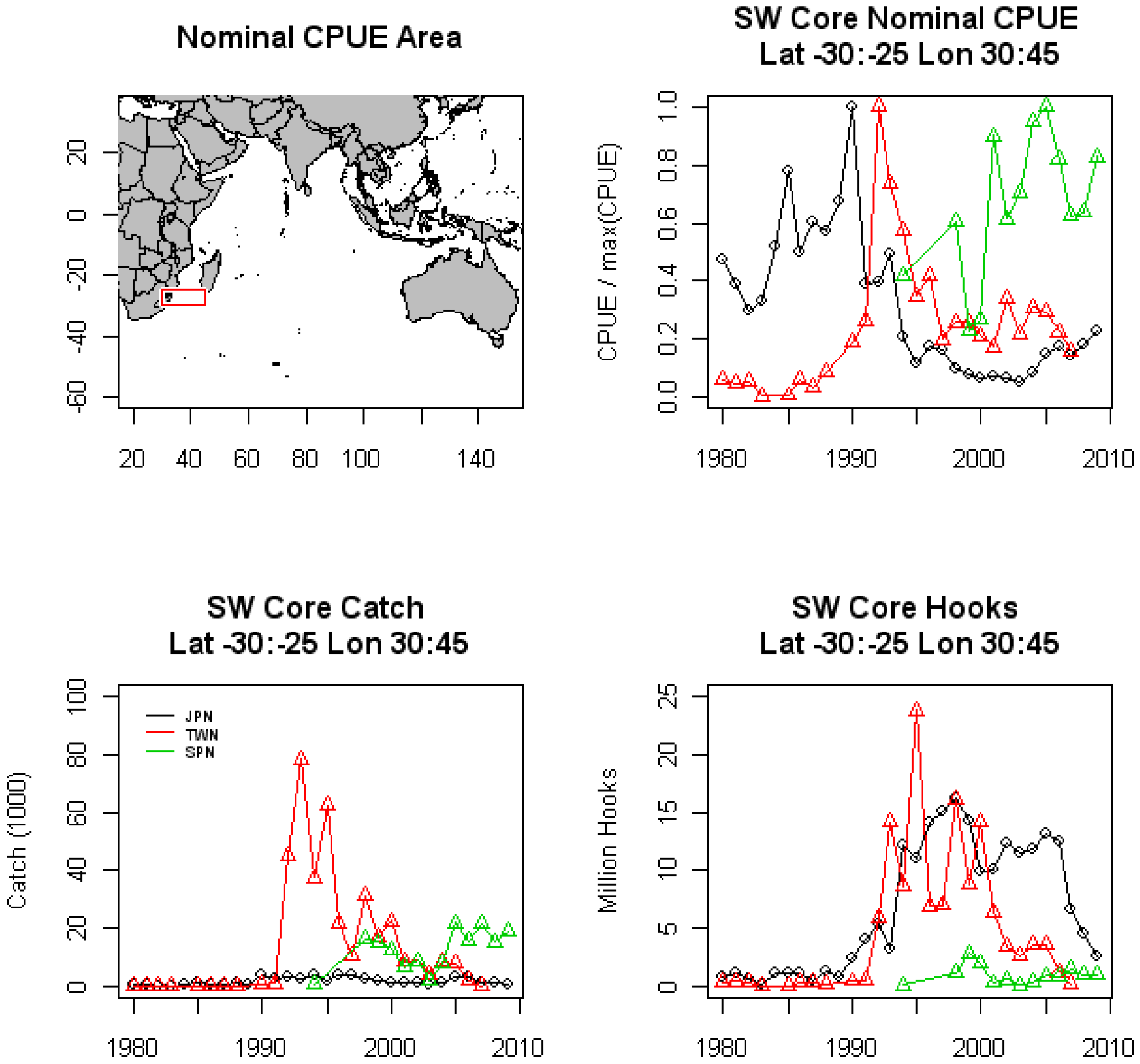


Figure 9. Time series of JPN, SPA and TWN longline swordfish Catch, Effort and Nominal CPUE (effort-weighted) in the (approximate) South-West core area.

