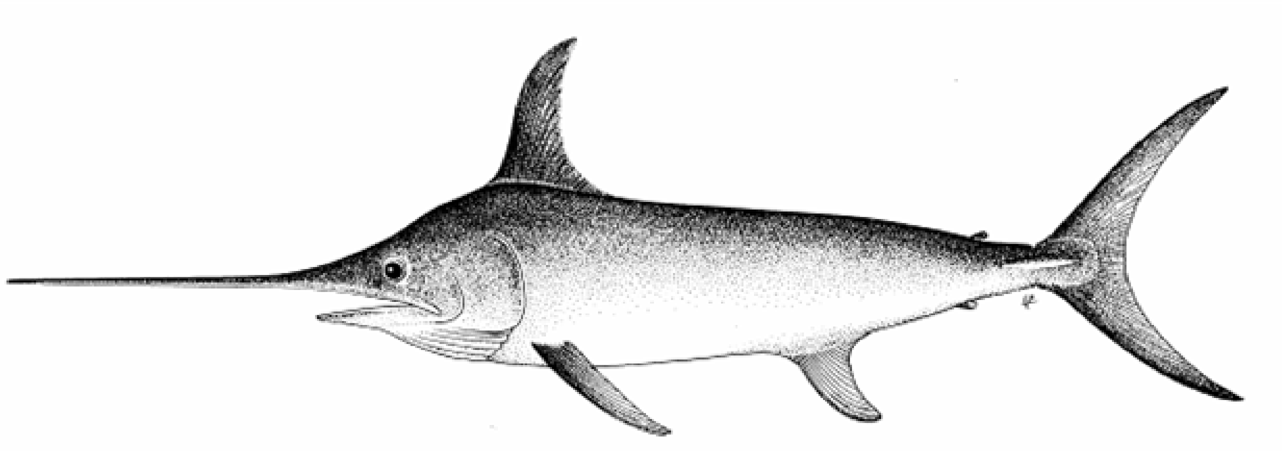
Western and Central Pacific Fisheries Commission

1st Meeting of the Scientific Committee of the
Western and Central Pacific Fisheries Commission
WCPFC–SC1
Noumea, New Caledonia
8–19 August 2005

WCPFC–SC1 **SA WP–6**

Annual indices of swordfish availability in the south-west Pacific



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1. Introduction

This paper is divided into the following sections.
1) Provides an annual index of swordfish availability within the main swordfish region (referred to as the Mooloolaba Grounds) off the east coast of Australia fished by the Australian longline fleet.
2) Provides an annual index of swordfish availability within four regions off the central east coast of Australia for the years 1997 to 2004 fished by the Australian longline fleet.
3) Provides an annual index of swordfish availability within six regions across the SW Pacific fished by the Japanese longline fleet.

2. Annual Indicator on the Mooloolaba Grounds

2.1 Definition of Mooloolaba Grounds

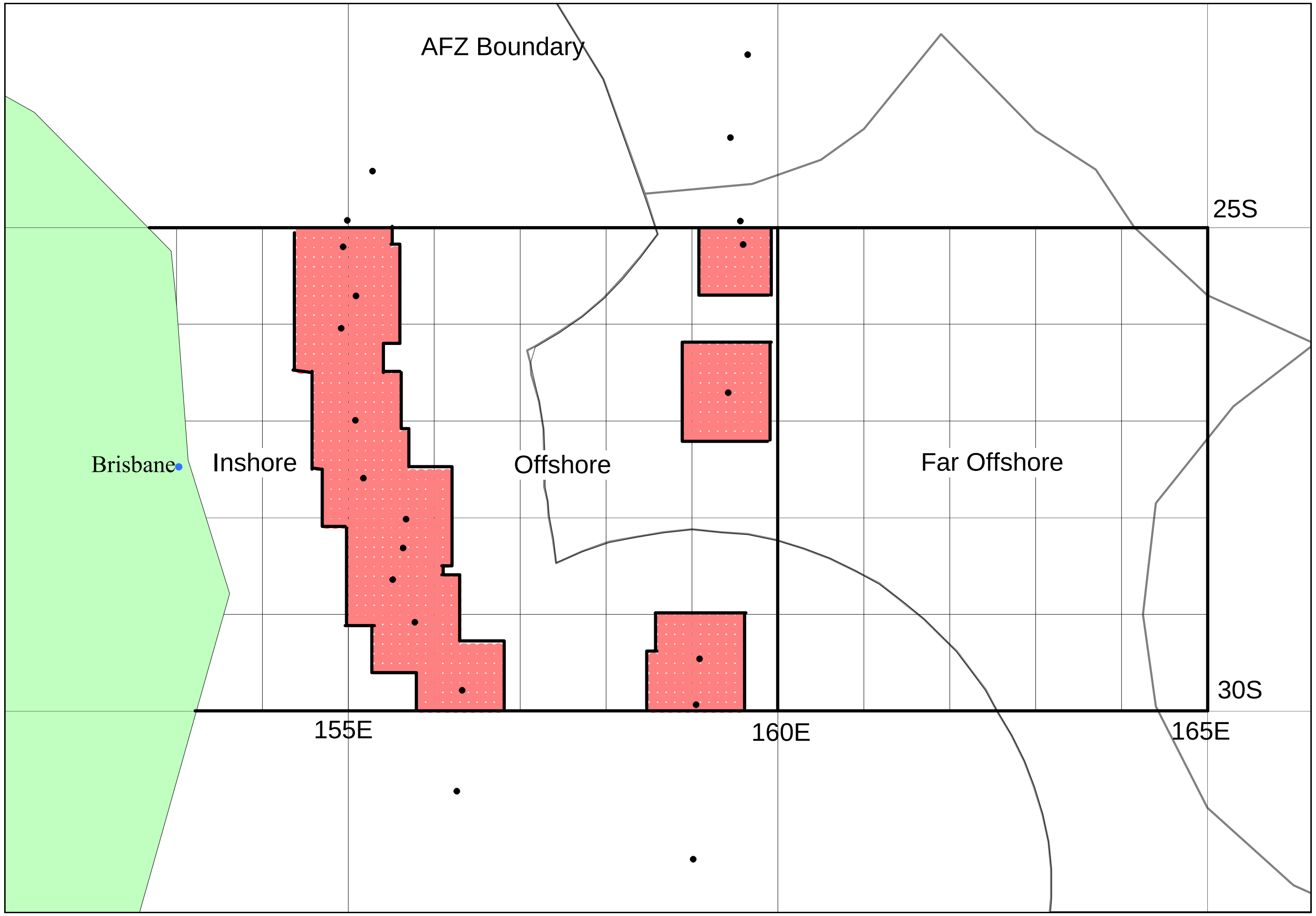
The region of interest is limited to between the latitudes 25-30°S and 160-165°E. This region is shown in Figure 1. As the principal fishing port for this fishery is Mooloolaba, we shall refer to this region as the Mooloolaba Grounds.

The annual catch of swordfish (number of fish) and associated effort within this region for Australian longliners is given in Table 1, together with the percentage this represents of the total catch and effort for the entire ETBF. Between 1997 and 2004 around 42% of all sets (45% of all hooks) in the ETBF were deployed on the Mooloolaba Grounds and the associated catch of swordfish represented 62% of the total swordfish catch for this period.

Table 1 Annual catch of swordfish (number of fish) and associated effort on the Mooloolaba Grounds, together with the percentage each represents of the total catch and effort for the entire ETBF.

Year	Sets	%ETBF	Squares	%ETBF	Hooks	%ETBF	Catch	%ETBF
1990	314	14%	33	36%	101,192	9%	28	7%
1991	179	5%	54	39%	122,638	7%	58	6%
1992	199	6%	57	45%	90,128	4%	24	3%
1993	165	6%	32	34%	67,710	4%	30	5%
1994	112	3%	43	33%	100,970	4%	103	9%
1995	527	10%	59	38%	358,078	9%	500	36%
1996	1,025	16%	59	36%	708,888	16%	6,349	70%
1997	3,036	35%	76	45%	2,408,882	38%	23,231	85%
1998	4,215	37%	86	42%	3,836,628	40%	23,446	67%
1999	4,790	41%	115	47%	4,500,628	44%	25,172	63%
2000	4,315	39%	125	50%	4,080,545	43%	22,660	60%
2001	4,784	38%	116	50%	4,595,031	41%	17,404	53%
2002	5,754	45%	117	46%	5,730,901	48%	21,622	60%
2003	6,704	51%	118	44%	6,868,590	54%	17,950	61%
2004	4,672	44%	119	46%	4,631,758	47%	13,601	52%
Tot 97-04	38,270	42%			36,652,963	45%	165,086	62%

Figure 1 Location of seamounts within the "Brisbane Grounds" and the associated regions of influence around each seamount (1-degree squares centered on seamounts and indicated by the shading) used in the analyses described in the text. The displayed grids are one-degree square.



2.2 Spatial Strata on Mooloolaba Grounds

Information on the spatial location of seamounts within the Mooloolaba Grounds was used to divide the total region into five sub-regions or areas. These were based on defining an area of influence around each seamount extending one degree in both an east-west and north-south direction and centered on each seamount, and dividing the total region into three main regions (inshore, offshore, and far-offshore). The five areas were then defined as follows:

1) In-Off — Inshore of the inshore chain of seamounts,

2) In-On — Within the influence of the chain of inshore seamounts,

3) Off-Off — Between the inshore chain of seamounts and 160°E and not within the influence of the offshore seamounts,

4) Off-On — Between the inshore chain of seamounts and 160°E and within the influence of the offshore seamounts,

5) Far-Off — East of 160°E.

These five areas are also shown in Figure 1. The relative size of each area was calculated by totaling the number of grids (each one-tenth of a degree square) comprising each area. The details are shown in Table 2 and indicate that the total area of influence around seamounts accounts for around 27 percent of the total area.

Table 2 Identification and relative size of the four areas used in the analysis of data on the Brisbane Grounds. Note the short name given to each area is those used refer to that area in the rest of this chapter.

Area	Name	Short Name	Number of grids	Relative Size
1	Inshore –Off seamount	In-Off	789	13.4%
2	Inshore – On seamount	In-On	591	10.0%
3	Offshore –Off seamount	Off-Off	1741	29.6%
4	Offshore – On seamount	Off-On	269	4.6
5	Far-Offshore	Far-Off	2500	42.4%
Total			5890	100.0%

2.3. Selection of Vessel, Fishing Gear and Environmental Factors

For the period of interest (1997–2001) two different logbooks have been used by the domestic longline fleet (AL04 and AL05). The information requested to be recorded for each logbook has varied to some extent between these two logbooks, and given that some fields on logbooks are sometimes not filled in, the time-series of data for some of the auxiliary gear information is not complete across entire period of interest. Because of these limitations, only the data on start set time, number of hooks deployed, number of lightsticks used, number of hooks-between-floats (referred to subsequently as HPF), bait-type used and the indicated target species were used in the subsequent analyses. Furthermore, in order to ensure a reasonable data coverage for each vessel, only the top 50 vessels ranked by the number of sets deployed within the Mooloolaba Grounds (and for which all the previously mentioned data were available) between 1997 and 2004 were used. Collectively, these 50 vessels accounted for 23,449 (66.4%) of the 36,980 sets from 197 vessels having the required information in this region between 1997 and 2004. (Note, in total there are 36,980 sets for 203 vessels).

Various other data were also acquired in order to provide additional information on the environmental conditions prevailing at the time of individual sets. These data related to:

1) Sea-surface temperature (SST) based 3 day composites, centered on the specified date, and a 2d linear interpolation on the surrounding grid points where the SST product used has a resolution of 0.036 degrees latitude and 0.042 degrees longitude,
2) the daily phase of the moon, and
3) the monthly Southern Oscillation Index.

Finally, in order to assist in summarizing the data and facilitate later analysis of the data, a range of categories were developed for many of the selected variables. These categories are shown in Table 3, together with the number of observations (individual longline sets) within each category. For some of these categories there is a one-to-one correspondence with a single value for the associated variable (ie. number of hooks-per-basket). However, most categories correspond to a range of values for the associated variable, such as all start times between midnight and 4am are put in a single category. Note: the species targeted categories are based on the principal target species identified by fishers in the logbook data. However, due to the fact that in most instances more than one species was identified, it was not possible to simply use a single species categorization only. In order to keep the number of categories manageable, all combinations for the three main target species only (swordfish, yellowfin and bigeye) were used. This gives a total of eight target species categories which are listed in Table 3.

2.4. Annual Change in Fishing Practices and Catch

For each area the annual distribution of sets within each of the selected operational and environmental categories listed in Table 3 is shown in Appendix A, while the percent of sets each year comprised of different proportions of the four main target species is shown in Appendix B. A number of notable changes are apparent.

Area 1: Inshore – Off Seamount

The target species information indicates a gradual increase over time in the targeting of both yellowfin only and combined yellowfin and bigeye sets. The percent of total sets in any year not including swordfish as a target species increases from around 26% in 1997 to around 56% in 2003, while the percent of total sets in any year including swordfish as a target species decreases from around 55% to around 23%. Corresponding to this change in target practices, the percentage of sets deployed between 4am and noon increases from around 5% in 1997 to 31% in 2003 and 2004 while the proportion of sets deploying 8 hook-per-float increases from 6% in 1997 to 60% in 2004. Lightstick usage also decreased (the proportion of sets deploying no lightsticks increased from 6% in 1998 to 25% in 2004) while use of squid bait also decreased (from over 80% in 1998-99 to 43% in 2004). Given these changes, there is a large shift in the mean catch composition, with the proportion of sets not catching swordfish increasing from less than 20% to over 50% and the proportion of sets with yellowfin comprising more than 80% of the catch increasing from less than 20% to over 80% (Appendix B(i)).

