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AGGREGATE AND SIZE-BASED STANDARDISED CPUE INDICATORS FOR LONGLINE TARGET SPECIES CAUGHT IN THE SOUTH-WEST PACIFIC

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Robert Campbell[1]

[1] CSIRO Marine and Atmospheric Research, Australia

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Robert Campbell
CSIRO Marine and Atmospheric Research, Melbourne Australia

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1. Introduction

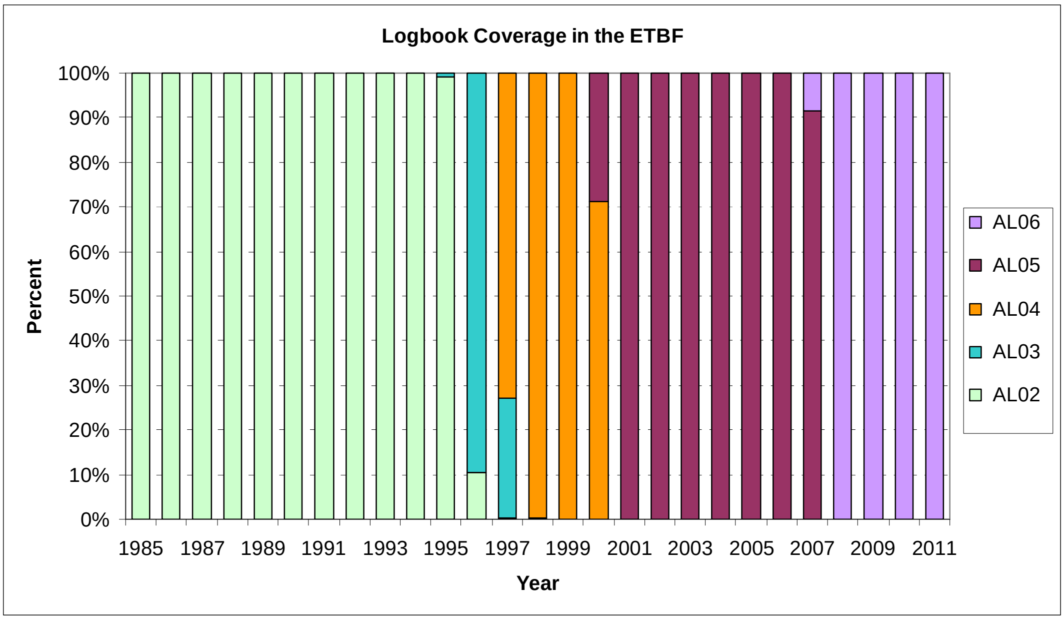
This document outlines the data and methods used to standardise the CPUE for four target species (yellowfin tuna, bigeye tuna, broadbill swordfish and striped marlin) caught by vessels operating within the longline sector of the Australian Eastern Tuna and Billfish Fishery (ETBF). These indices provide indices of stock abundance for stock assessments being undertaken for these species within the south-west Pacific. The results also provide the primary inputs into the harvest strategy used to assist the setting of catch levels within the ETBF (Campbell 2010).

2. Data Coverage

The ETBF has undergone several periods of development and associated changes in targeting practices since the advent of the logbook program in 1987. For example, the fishery largely targeted only yellowfin, and to some extent bigeye, until the mid-1990s at which time a component of the fleet switched to targeting broadbill swordfish. The catches of striped marlin also increased considerably through the 1990s, such that by the year 2000 there were four principal target species in the fishery. The size of the fishery also changed significantly throughout the 1990s, with the effort in the fishery increasing from 1.1 million hooks in 1990 to 9.6 million hooks in 2000 and the spatial extent of the fishery increasing by more than 2.5 times over this period. Effort peaked in 2003 when 12.75 million hooks were deployed and the spatial extent of the fishery reached 273 1-degree squares. However, with the advent of lower catch rates and poor economic returns throughout the early to mid 2000s a number of vessels left the fishery and both effort and catches declined. The targeting of albacore tuna and its addition as a primary target species provided some assistance to the fishery with the catch of albacore in 2006 and 2007 being the largest of the now five principal target species. Finally, a government-based restructuring of the fishery in 2007 saw the number of active vessels remaining in the fishery decline to around 50 during 2008 when around 8 million hooks were deployed. Effort increased to around 9 million hooks in 2009 but has again declined in more recent years with around 6.7 million hooks being deployed in 2011 when 49 vessels (some only briefly) operated in the fishery. Total allowable catch quotas (based on individual transferrable quotas) for the five principal target species were introduced into the fishery in March 2011.