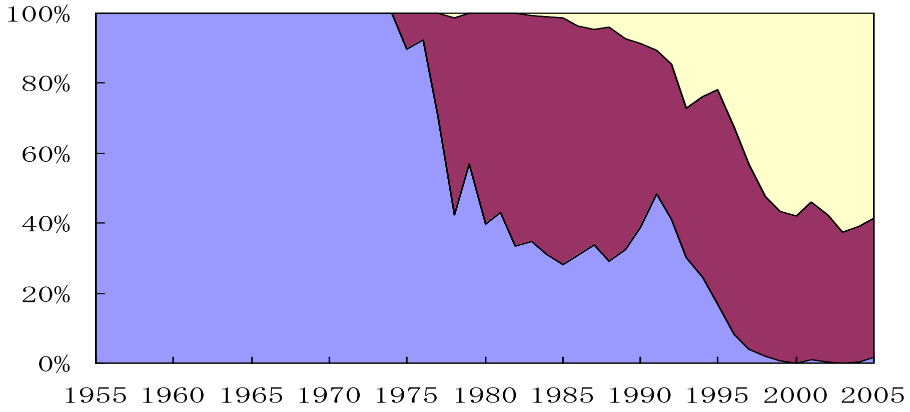


Figure 10. Changes in the gear deployed by the Japanese longline fleet over time. Blue (left) reflects <= 9 hooks between floats. Red (middle) reflects 10 to 14 hooks between floats and the yellow (right) indicated ≥15 hooks between floats (from Nishida 2008).