Area 2: Inshore – On Seamount

The change over time in operational practices are less pronounced than the changes seen in Area 1. While the proportion of sets in any year not including swordfish as a target species increased from less than 10% in 1997 to around 40% in 2003 (and the percent of total sets in any year including swordfish as a target species decreased from around 81% to around 34%), the proportion of sets deployed after 4pm remained relatively constant over this period (averaging around 78%). Furthermore, while the proportion of sets deploying 8 hook-per-float increased almost doubles between 1998 and 2004, the use of lightstick remained relatively stable while only in 2004 is there a notable change in the use of squid bait. Given these

Table 3 Factors (with category levels) and covariates used in the GLM analysis.

Factor	Level	Category	Number of Sets
Vessel	1 to 50	50 vessel identifiers	na
Year	1	1997	1191
	2	1998	2113
	3	1999	2738
	4	2000	2982
	5	2001	3240
	6	2002	3682
	7	2003	3934
	8	2004	2935
Quarter	1	Jan-Mar	4193
	2	Apr-Jun	4972
	3	Jul-Sep	7283
	4	Oct-Dec	6367
Area Fished	1	Inshore, off seamount	7551
	2	Inshore, on seamount	3646
	3	Offshore, off seamount	8437
	4	Offshore, on seamount	527
	5	Far Offshore	2654
Start Time	1	before 4am	2072
	2	4am to 8am	757
	3	8am to noon	808
	4	noon to 4pm	1688
	5	4pm to 8pm	13072
	6	8pm to midnight	4418
Bait	1	squid, dead	19251
	2	yellowftail scad, alive	510
	3	pilchard, dead	170
	4	other, dead	371
	5	other, alive	320
	6	mixed species, dead	1590
	7	mixed species, alive & dead	603
Hooks-per-Basket	1	HPB = 5 and below	626
	2	6	1423
	3	7	1491
	4	8	10164
	5	9	1249
	6	10	5409
	7	11	159
	8	HPB = 12 and above	2294
Hooks with Lights	1	0%	1332
	2	1 to 19 %	350
	3	20 to 39 %	1268
	4	40 to 59 %	9808
	5	60 to 79 %	1617
	6	80 to 99 %	1299
	7	100%	7141
Species Targeted	1	None	5259
	2	YFT only	2014
	3	BET only	595
	4	SWO only	2698
	5	YFT and BET	1591
	6	YFT and SWO	2927
	7	BET and SWO	1723
	8	YFT, BET & SWO	6008
Sea-Surface Temp	1	sst<-1sd	3397
Temperature	2	:-1sd<sst<-0.3sd	6072
(standardised)	3	sst<abs(0.3sd)	4810
	4	0.3sd<sst<1sd	3982
	5	sst>1sd	4554
Southern Oscillation	1	soi<-1sd	1302
Index	2	:-1sd<soi<-0.3sd	6726
(standardised)	3	soi<abs(0.3sd)	7433
	4	0.3sd<soi<1sd	0
	5	soi>1sd	7354
Number of other	1	0	8924
vessels fishing same	2	1	5435
1-degree square on	3	2	3336
same day	4	3	2072
	5	3 or more	3048
Number of other	1	0 to 2	3616
vessels fishing same	2	3 to 5	4328
1-degree square during	3	6 to 8	3870
same month	4	9 to 11	3478
	5	12 or more	7523
Moon-phase (days since full moon)	covariate	abs(cos(moon*3.14152/29))	22815

changes, there is a decrease in the proportion of sets mainly composed of swordfish and a corresponding increase in the proportion of sets mainly composed of either yellowin or bigeye tuna (Appendix B(ii)).

Area 3: Offshore – Off Seamount

The changes in this area are again less pronounced than the two inshore areas. Whilst the proportion of sets targeting all three species remains relatively stable over the whole period, the proportion of sets not targeting swordfish has increased significantly only during the last two years to average around 19%. There has been an increase in the proportion of sets deployed between 8pm and midnight (rising from around 5% in 1997 to 30% in 2003) offset by a decrease of sets deployed in the early morning. As with the two inshore areas there has been a significant increase in the proportion of sets deploying 8 hooks-per-float, though the usage of lightsticks has been relatively stable, as has the use of squid as the dominant bait type (with a change in 2004 only). As with area 2, there has been a shift in the catch composition with an increase yellowfin and bigeye tuna dominating the catch.

Area 4: Offshore – On Seamount

During 1997 and 1998 most sets (around 70%) solely targeted swordfish. While swordfish remains the principal target species in recent years it is targeted in combination with either yellowfin or bigeye (with such sets comprising around 70% of all sets). Evening remains the dominant start time, as does the use of squid (which a similar drop in 2004 seen in the other areas), though the percentage of sets with total lightstick coverage has decreased from near 100% to around 40% in recent years, the shift being mainly to using lightsticks on around half of the hooks deployed. The most significant shift in catch composition has been an increase in the proportion of yellowfin tuna and a corresponding decrease in swordfish. The proportion of bigeye tuna in the catch has remained relatively constant over time.

Area 5: Far Offshore

Swordfish is the predominant target species in this area, though as with area 4 the proportion of sets indicating that swordfish is targeted in combination with yellowfin and bigeye has increased over time (accounting for around 60% of all sets in 2004). Most sets have been deployed between 4-8pm during all years and squid continues to be the preferred bait-type, though there has been a decrease in the total coverage of hooks with lightsticks, with around 40% of sets having a coverage rate of between 40-80%. As with area 4, there has been an increase in the proportion of yellowfin tuna in the catch and the proportion of bigeye tuna remains similar over time.

2.5. Standardisation of CPUE

The previous sections have provided a qualitative analysis of the relationship between fishing practices and the selected targeting of the principal catch species, and changes in fishing practices over time. Here we provide a quantitative analysis of the importance of each of these factors (and others) in influencing the catch rates of swordfish on the Mooloolaba Grounds. In so doing we also provide an annual index of availability (or abundance) of swordfish to the fishery in this region based on the standardisation of the swordfish catch rates for each set.

For the following analysis it is assumed that the swordfish catch related to a given level of effort deployed by a domestic longline vessel operating on the Mooloolaba Grounds has a Negative Binomial distribution. This is a generalisation of the Poisson distribution assumed in the previous analysis and assumes that the variance observed in the catch has a linear relationship with both the mean of the catch and the square of this mean (for a given effort). The Negative Binomial model allows the inclusion of the zero catch information in the data since zero is a legitimate response value from this distribution (unlike the log-normal and gamma distributions often used in similar types of analyses). Assuming then that the catch, C, has a Negative Binomial distribution with mean μ, and using a log link between this mean and the linear predicator of standardising factors, the fitted model will have the following form:

$$\log(\mu) = \log(E) + LinearPredictor(Factors)$$

The logarithm of the effort, E, is used as an offset, that is a regression variable with a constant coefficient of 1 for each observation. The log link function ensures that the mean catch for each combination of factors will be positive.

The linear predictor of explanatory factors includes the following terms:

1) Year
2) Quarter
3) Area Fished
4) Vessel
5) Hooks-per-float (HPF)
6) Percentage of hooks with light-sticks
7) Start-time of set
8) Bait-type used
9) Species targeted
10) Sea-surface temperature (SST)
11) Monthly Southern Oscillation Index (SOI)
12) Daily level of moon light – based on Moon-phase

Each of the factors 1-10 were fitted as categorical variables with the associated levels for each factors being those described in Table 3. The variable used to measure the daily level of moon light was based on the following transformation of the daily moon-phase (which was based on the number of days since the last full moon with Moon-Phase=1 corresponding to the day of the full moon):

Level of Moon Light = abs[cosine((Moon-Phase-1)*Π/29)

This results in a variable which varies between 0.05 and 1.

Two additional terms were also added to help account for the influence of cooperative or competitive factors between vessels.

13) The number of other vessels fishing in the same 1x1-degree / day strata.
14) The number of other vessels fishing in the same 1x1-degree / month strata.

Again, each of these factors fitted as a categorical variable with the associated levels for each factor being those described in Table 3.

The form of the model fitted to the data was as follows:

$$\begin{aligned} log(Catch_i) = {} & log(Effort_i) + Year_i * Quarter_i * Area_i \\ & + Vessel_i + HPB_i + Light\text{-}Sticks_i + Start\text{-}Time_i + Bait_i + Target_i \\ & + Moon_i + SST_i + SOI_i + \\ & + Day\_Comp_i + Mon\_Comp_i \end{aligned}$$

where the subscript *i* refers to the appropriate categorical level and value of the covariates corresponding to the *i-th* data record. A backwards stepwise fitting procedure was used to fit the model, with a each step the least significant factor removed until all remaining factors were found to be significant (at the 0.10 level).

Table 4 GLM results of fitting the Model.

Fitted Variable	df	Type 3 Analysis ChiSq	Pr>ChiSq
Year*Quarter*Area	154	4639.25	< 0.0001
Vessel	49	1005.08	< 0.0001
Species Targeted	7	2492.31	< 0.0001
Hooks with Lights	6	341.39	< 0.0001
Bait Type	6	136.71	< 0.0001
Start Time	5	580.98	< 0.0001
Hooks-per-Basket	7	71.66	< 0.0001
Moon Phase	1	873.94	< 0.0001
Sea-surface-temperature	4	80.00	< 0.0001
Southern Oscillation Index	3	11.83	0.008
Daily Vessels in Square	4	27.58	< 0.0001
Monthly Vessels in Square	4	9.20	0.0562
	250		

	df	Deviance	Deviance/df
Negative Binomial Model	22564	24782	1.0983
Normal Model	22564	18959	64.21%

The results after fitting the final form of the model are shown in Table 4. Based on the Type-3 analysis, apart from the 3-way *Year*Qtr*Area* interaction term, the factor which explains the largest degree of deviance in the data is the Species Targeted factor, followed by the Vessel factor. Moon Phase, Start-time and the percentage of hooks having lightsticks were also found to be major explanatory factors, while the Southern Oscillation Index and the number of other vessels fishing the same square per month had the least explanatory power. In order to estimate the explanatory power of the model, a similar model was fitted using a Normal Distribution. The result of this fit indicated an R^2 of around 64 percent, indicating a large degree of the variation in the data has been explained by the model.

2.6 Influence of Factors on Swordfish Catch Rates

The relative influences of each level of the categorical factors on the catch rate of swordfish are shown in Figures 2 and 3. For each factor, the influence of each level is relative to a selected level – the value of which is set equal to 1. For example, for the Lightstick factor, the influence of each level is relative to the central level (40-59%). It is seen that the catch rates increase as the percentage of hooks with lightsticks increases, with sets deploying lightsticks on all hooks achieving catch rates around double the catch rates achieved on similar sets deploying no lightsticks.

There is seen to be a large degree of variation in the relative influence of the 50 vessels on catch rates, with some vessels having an influence on catch rates at least twice that of other vessels. The vessel factor acts as an amalgam for all factors specific to a vessel and its crew which contribute the fishing success associated with that vessel. Apart from the specific gear-related factors which have been fitted in the model, it will include a number of other factors such as the skill and experience of the crew in both finding productive areas to fish and the manner in which they use the vessel and the respective fishing gears.

Figure 2 Relative influences of various categorical factors on catch rates.