This brief history indicates that there have been a number of significant changes in the operation of the ETBF including changes in the range of species targeted and the spatial extent of the fishery. As both these features influence the catch and effort data collected from the fishery, they also influence the ability to formulate meaningful abundance indices for any given species. In particular, there are two changes which have an important bearing on this issue. First, changes in the species targeted means that the effective effort targeted at any species is not equivalent to the nominal effort

Figure 1. Annual logbook coverage (as a percentage of sets) in the ETBF.



within the fishery. To overcome this problem the nominal effort needs to be adjusted (standardised) to account for the different fishing practices adopted when targeting the different species. These different practices include decisions relating to the time of the set (i.e. day versus night set), the number of hooks-per-float (which influences hook depth), bait-type and the use of light-sticks used. Annual distributions showing the percentage of longline sets within the ETBF utilising these different operational practices are shown in Figure 2 and indicate significant changes over time. However, as described in Campbell (2007), the information required to adequately account for these different targeting practices has only been recorded and collected since 1997 when the AL04 logbook was introduced into the fishery (c.f. Figure 1). As such the analyses presented here commence in mid-1997.

Second, due to the changes in the spatial extent of the fishery over time, there is a non-continuous coverage of data across some regions of the fishery and this constrains the ability to construct an ongoing annual index of abundance in these regions. The number of 1-degree squares fished in the ETBF each year between 1997 and 20011, together with the number of 1-degree squares in which each of the five principal target species have been caught, are shown in Figure 2. This indicates that the spatial extent of the fishery has ranged between 129 and 264 1-degree squares over the 15 years displayed, with the extent of the fishery increasing by 54 % between 1997 and 2003 after which it has decreased so that by 2011 the spatial coverage was 25% less than in 1997. Apart from striped marlin, the spatial extent of the other four principal catch species is seen to be similar for each year. Of the total of 368 1-degree squares fished during this period, less than one-quarter (83) have been fished in all 15 years, with a further 19 squares fished for 14 years and 14 squares fished for 13 years. Thirty-eight squares (or 10 percent of all squares) have been fished for one year only. A more detailed examination of areas appropriate for the calculation of an abundance index for each species is provided in section 6.

Figure 2. Annual distribution of fishing practices deployed by longline vessels in the ETBF.