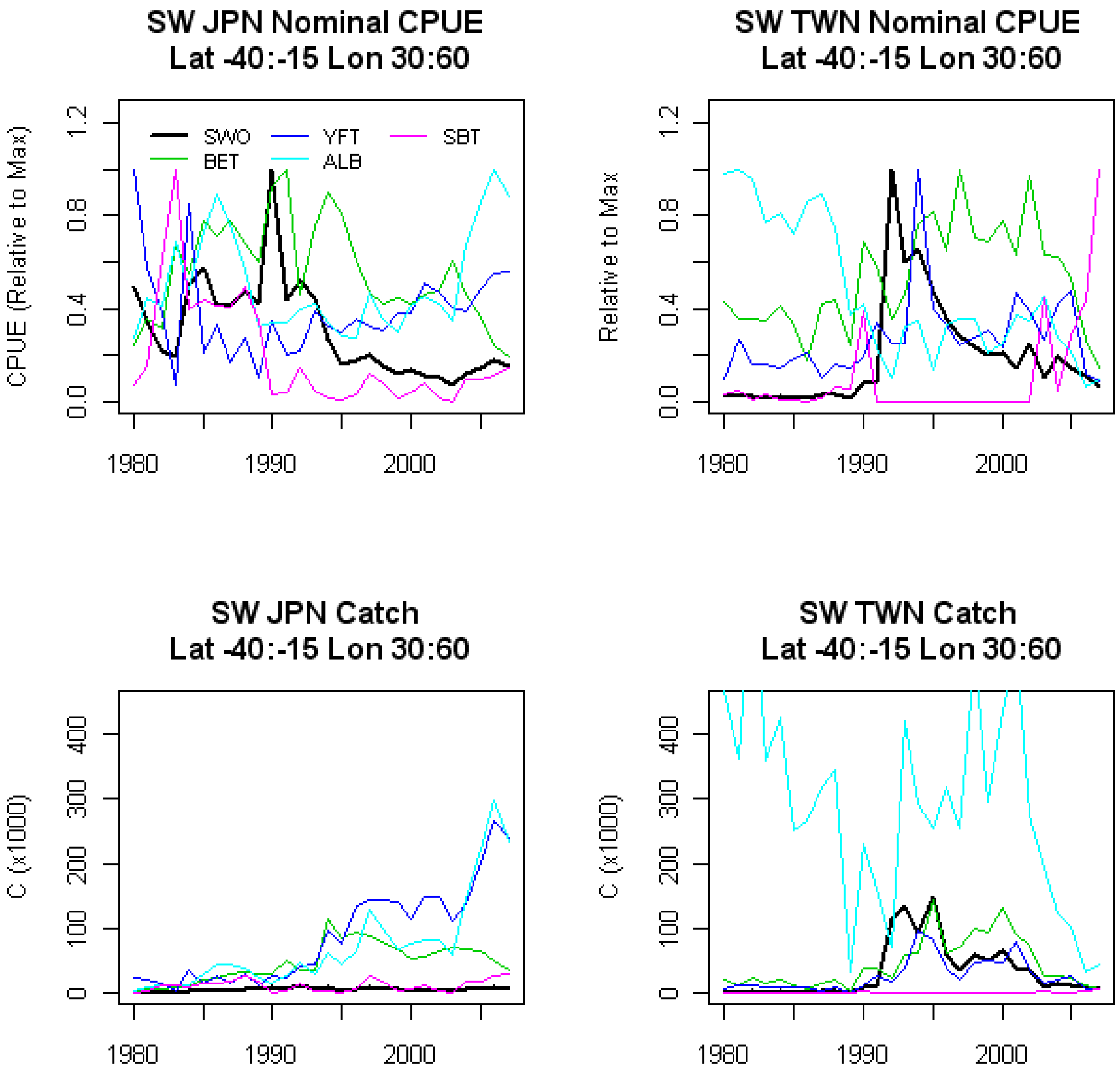


Figure 8. Time series of Japanese and Taiwanese longline nominal CPUE and Catch for the 5 main species from the SW region of the Indian Ocean (e.g. shown in fig. 5).

Attachment A. Is the inclusion of environmental data in a GLM standardization likely to be informative? A quick experiment with the Seychelles industrial LL fleet.

Table A1 describes the results of 6 GLM CPUE standardization models, explored during the WPB 2010. The set by set data from the Seychelles industrial fleet for the period 2005-8 were used from the Seychelles region (as defined in Kolody et al. 2010). The modelling was undertaken to test the relative importance of environmental covariates and fixed spatial effects, and to see whether significant environmental effects would be identified for spurious reasons. Environmental variables were adopted in a manner similar to that used in the JPN and TWN CPUE standardization analyses (Nishida and Wang 2009).

Results suggested that the environmental covariates could be identified as statistically significant for spurious reasons (i.e. some were identified as significant even when displaced 30° in space and 20 years in time). Using a grid of fixed spatial effects seemed to have more explanatory power than the environmental factors. It was noted that there was an error (minor spatial displacement?) in the environmental data provided for this analysis, but there is no reason to expect that this would qualitatively change the conclusions.

Table A1. Total explained variance and statistical significance of individual environmental covariates from GLM CPUE analysis for years 2004-8.

	MODEL					
Covariate	**Y + M**	**Y+M +E04NW**	**Y+M +E84NW**	**Y+M +E84SE**	**Y+M +Emean**	**Y+M+I55**
R^2	0.074	0.076	0.079	0.077	0.076	0.085
SC	NA			**		NA
AM	NA	.	**			NA
S45	NA	.				NA
T45	NA		.	.		NA
TD	NA		.			NA
TG	NA					NA
SG	NA		**	.		NA
I55	NA	NA	NA	NA	NA	***

Significance codes: <0.001= ‘***’; >0.001= ‘**’; >0.01= ‘*’; >0.05= ‘.’; >0.1= ‘ ‘

Dependent variable = $\log_e$(CPUE+C), where C = the lower 10th %ile SWO CPUE, and CPUE was by set.

Explanatory variables: (environmental variables were not interpolated)

- Y = year, M = month,
- I55 = 5x5 degree fixed spatial factor
- E04NW = environmental variables from the correct years and location
- E84NW = environmental variables from the period 20 years before the CPUE observations, correct location
- E84SE = environmental variables from the period 20 years before the CPUE observations, location displaced 30° S and 30° E of the CPUE observations
- Emean = multiyear average environmental variables (i.e. spatially resolved mean seasonality)
    - SC-sheer current
    - AM – amplitude of sheer current
    - S45 – salinity at 45m
    - t45 – temperature at 45m
    - TD – ?
    - TG – temperature gradient
    - SG –salinity gradient.