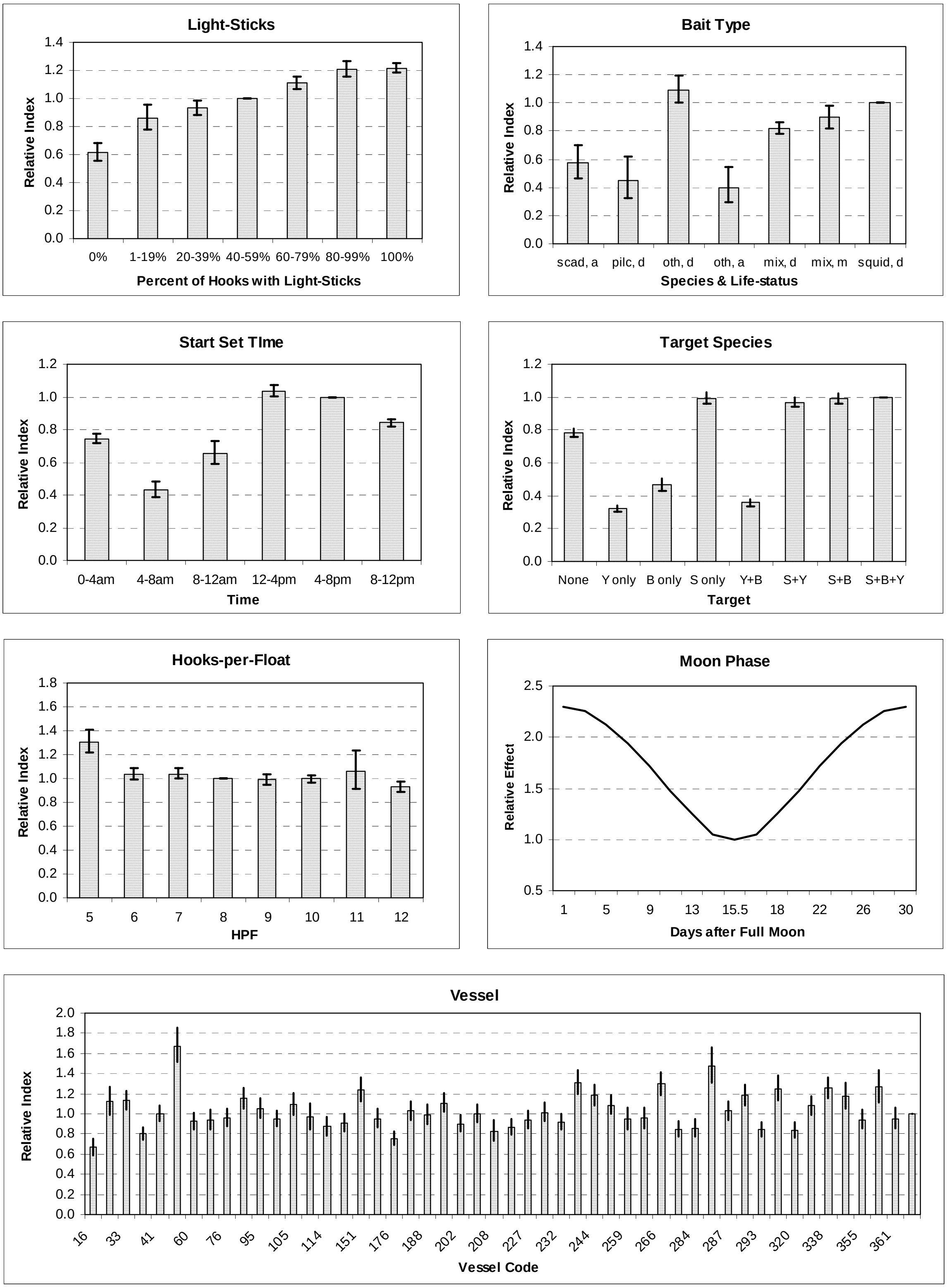
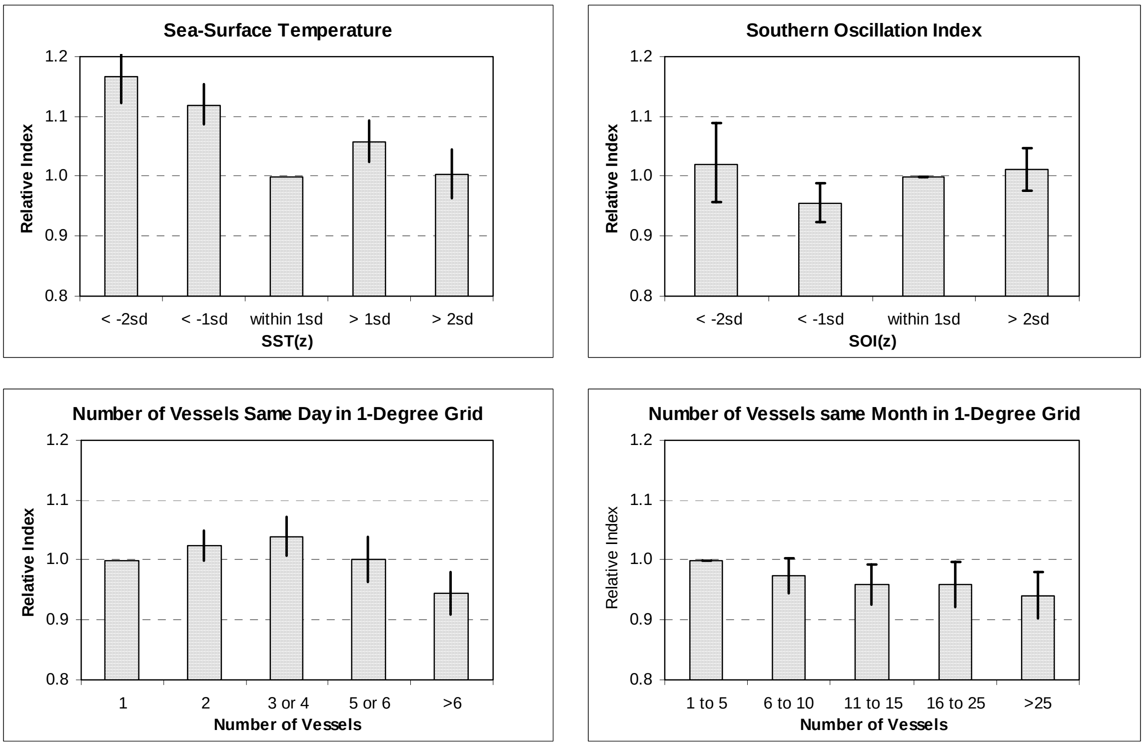


Figure 3 Relative influences of oceanographic and cooperative / competitive vessel numbers on swordfish catch rates.



For most of the operational factors fitted in the model there is a significant differences in relative catch rates dependent on the level of each factor. The strong influence of increased use of lightsticks has already been mentioned, while there is a strong diurnal cycle in relative swordfish catch rates, with catch rates being lowest for sets deployed between in the early morning (4-8am) and highest in the afternoon (no0n-8pm). Swordfish catch rates also vary significantly between bait-type used, which catch rates being highest with the use of squid and those classified as 'Other species'. On the other hand, catch rates appear to be relatively insensitive to the number of hooks-per-float deployed, but are highest for those sets using 5 or less. Historically, the number of hooks-per-basket has been used in standardized models as a proxy for depths fished, and is based on the shallow-versus-deep longlining practices of the Japanese. However, the result obtained here may indicate that this factor is not actually a good indicator of depth, as many other factors such as the degree of slack in the line also influence the depth to which a hook will sink. Finally, as would be expected, swordfish catch rates are seen to be highest in those sets where the target species includes swordfish.

In agreement with anecdotal reports, there is a significant influence of the phase of the moon on catch rates, with the results here indicating that catch rates obtained near a full moon are around 130 percent higher than those obtained around a new moon. The influence of the sea-surface temperature is also seen to be significant (cf. Figure 3), with the catch rates generally increasing with decreasing water temperatures. Catch rates also show some variation with the prevailing Southern Oscillation Index thought the nature of the this relationship is less clear.

The influence of the two 'vessel density' factors are also note-worthy. There is seen to be an almost linear decrease in catch rates associated with an increase in the density of vessels fishing in the same 1x1-degree / month strata. This decrease is around 5 percent for 10 or more additional vessels fishing in the same area / month. On the other hand, the alternative measure of daily vessel density shows a slight increase in relative catch rates when there are 2-4 other vessels in the area but a 5 percent decrease when more than 6 other vessels fish in the same area on the same day. Whether or not the slight positive effect is significant remains uncertain, but may be related to the ability of vessels to cooperate with each other or at least learn from the activities of other vessels. However, as with the previous factor, ultimately too much additional effort in the same area has a negative impact on catch rates.

2.7. Annual Index of Swordfish Availability

The *Year*Qtr*Area* parameters estimated by the GLM can be used to calculate a standardized catch rate in each area for each year and quarter. The corresponding results for the individual quarters can then be combined (by taking the geometric mean) to give a mean standardized catch rate in each area for each year. The resulting time-series of annual standardized catch rates for each area are displayed in Figure 4a. A relative index within each area can also be calculated by dividing the standardized catch rate for a given area and year by the corresponding catch rate for that area in the first year (1997). The relative index more clearly indicates the percentage change over time. Finally, a relative index for the entire region can be calculated by summing the relative indices for the five GLM areas, weighting each area by its spatial size. The relative indices for all areas and for the total region are shown in Table 5 and Figure 4b. (Note: there were little or no data for the Far-Offshore area in 1997 and as a result the value of the index for this region in 1997 was set equal to the value calculated for 1998. Similarly, there were little or no data for the Off-On area in the first and third quarters of 1997 and for the Off-Off area in the first quarter of 1997 and again the standardized catch rates in these area/qtr strata were set equal to the corresponding values in the next year.)

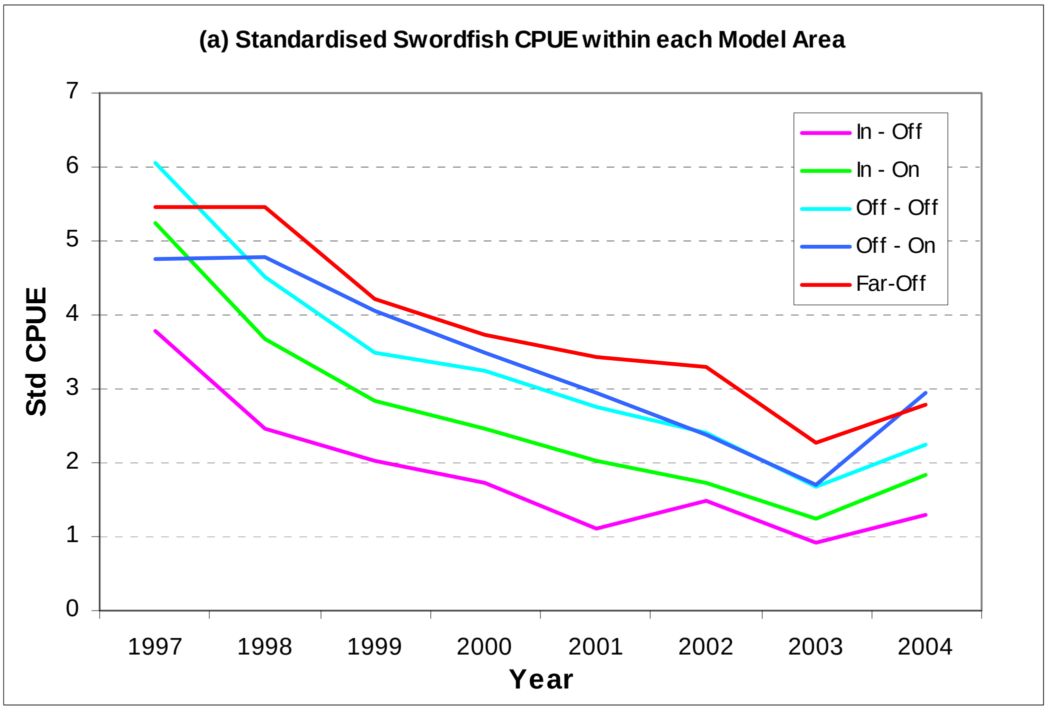
Table 5 Relative standardized CPUE indices for each area and year.

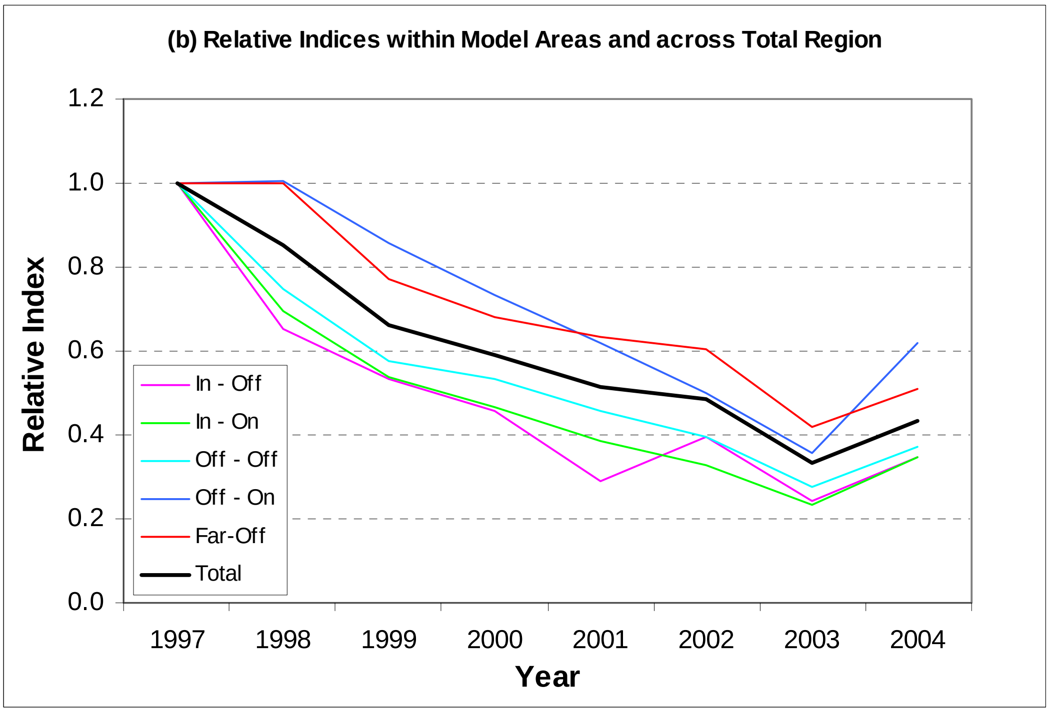
Year	GLM Area					Total Region
	In - Off	In - On	Off - Off	Off - On	Far-Off	
1997	1.00	1.00	1.00	1.00	1.00	1.00
1998	0.65	0.70	0.75	1.01	1.00	0.85
1999	0.53	0.54	0.58	0.86	0.77	0.66
2000	0.46	0.47	0.53	0.73	0.68	0.59
2001	0.29	0.39	0.46	0.62	0.63	0.52
2002	0.40	0.33	0.40	0.50	0.60	0.48
2003	0.24	0.23	0.28	0.36	0.42	0.33
2004	0.35	0.35	0.37	0.62	0.51	0.44

The standardized catch rates for all five areas show a systematic decrease between 1997 and 2003, with all areas also showing an increase in the last year (2004). This increase is greatest for the offshore / on-seamount area. A notable feature of the results shown in Figure 4a is that despite the fact that the parameterization of the GLM allows independent time-series of catch rates in each area, the change over time is found to be similar across all areas (ie the slope of the indices is similar in each area). This is despite the fact that the level of effort in each area is quite different. In 1997 the value of the standardized catch rates increases as one more further offshore and whether this is a reflection of a general increase in swordfish availability as one moves further offshore or due to 'depletions' in the two inshore areas due to previous fishing in these area remains unknown. However, given that the standardized catch rates in the two areas fished last (ie areas 4 and 5) are somewhat similar to the catch rates in the areas first fished near the beginning of the time-series (ie areas 2 and 3) it may be that the later scenario is more likely.