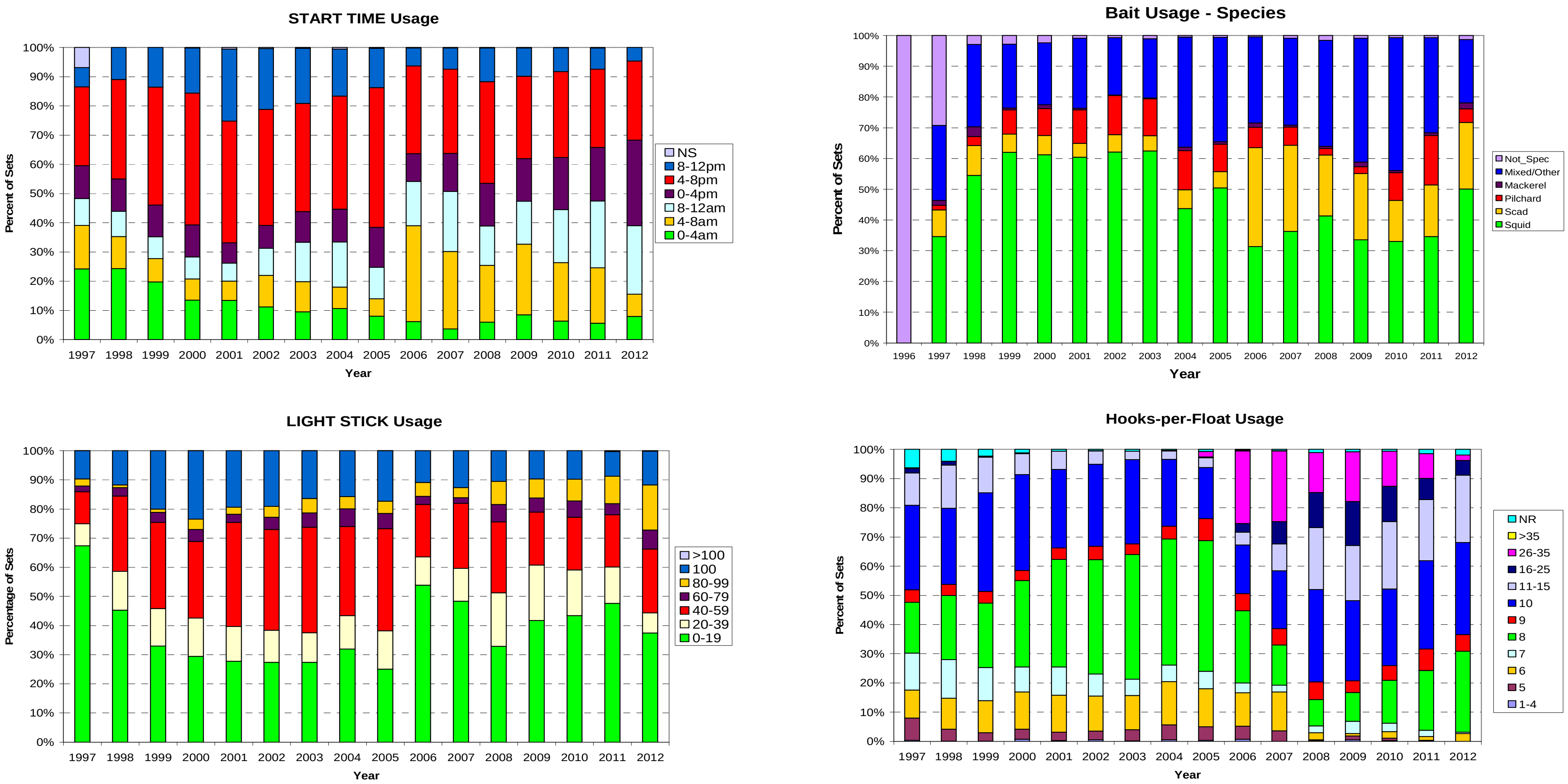
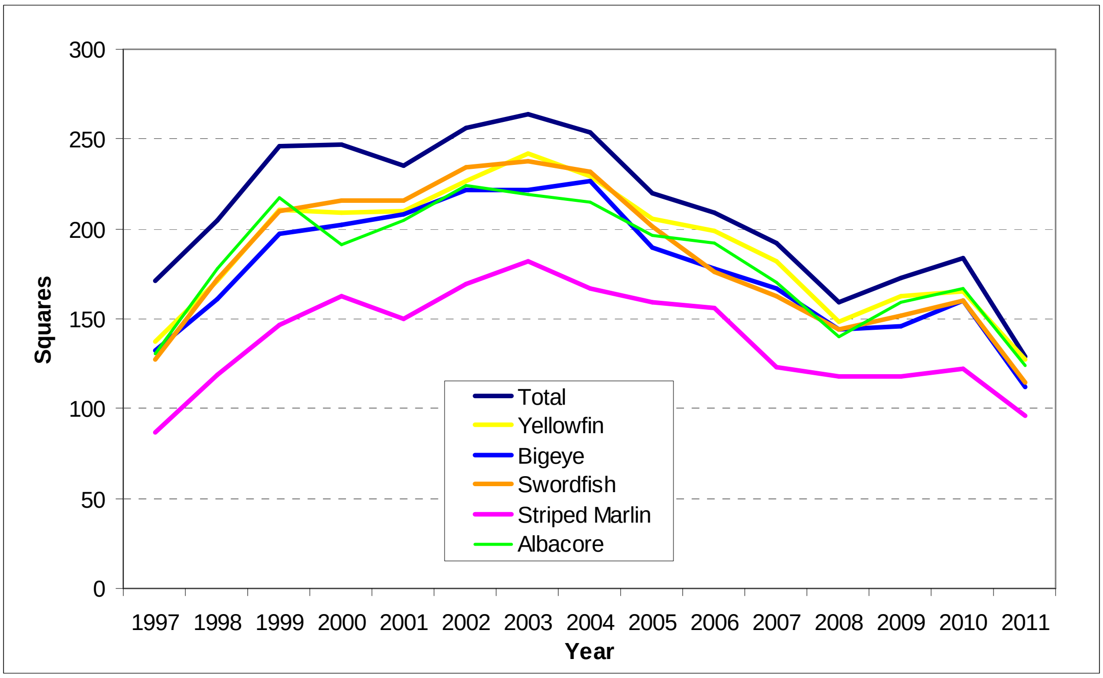


Figure 3. Number of 1-degree squares fished and with catch each year in the ETBF.