Since 1997 the three closest inshore areas (areas 1 2 and 3) all display a similar level of depletion over time, reaching between 23-28% of the 1997 level during 2003 then increasing to around 35% during 2004. On the other hand, the level of decline seen in the two areas

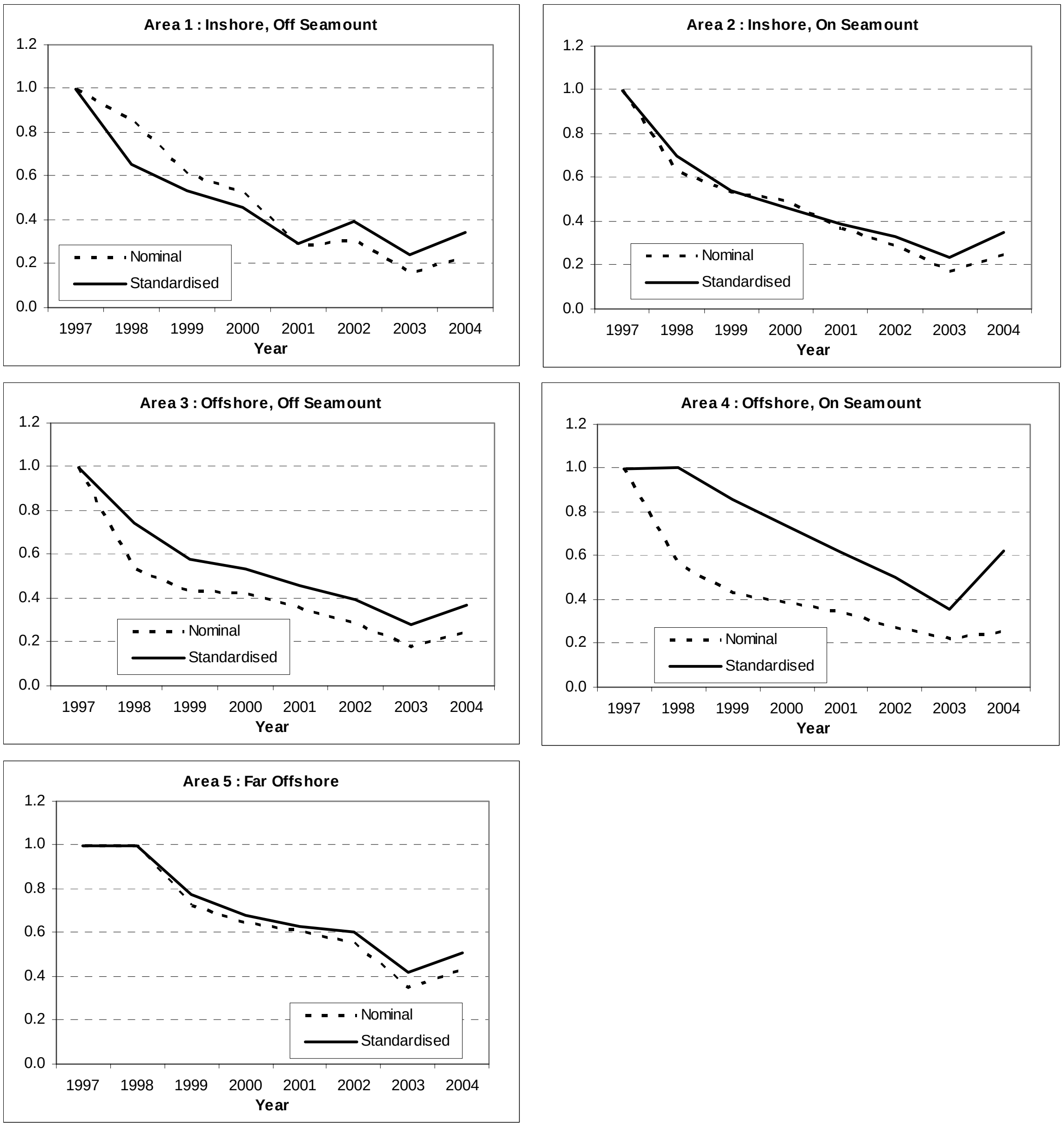
Figure 4 Time-series of (a) annual standarised CPUE, and (b) relative CPUE index within each of the GLM areas. A relative index is also shown for the entire region.





furthest offshore (areas 4 and 5) is smaller, with area 4 increasing from 36% to 62% between 2003 and 2004 and area 5 increasing from 42% to 51% respectively. The index for the total area declined to 33% of the 1997 level in 2003 before increasing to 44% in 2004. This index displays a relatively smooth decline between 1997 and 2002, a large decrease in 2003, followed by a smaller increase in 2004. The index value in 2004 appears to continue the trend line established before 2003, suggesting that the large decrease in 2003 may have been caused by factors other than fishing alone.

Figure 5 Comparison of the time-series of annual nominal CPUE and the standardised CPUE within each GLM area. Note, both time-series have been made relative to the value in 1997.



Finally, given the shifts over time in the operational characteristics of fishing operations (and corresponding shifts in catch compositions) in each area discussed previously, it is interesting to compare the nominal swordfish catch rate with the standardised swordfish catch rate. This is done in Figure 5. As expected, for all areas the decline in standardised catch rate is less than the decline in nominal catch rate. These differences indicate that there has been a decrease in effective swordfish effort relative to nominal effort in all areas over time – this is likely to reflect to decrease in the targeting of swordfish and the increase in the targeting of yellowfin and bigeye tunas discussed previously.

2.8 Alternative Models

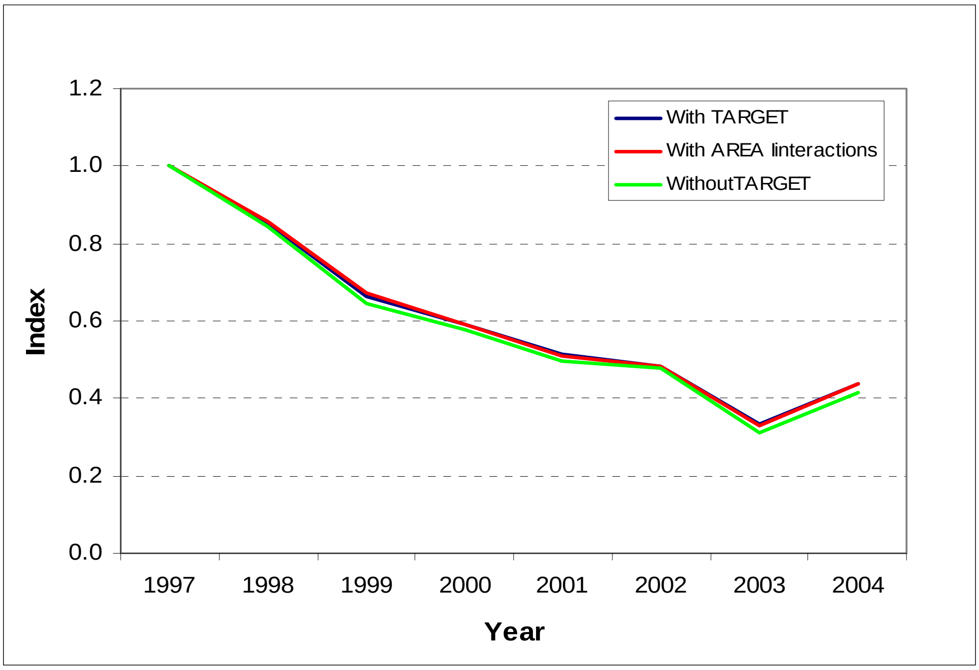
Two variations on the above model were also fitted to the data. These two models, and the rationale for their consideration, were as follows:

1) *AREA Interactions*
All explanatory factors in the base model (except the VESSEL factor) were crossed with the AREA factor. It is possible that the influence of the various gear setting and environmental factors may differ across the five areas. This may be due to the differences in the depths of habitats of the various target species due to differences in oceanographic conditions across the longitudinal gradient as one moves offshore and the consequent need to deploy fishing gears differently. For example, the East Australia Current is mainly a near-shore phenomenon.

2) *No TARGET factor*
The TARGET factor was removed from the base model. Fishers are asked to record on their logbooks the species being targeted for each individual set and this information was used in the base model to help differentiate the various types of sets. However, it is likely that the corresponding TARGET factor is correlated with different gear settings also included in the model. Furthermore, ideally the target species information should be filled just after the set is deployed, but if in fact this information is provided after the catch is hauled, and is consequently correlated with what was actually caught, then this factor is no longer serving the purpose for which is was designed (it will be highly correlated with the resulting CPUE but not be explanatory).

The resulting indices for the entire region based on each of the above two models are compared with that obtained for the base model in Figure 6. The indices for all three models are seen to be very similar.

Figure 6 Comparison of standardised indices of annual swordfish availability across the entire Mooloolaba Grounds for three different GLM models.



3. Annual Indicators off Eastern Australia

A stock assessment of swordfish in the south-west Pacific is currently being undertaken jointly by CSIRO in Australia and NIWA in New Zealand (Kolody et al, 2005). The stock assessment model to be used is spatially disaggregated with the SW Pacific divided into the seven spatial regions displayed in Figure 7. The Australian longline fleet fishes in regions 1, 2, 3, 4 and 6 and the catch and effort data for this fleet was used to calculate an annual index of swordfish availability in each region and to standardise the Australian fishing effort.

The analyses undertaken assumed the swordfish catch rates in each region have a log-Normal distribution and in order to allow inclusion of zero catch records a small constant, *k*, equal to 10% of the mean CPUE across all the data fitted, was added to each record. The following model was fitted to the data in each region:

$$log(Catch_i) + k = Year_i * Quarter_i + Latitude_i + Target_i$$
$$+ HPB_i + Light\text{-}Sticks_i + Start\text{-}Time_i + Bait_i$$
$$+ Moon_i + + SOI_i + Day\_Comp_i + Mon\_Comp_i$$

where *Latitude* refers to 1-degree strip of latitude within which the fishing observation occurred, while the other factors are as described in the previous section. The data fitted was filtered to exclude levels of each factor having only a small number of observations. In particular, all observations with a *HPB* level less than 4 or greater than 29 were excluded and all observations below a given *HPB* level were aggregated into a single level as were all observations above a given *HPB* level. Within each area the number of data points, the mean CPUE, and the resulting R^2 value of the fitted model is provided in Table 6.

Table 6 Summary of data fitted within each Area.

	Area 1	Area 2	Area 3	Area 4	Area 6	Total
N observations	13,075	45,646	14,205	1,587	9,701	74,224
Mean CPUE	1.23	2.72	6.97	10.94	0.994	3.17
R^2 - with TARGET	73.0%	54.9%	44.2%	38.2%	47.4%	65.1%
R^2 - with VESSEL						67.1%
R^2 - with *AREA						67.2%
R^2 - no TARGET	38.2%	37.9%	34.2%	31.1%	33.1%	51.8%

Due to the uncertainty in the validity of including the *Target* factor in the model (as described in the previous section), the data was also fitted to the above model with this factor removed. The standardised annual index was determined for each area and then compared with both the nominal CPUE and mean CPUE for each year. All indices were made relative to the initial year (1997) and the results are shown in Figure 8.

A similar model, but with the *Year*Quarter* factor also crossed with an *Area* factor, was also fitted simultaneously to the data for all five areas combined:

$$log(Catch_i) + k = Year_i * Quarter_i * Area_i + Target_i$$
$$+ HPB_i + Light\text{-}Sticks_i + Start\text{-}Time_i + Bait_i$$
$$+ Moon_i + + SOI_i + Day\_Comp_i + Mon\_Comp_i$$

The data fitted to this model was limited to those sets having a HPB level between 5 and 10 and deploying one of the six main bait types. Three variations on this model were also fitted to this combined data as follows:

2) a *VESSEL NAME* factor was included in the model
3) all additional factors in the original model were crossed with the *AREA* factor
4) the *TARGET* factor was removed.

A comparison of the standardized annual index for each model (relative to 1997) is shown in Figure 8.

Figure 7 Spatial regions in the SW Pacific to be used in swordfish stock assessment.