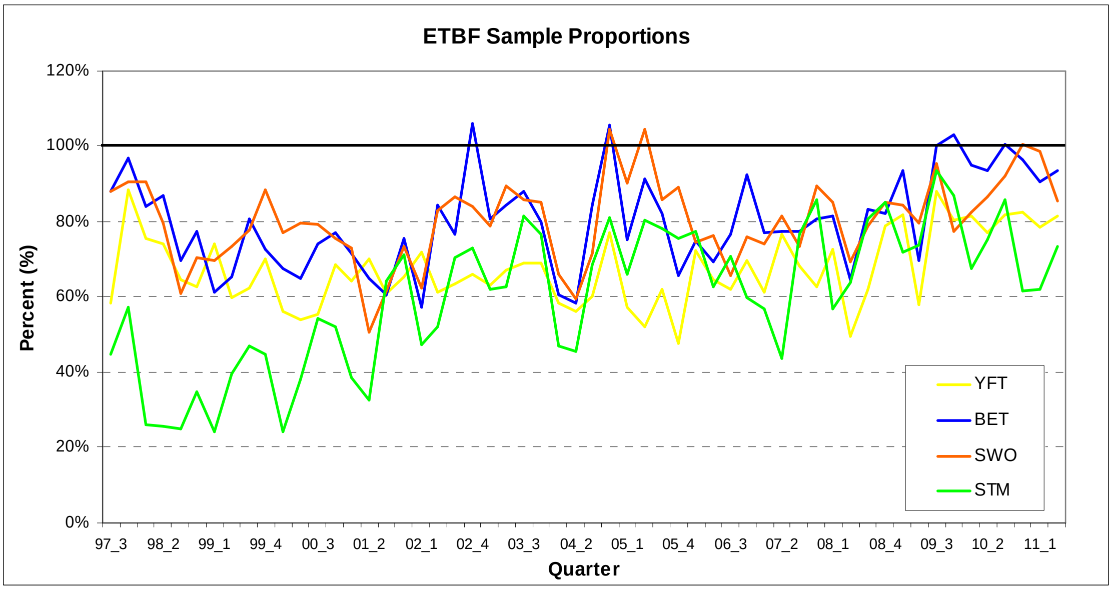
Together with the logbook catch and effort data, size data collected from the fishery is used for partitioning the catch into the three size categories used in the ETBF harvest strategy – small, prime and large fish. The data used for this purpose are the individual weights which have been collected from ETBF processes since mid-1997. (Note: it is somewhat fortuitous, or perhaps a good example of enlightened planning, that the commencement of this program coincided with the introduction of the AL04 logbook which gathered the auxiliary gear setting information).

A summary of the number of individual fish weights recorded by region during the period from July-1997 to December-2011 for four of the principal target species is given in Table 1, whilst the sampling proportion each quarter (i.e. the ratio of the number of fish sampled to the number of fish recorded as retained in the logbooks) is shown in Figure 4. The reason that the sampling proportion exceeds 100% in some quarter remains unclear but may be due to under-reporting in the logbooks, the inclusion of non-longline fish in the number sampled, or differences in the quarter that the fish were sampled and the quarter that they were caught.

Table 1. Number of individual weights recorded for selected species landed in the ETBF between 1-July 1997 and 30-December 2011.

Region	**Bigeye Tuna**	**Broadbill Swordfish**	**Striped Marlin**	**Yellowfin Tuna**	**Total**
Northern QLD	74,491	10,589	42	135,029	220,151
Southern QLD	168,548	278,503	40,499	305,526	793,076
QLD General	1,695	7,296	420	6,395	15,806
Northern NSW	13,466	17,159	31,171	572,234	91,030
Southern NSW	13,481	8,334	5,392	58,338	85,545
NSW General	1,211	2,935	845	19,476	24,467
Total	272,892	324,816	50,369	581,998	1,230,075

Figure 4. Sampling proportion, by quarter, of sizes for the main target species caught in the ETBF.