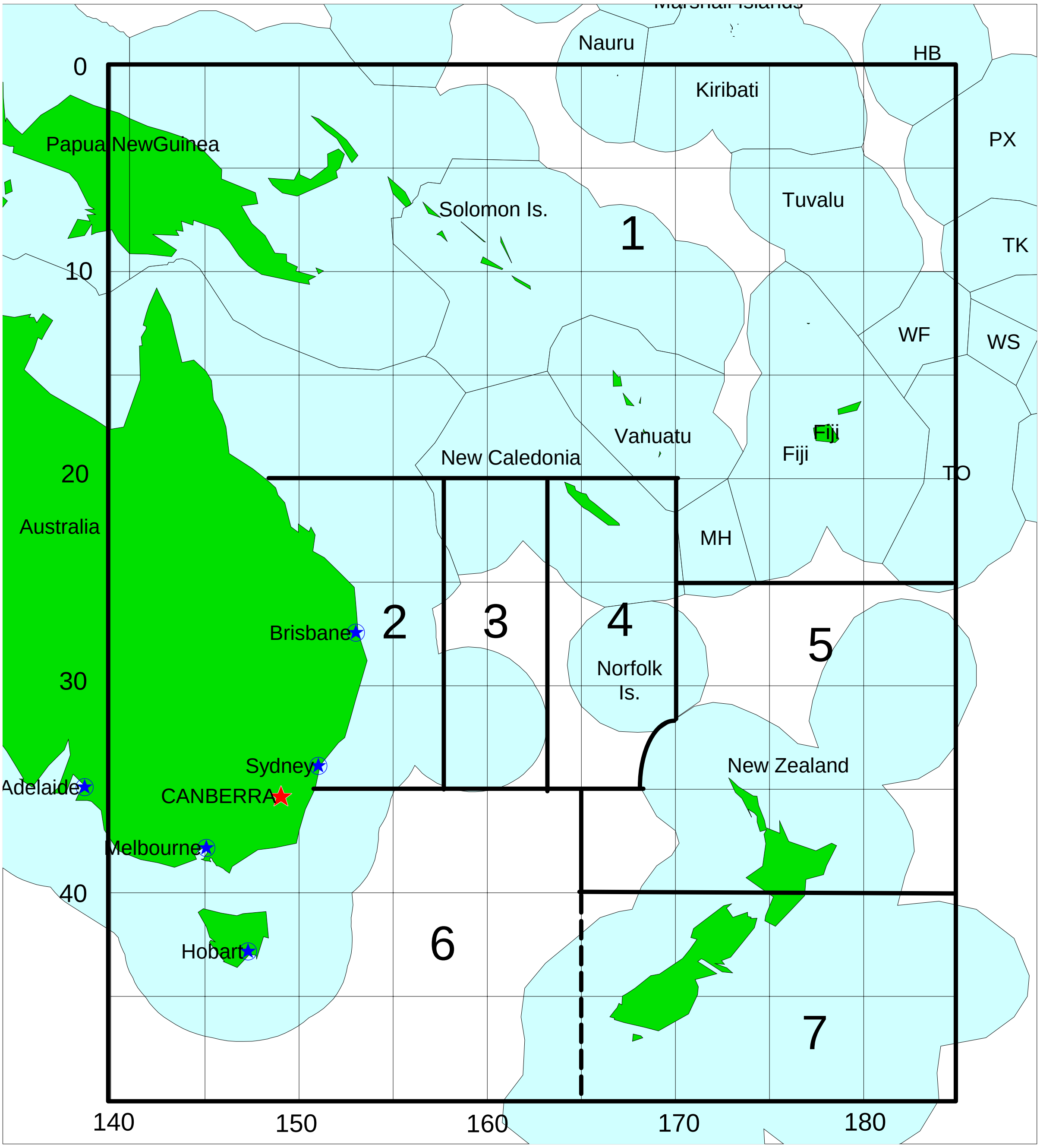
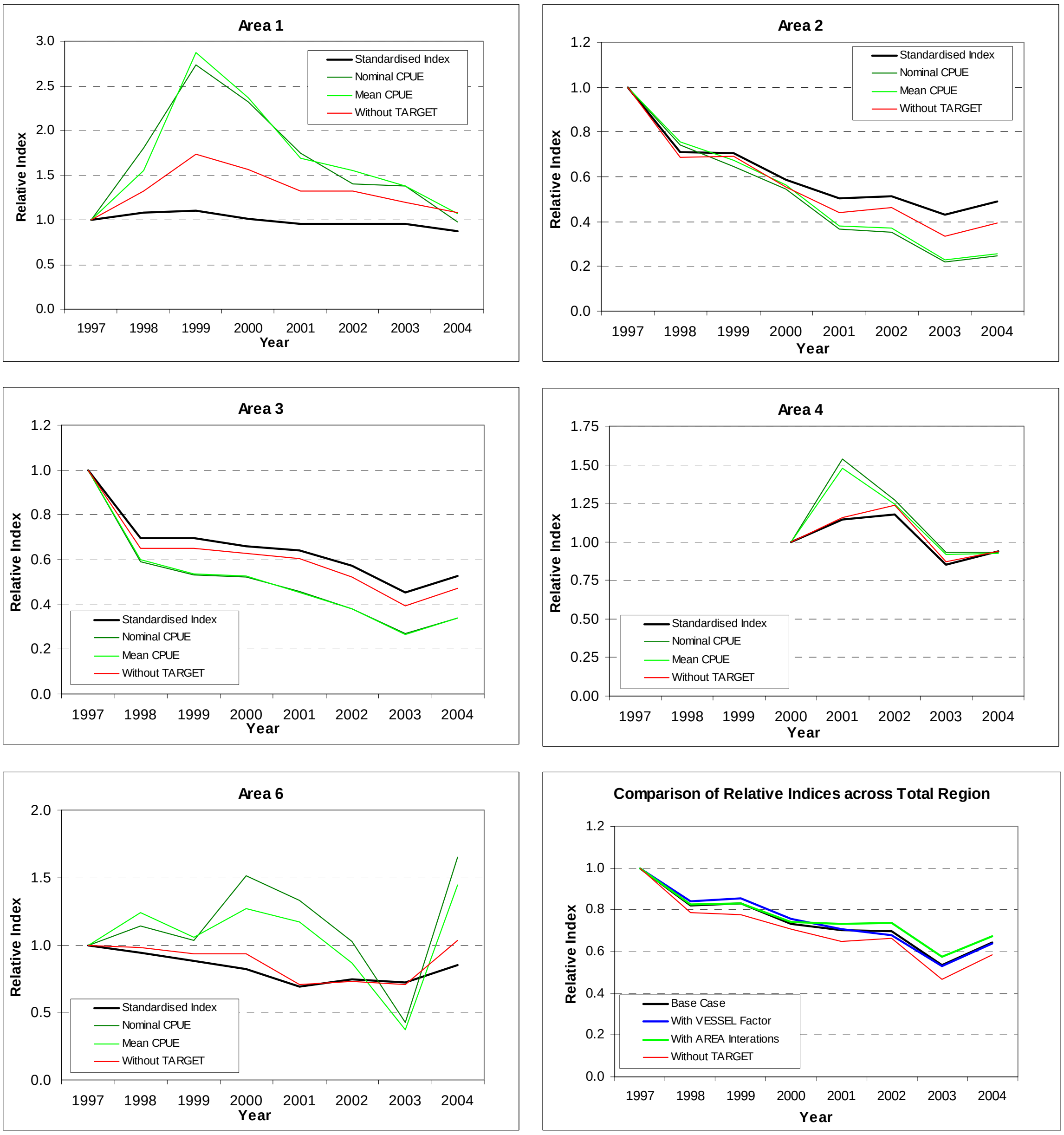


Figure 8 Comparison of indices of swordfish availability in the five regions fished by Australian longline vessels.



4. Annual Indicators within the SW Pacific

A similar analysis as for the previous section was undertaken using Japanese longline catch and effort data within each of the areas 1-6 in the SW Pacific. The data, kindly made available by the National Research Institute of Far Seas Research in Shimizu Japan, was aggregated by 1x1-degree square, month and number of hooks-per-basket and covered the years 1971-2003.

The analyses undertaken assumed the swordfish catch rates in each region have a log-Normal distribution and in order to allow inclusion of zero catch records a small constant, *k*, equal to 10% of the mean CPUE across all the data fitted, was added to each record. The following model was fitted to the data in each region:

$$log(Catch_i) + k = Year_i * Quarter_i + Five_i * HPB_i + SOI_i$$

where *Five* refers to the 5-degree strip of latitude within each area that the fishing occurred, all *HPB* observations were categorised into one of eight levels between 4 and 16, and SOI was fitted as a 5-level categorical factor. In order to remove outliers, generally being data with a small amount of effort, all observations having a CPUE>20 fish per 1000 hooks were excluded from the analysis. Within each area the number of data points, the mean CPUE, and the resulting R^2 value of the fitted model is provided in Table 7.

Table 7 Summary of data fitted within each Area for the Japan longline vessels.

	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6
N observations	49,813	7,744	8,080	3,908	5,697	13,514
Mean CPUE	0.12	1.26	1.03	1.34	0.76	0.38
R-square	6.4%	18.5%	21.1%	29.6%	17.0%	62.9%
Quarters used for Annual Index	All	2 & 3	All	1, 2 & 3	2 & 3	2 & 3

For each area, the standardised CPUE in each area was calculated for each year and quarter. This time series is compared with the nominal CPUE in Figure 9. The nominal time series extends back to 1952 and is based on the monthly 5x5-degree aggregated catch and effort data provided by SPC. The standardised CPUE was scaled so that the average CPUE over the period 1971-75 was equivalent to the average of the nominal CPUE over the same period. This was done so that the standardised effort time series, although based on the nominal CPUE before 1971, could be extended back to 1952.

Finally, an annual index of swordfish availability within each area was calculated by taking the geometric mean of the standardised CPUE across those quarters, indicated in Table 7, for which data was consistently available. A comparison of the annual index for the years 1980-2003 within each area is shown in Figure 10, while a comparison of the relative Japanese based index since 1997 with the corresponding Australian based index within three separate areas of the SW Pacific is shown in Figure 11.

Figure 9 Nominal and standardised catch rates for Japanese longline vessels within each of six areas in the SW Pacific.

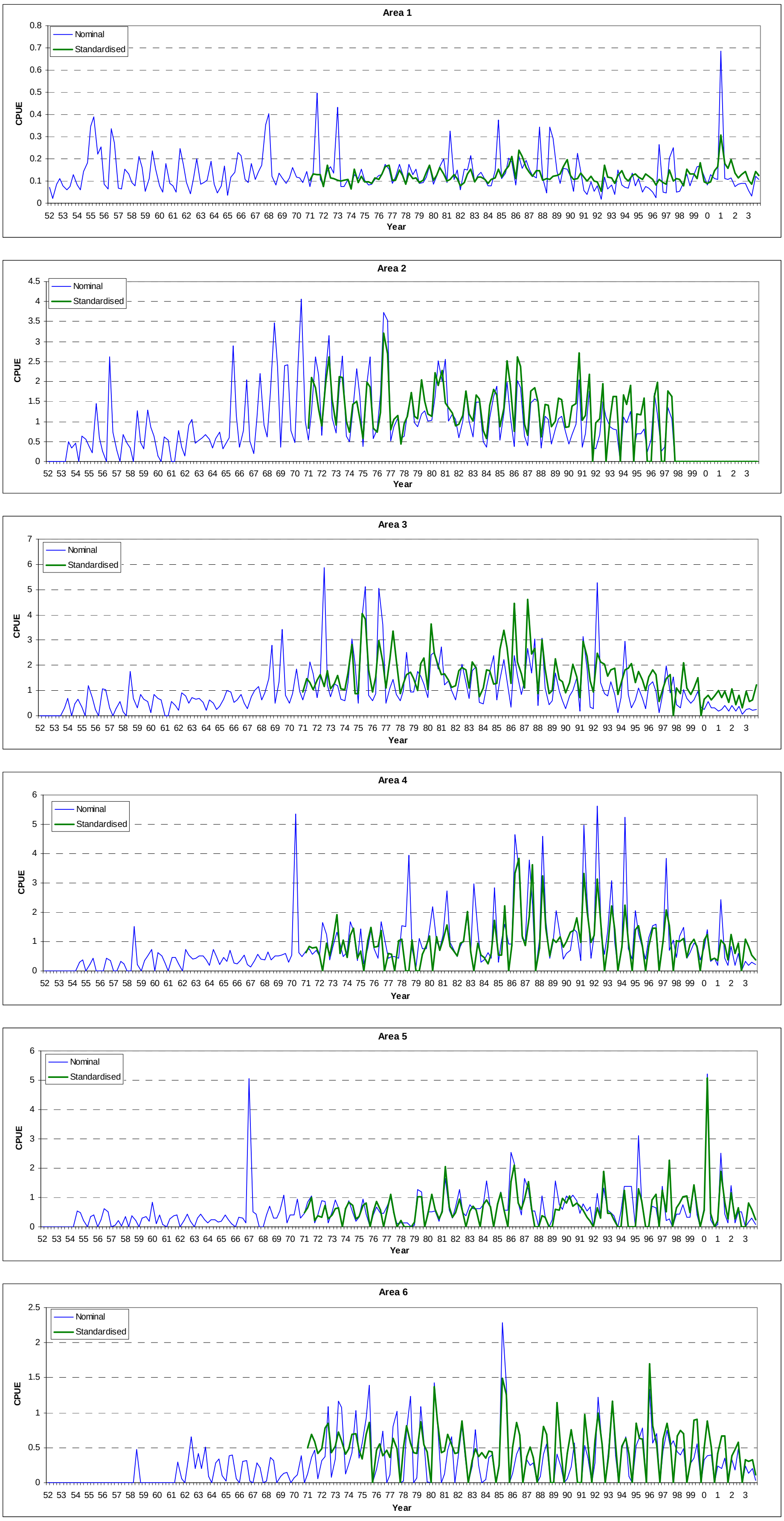


Figure 10 Annual indices of swordfish availability within various regions of the SW Pacific based on standardised Japanese CPUE.