For the 14 year period between July-1997 and June-2011 information recorded in vessel logbooks indicates that a total of 846,509 yellowfin tuna were retained while during the same period 563,012 yellowfin were sampled. This represents a total sampling proportion of 66.5%. For bigeye 339,450 fish has been retained and 267,420 fish sampled (78.8%), for swordfish 393,416 fish have been retained and 312,961 fish sampled (79.5%) and for striped marlin 83,807 fish have been retained and 48,694 fish sampled (58.1%). Given these high sampling rates (apart from the somewhat lower than average sampling rates for striped in the early years of the sampling program) the collection of size-data are assumed to be comprehensive and representative of the distributions of all size classes of the main target species caught in the fishery. (For a comprehensive summary of these data, together with a number of time-series of indicators based on these data, see Campbell et al, 2012).

3 Apportioning Catch by Size Categories.

Histograms of the dressed weight, binned by 5 kg categories, of all fish measured between 1 July 1997 and 30 June 2008 for each of the four main target species are shown in Figure 5. (Note, the cut-off sizes described in this section were first determined in 2009 and explains why only the size data up to mid-2008 was used.) Based on these distributions of weights the following three size categories were defined for each species:

Small Fish	those fish within the lower 25-percentile of the weight distribution
Prime Fish	those fish within the mid 50-percentile of the weight distribution
Large Fish	those fish within the upper 25-percentile of the weight distribution

The selected cut-off weights, and the proportion of measured fish for each species within each size category, are given in Table 2.

Using these cut-off weights the proportion of small, prime and large fish in each size size-sample was then calculated. As the size sampling is undertaken at the processor

Figure 5. Histograms of dressed weights (to the nearest kilogram) of yellowfin, bigeye, swordfish and striped marlin sampled in the ETBF.

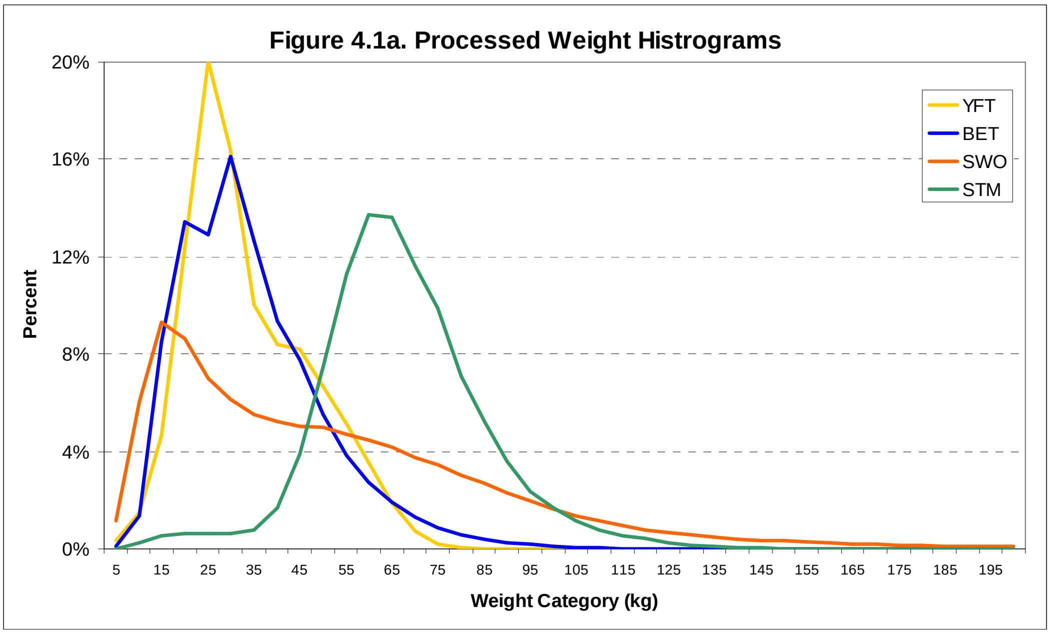


Table 2. Selected cut-off weights for each species and the number and proportion of weights samples within each of the defined size categories.