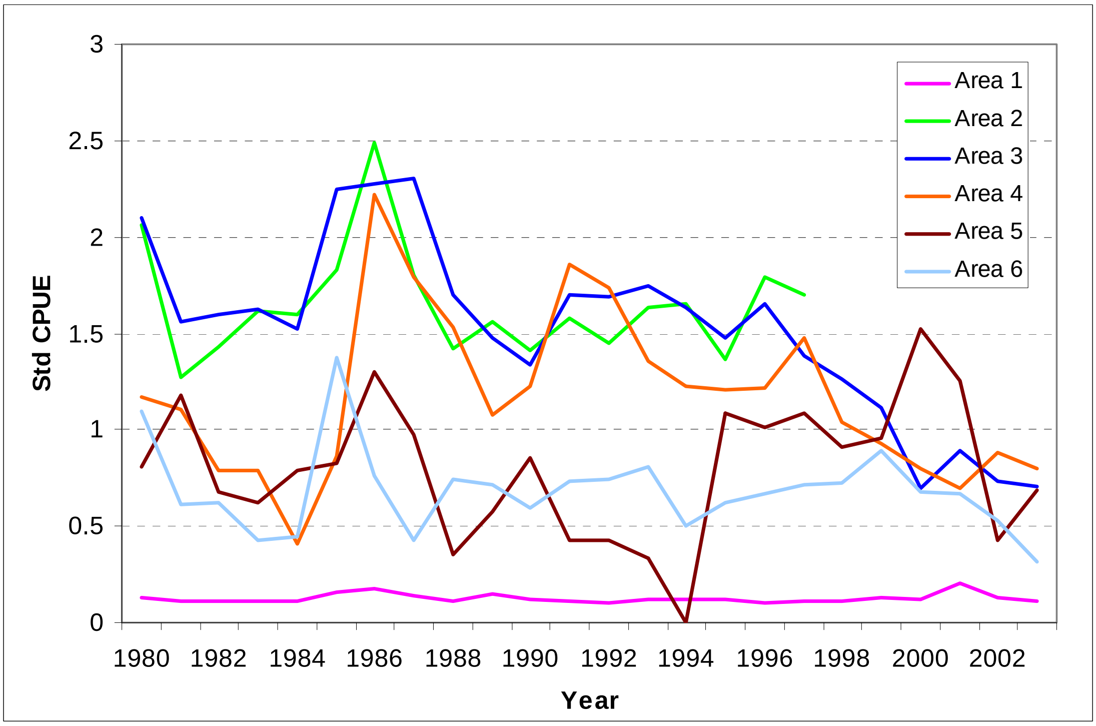
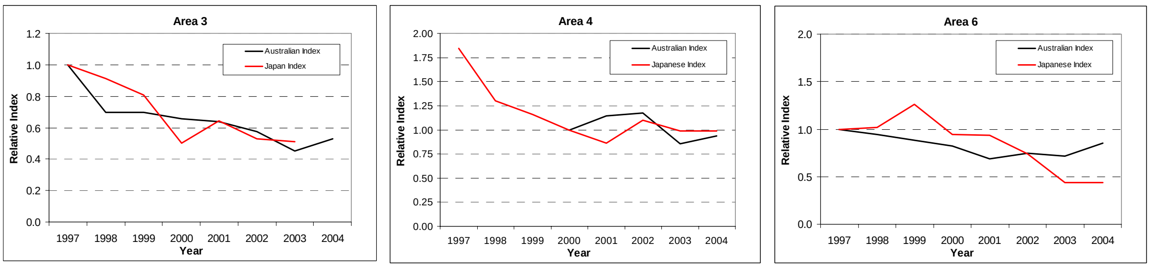


Figure 11 Comparison of Australian and Japanese based swordfish indices within three areas within the SW Pacific.

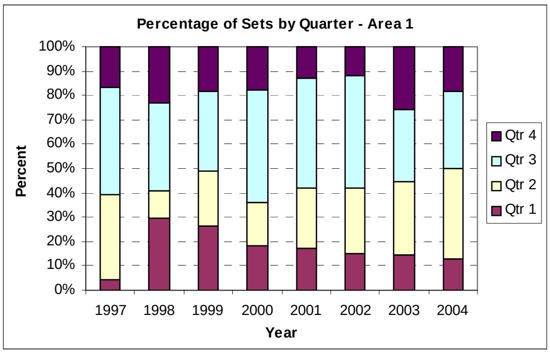


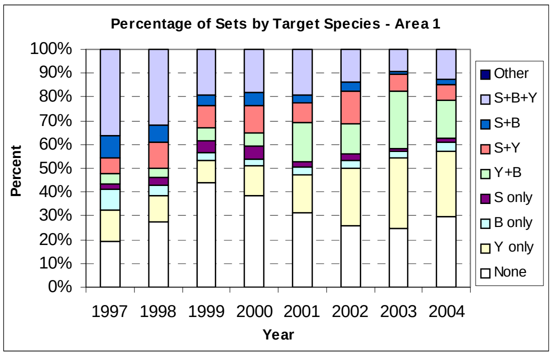
References

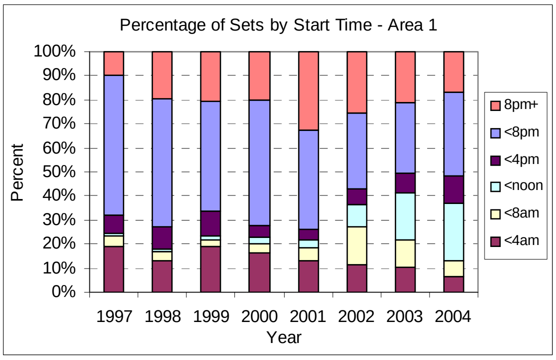
Kolody, D., Campbell, R., Jumppanen, P. and Davies, N. (2005) South-west Pacific swordfish assessment: 2005-06 objectives and preliminary results. Working Paper SA-WP-7 presented to the 1st meeting of the Scientific Committee for the Western Central Pacific Fishery Commission, held 8-19 August 2005, Noumea, New Caledonia.

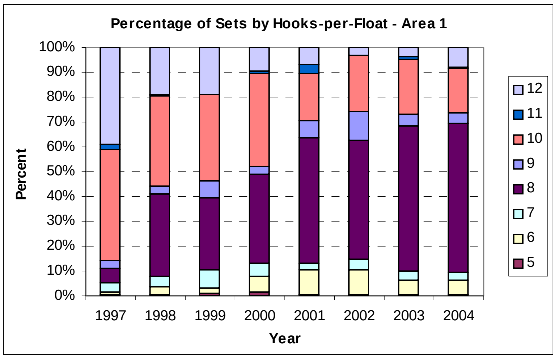
Appendix A. Fishing gears deployed and environmental conditions in each area (depicted as percentage of all sets) by year.

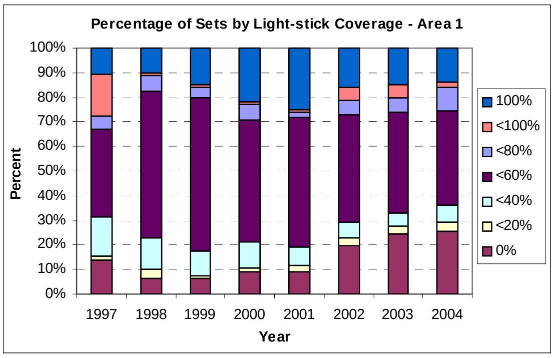
i) Area 1: Inshore – Off Seamount

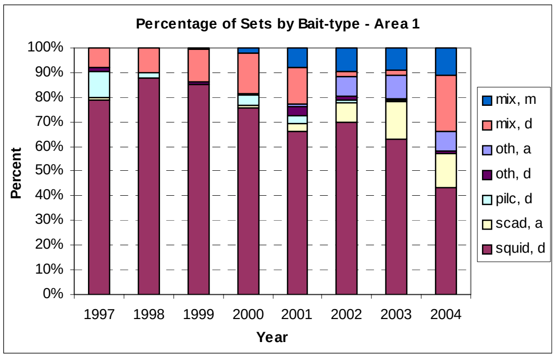


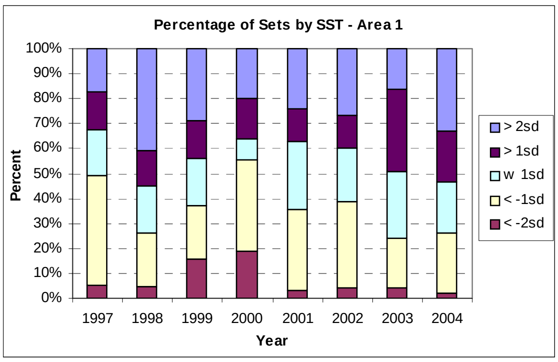


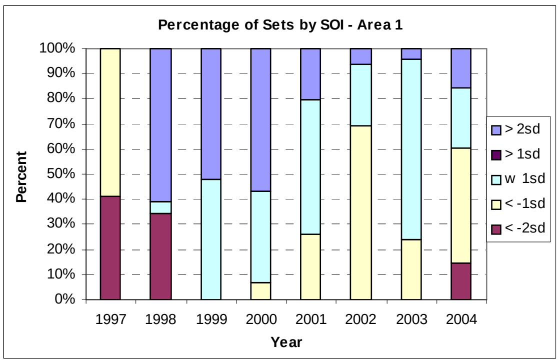






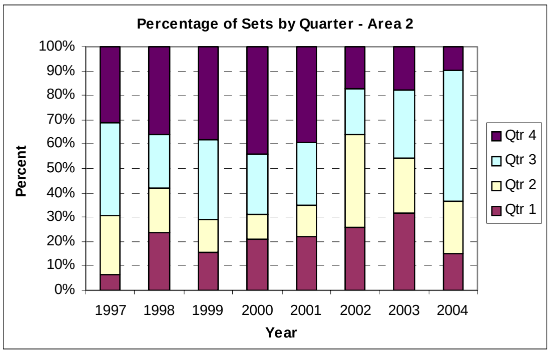


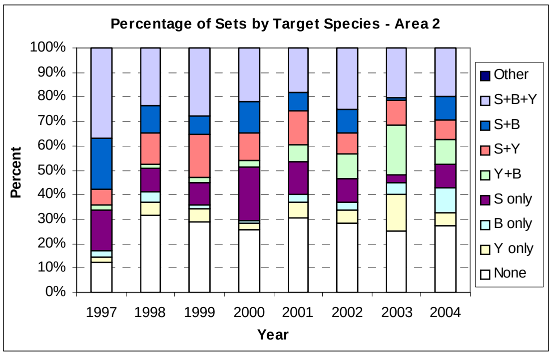


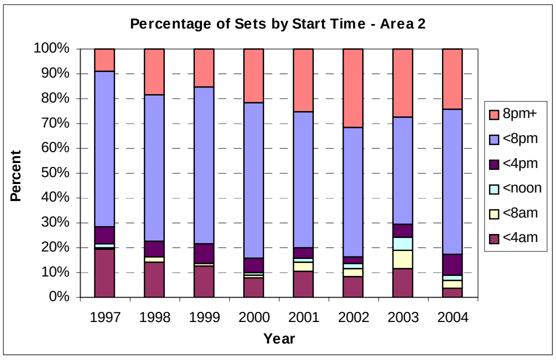


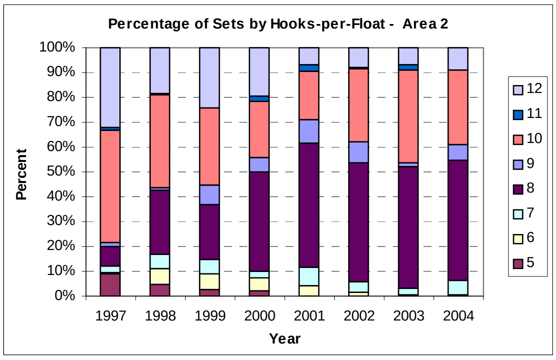
Appendix A (cont'd). Fishing gears deployed and environmental conditions in each area (depicted as percentage of all sets) by year.

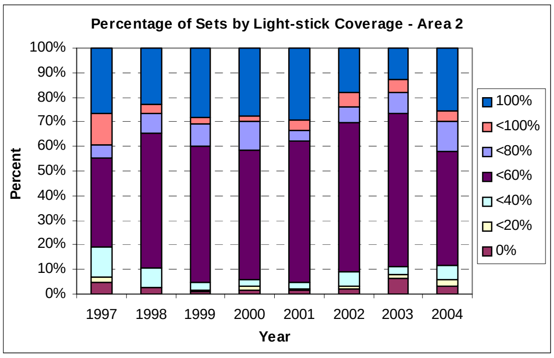
ii) Area 2: Inshore – On Seamount

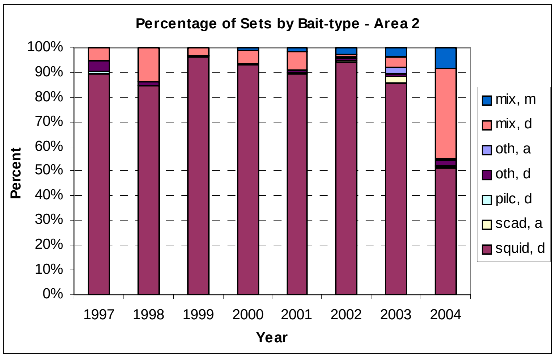


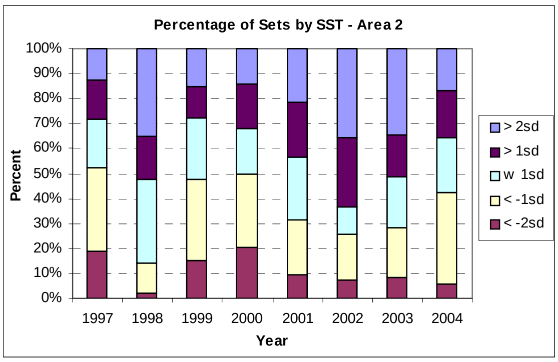


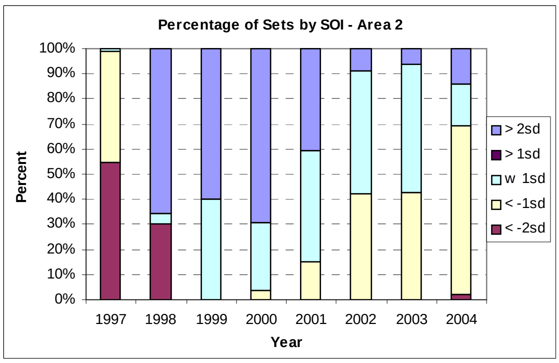






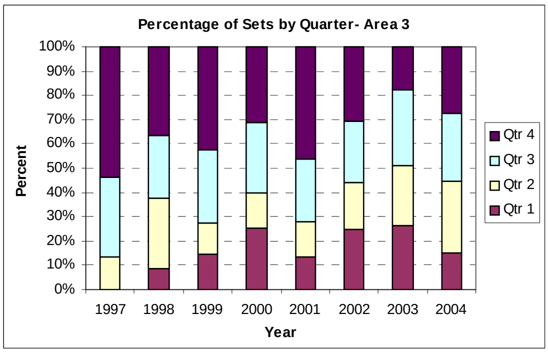


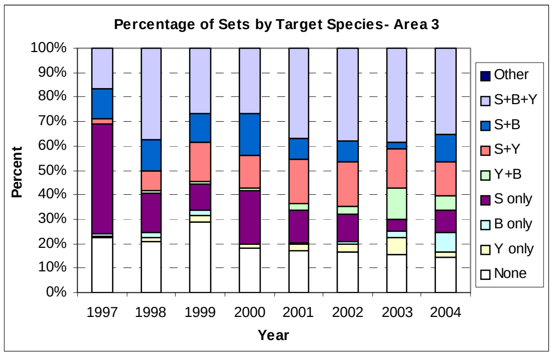


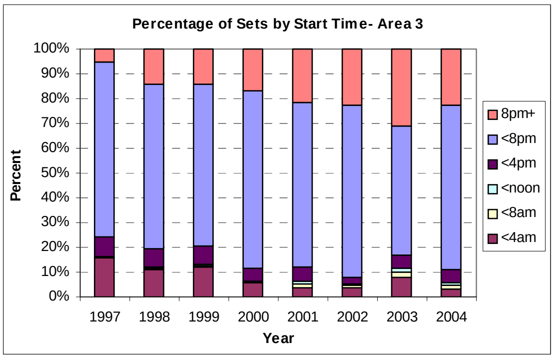


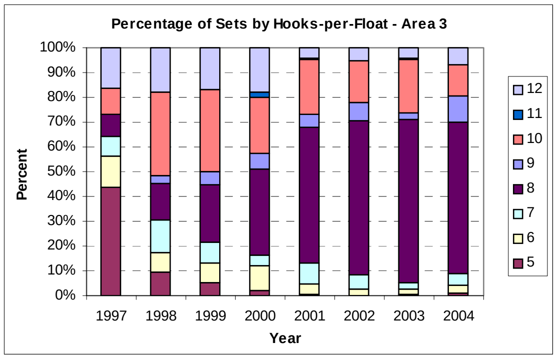
Appendix A (cont'd). Fishing gears deployed and environmental conditions in each area (depicted as percentage of all sets) by year.

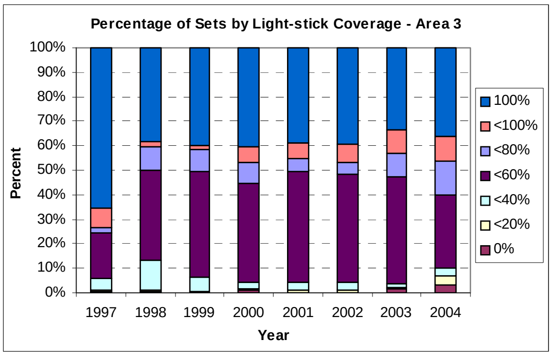
iii) Area 3: Offshore – Off Seamount

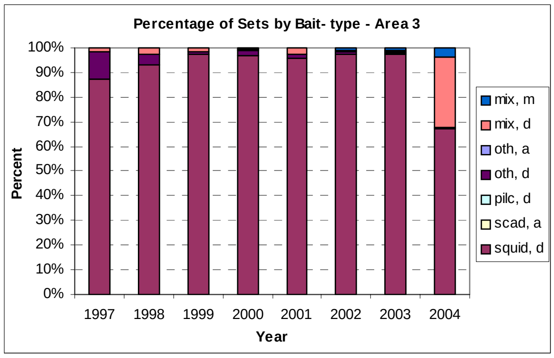


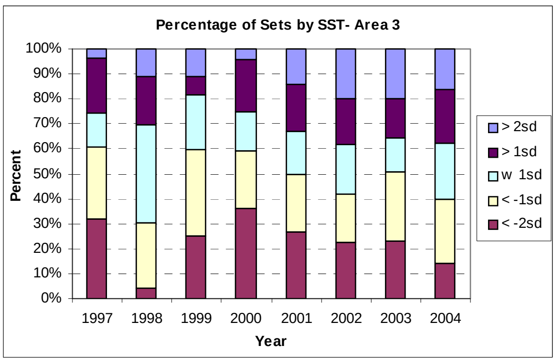


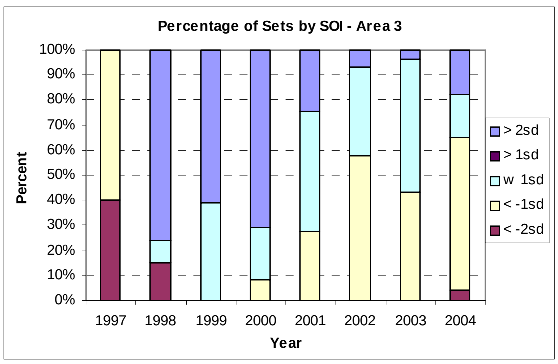






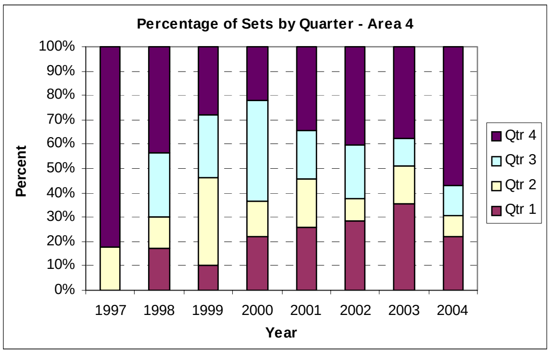


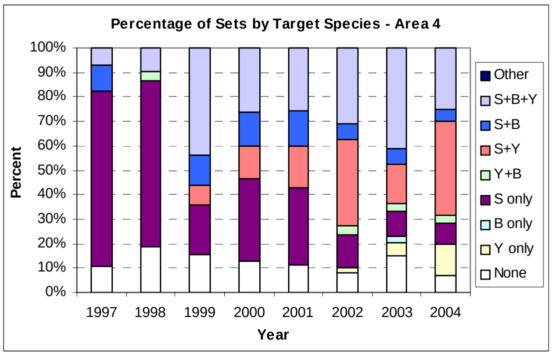


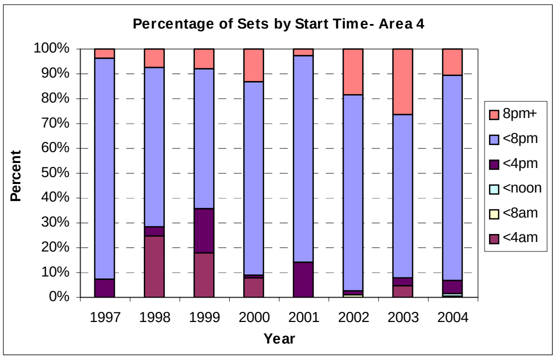


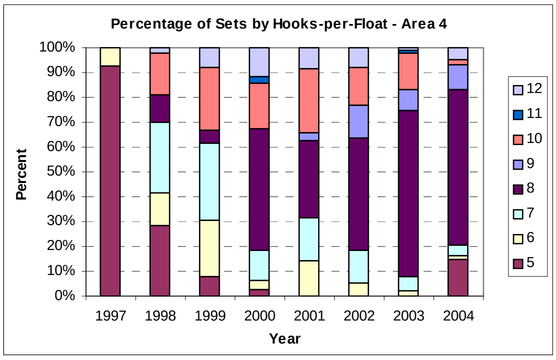
Appendix A (cont'd). Fishing gears deployed and environmental conditions in each area (depicted as percentage of all sets) by year.

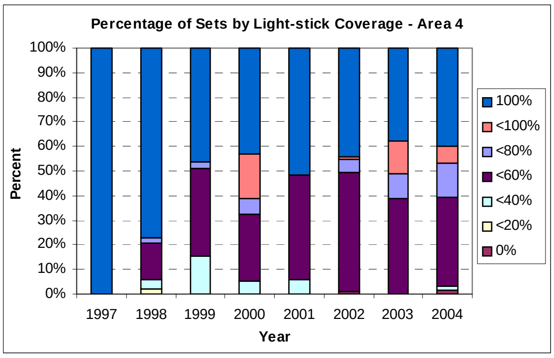
iv) Area 4: Offshore – On Seamount

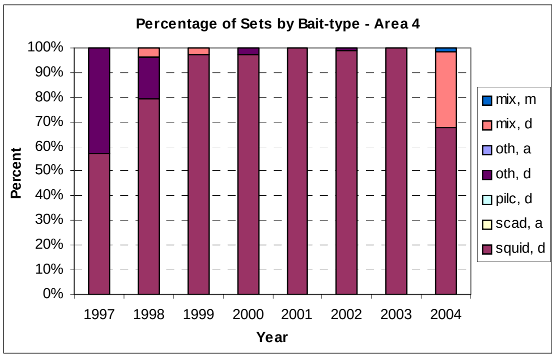


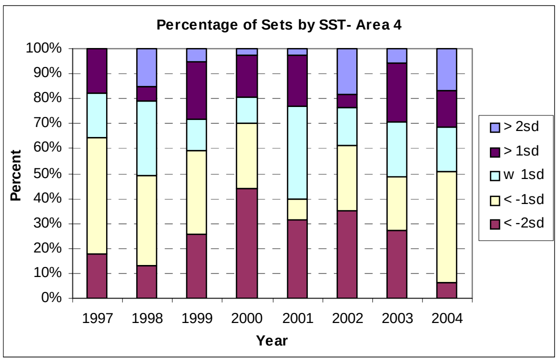


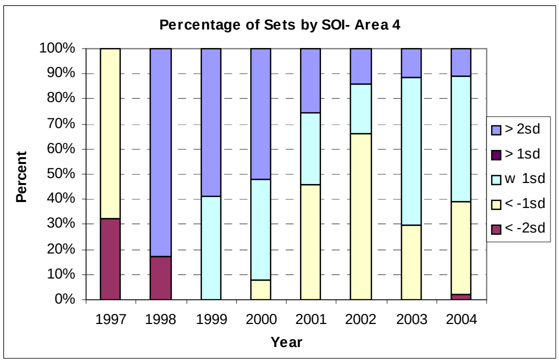






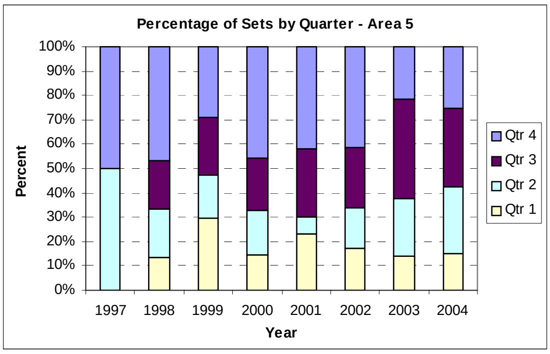


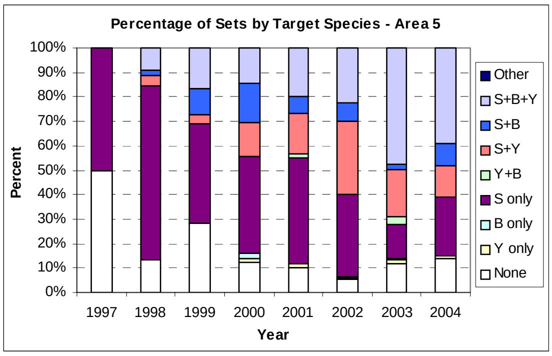


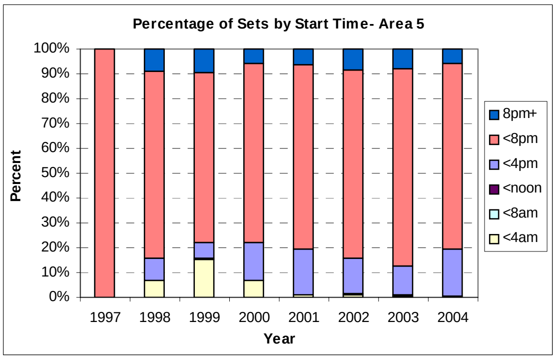


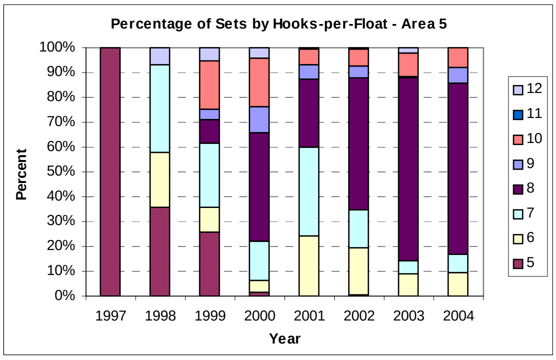
Appendix A (cont'd). Fishing gears deployed and environmental conditions in each area (depicted as percentage of all sets) by year.

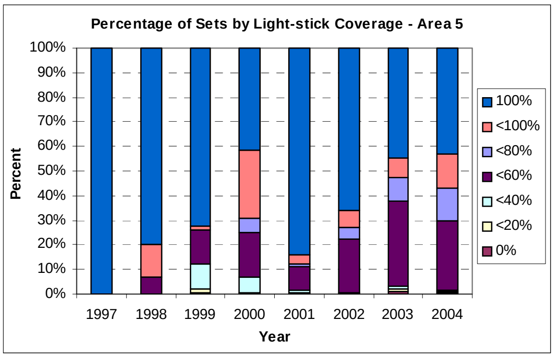
v) Area 5: Far Offshore

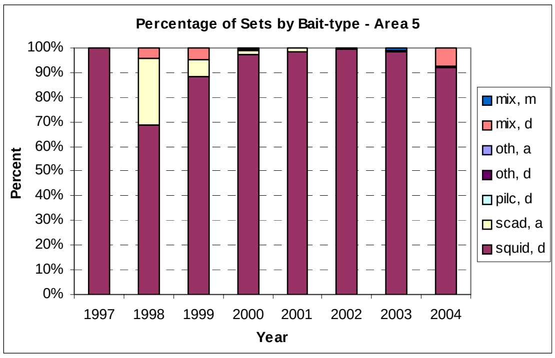


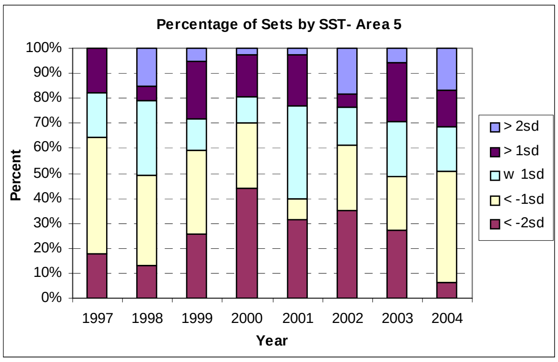


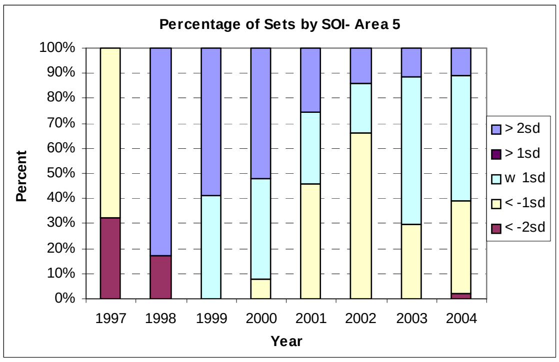






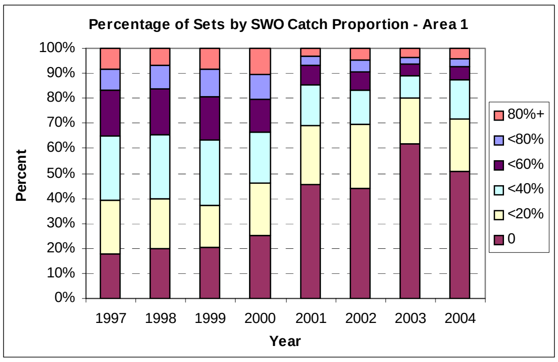


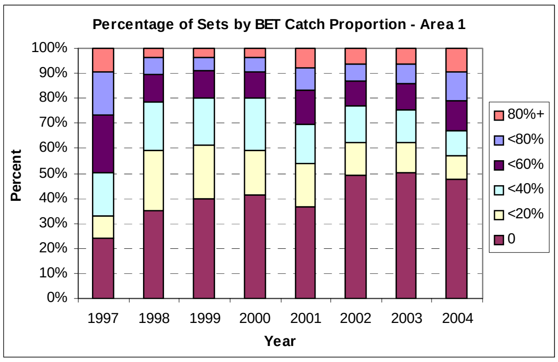


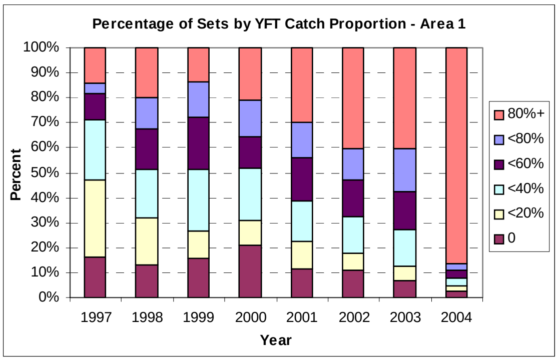


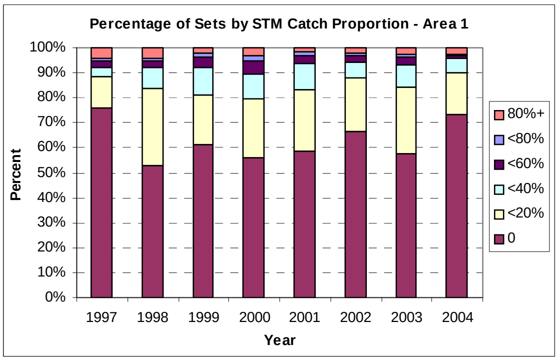
Appendix B. Catch of main target species in each area (depicted as percentage of total catch) by year.

i) Area 1: Inshore – Off Seamount

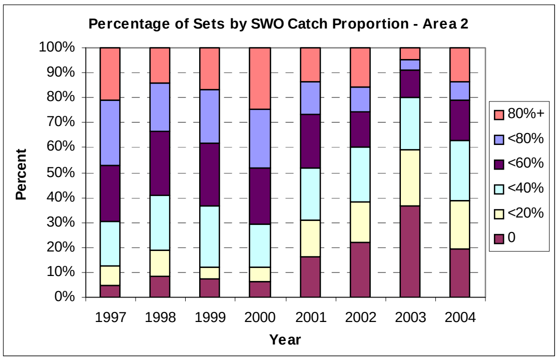


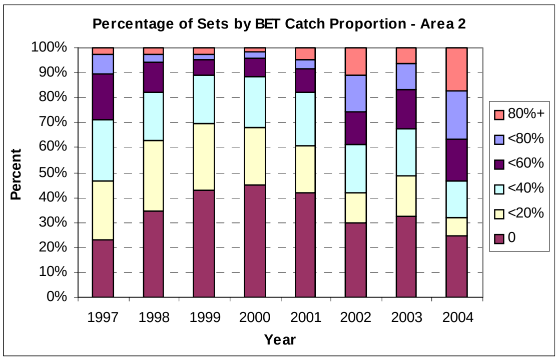


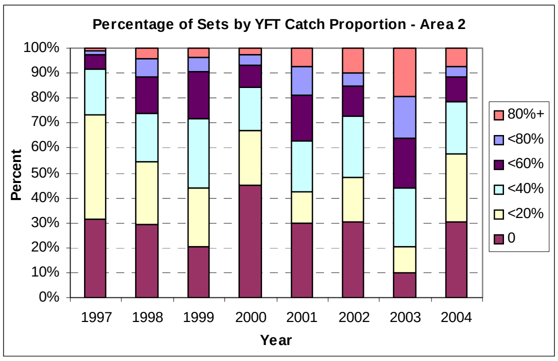


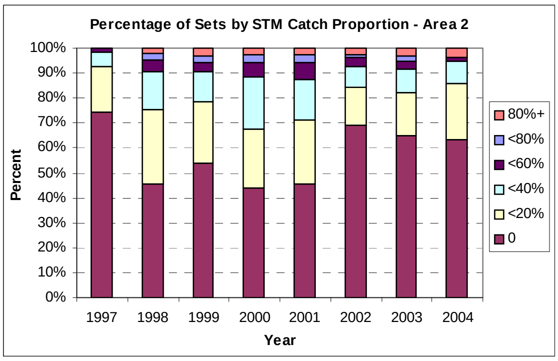


ii) Area 2: Inshore – On Seamount



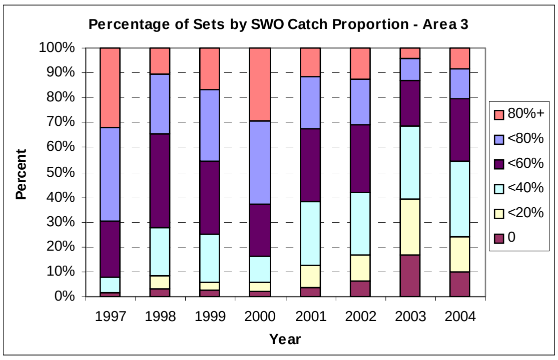


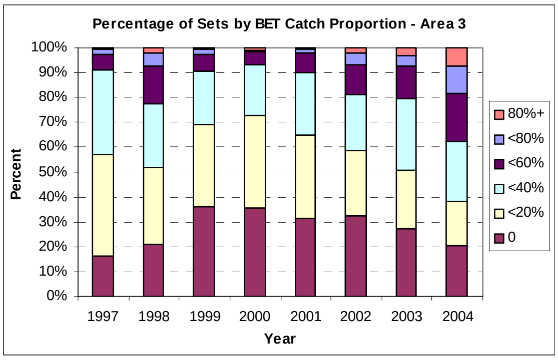


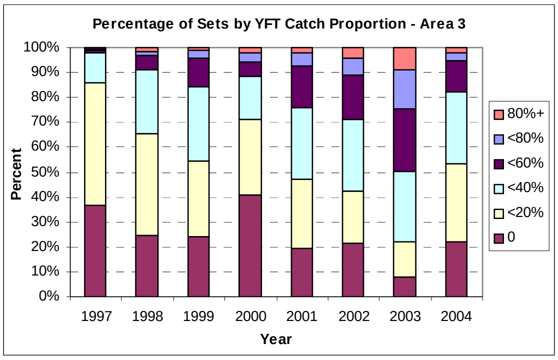


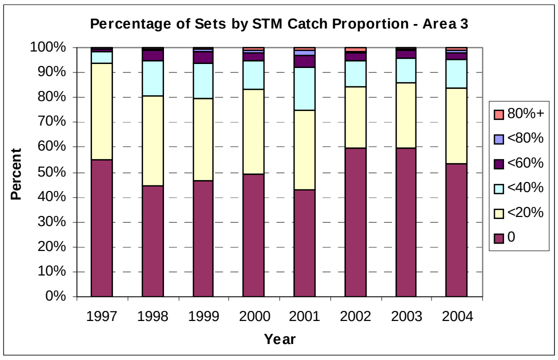
Appendix B (cont'd). Catch of main target species in each area (depicted as percentage of total catch) by year.

iii) Area 3: Offshore – Off Seamount

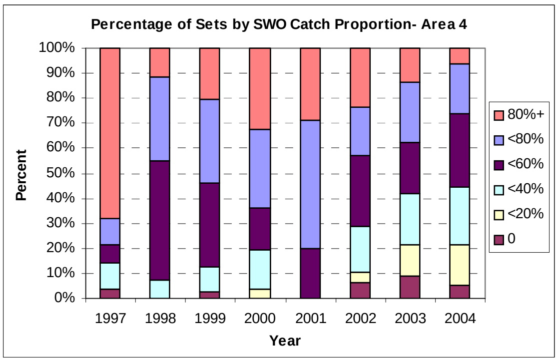


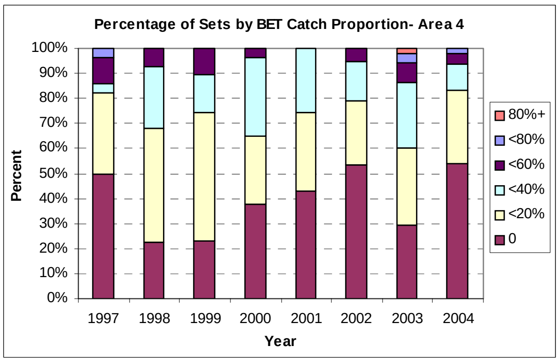


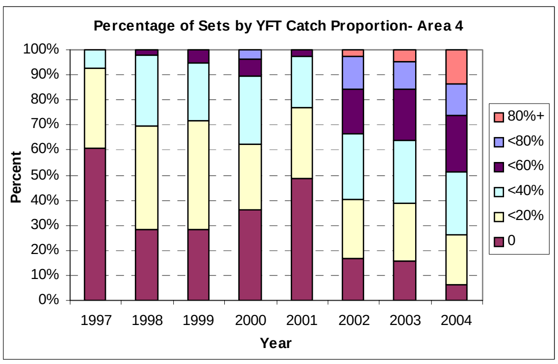


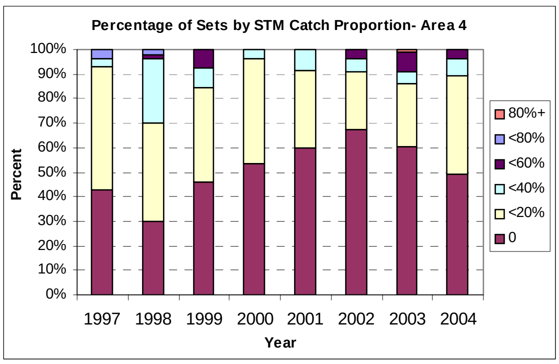


iv) Area 4: Offshore – On Seamount









Appendix B (cont'd). Catch of main target species in each area (depicted as percentage of total catch) by year.

v) Area 5: Far Offshore Catches