	YFT	BET	ALB	SWO	STM
	Cut-Off Processed Weights				
Small-Prime	21.4	20.5	11.0	20.0	53.9
Prime-Large	40.5	40.0	17.8	68.0	73.9
DWT-to_WWT ratio	0.85	0.84	1.00	0.726	0.726
	Cut-Off Whole Weights				
Small-Prime	25.2	24.4	11.0	27.5	74.2
Prime-Large	47.6	47.6	17.8	93.7	101.8
	Number of Measured Fish				
Small	112,356	56,387	14,086	65,339	10,107
Prime	223,816	112,373	28,484	129,371	20,102
Large	112,445	56,036	14,315	65,502	10,187
All Fish	448,617	224,796	56,885	260,212	40,396
	Percentage of Measured Fish				
Small	25.0%	25.1%	24.8%	25.1%	25.0%
Prime	49.9%	50.0%	50.1%	49.7%	49.8%
Large	25.1%	24.9%	25.2%	25.2%	25.2%

when unloading the fish at the end of a trip, each size sample is related to the size distribution of fish caught (by species) combined across all sets deployed during that trip. The species specific catch associated with each individual longline set (recorded in the catch and effort logbook data) was then apportioned into each of the three size classes by multiplying the catch of each species for each set within a trip by the proportion within each size class for each species as determined by the size sample for the related trip. This is obviously an approximation, as it is unlikely that the same size-distribution of fish was caught on all sets during a single trip.

Unfortunately, the vessel name is not associated with many of the samples and so the previous process of apportioning size proportions to the catch is not possible for these

Table 3. Number of sets and percent of fish matched with different levels of aggregation of the size-sampling data.

	Yellowfin Tuna		Bigeye Tuna		Broadbill Swordfish		Striped Marlin	
Aggregation Level	No. Sets	% Fish	No. Sets	% Fish	No. Sets	% Fish	No. Sets	% Fish
By Trip	63088	42.9%	59463	55.1%	55114	58.6%	36730	40.2%
Within 2.5-degree/month	33962	33.7%	21465	27.7%	24568	31.8%	7545	19.1%
Within region/month	21775	22.5%	10497	14.1%	10039	7.4%	7609	18.6%
By Region, Year,Qtr	621	0.8%	1916	1.5%	1546	0.8%	1464	3.0%
By State Year,Qtr	130	0.1%	2217	1.6%	2314	1.3%	7212	16.1%
By State,Qtr	0	0.0%	0	0.0%	0	0.0%	1254	2.9%
No Catch	15687	0.0%	39705	0.0%	41682	0.0%	73449	0.0%
	135263	100.0%	135263	100.0%	135263	100.0%	135263	100.0%

trips. For many other trips no corresponding size sample was collected. For both these types of trips the catches were apportioned to each size class using the average proportion of small, prime and large fish caught aggregated across all processor-matched sets within a spatial-temporal strata in which the trip occurred. A hierarchical approach was used such that larger spatial-temporal strata were chosen to ensure that the number of fish sampled in each strata was at least 100. A summary of the number of sets and catches matched at each level of sample aggregation is shown in Table 3. It is seen that between 40-58% of all fish caught were matched directly to a corresponding size sample for the related trip.

4 General Linear Models (GLMs)

A range of variables were used to standardize the CPUE for each size category and species. These variables, together with the model parameter names and category definitions, are listed in Table 4. The variables are divided into the following four groups:

1) Statistical effects – these effects attempt to account for differences in availability of the fish due to differences in the spatial and temporal distribution of the resource and changes in the size of the resource each year. Variables include Year, Quarter and Area.
2) Fishing Practice Effects – these effects attempt to account for differences in the effectiveness of the longline due to the use of different fishing gears and time of fishing. Variables include Hooks-per-Basket, Start-Time, Bait-Type and Use of Light-sticks.
3) Environmental/Oceanographic Effects – like the statistical effects listed above, these effects attempt to account for differences in the availability of the fish due to behavioral responses to local changes in ocean conditions and changes in their diurnal behavior. Variables include Sea-surface Temperature, Southern-Oscillation Index, Mixed-Layer-Depth, Sea-Height (Altimetry) and Moon-Phase.
4) Vessel Cooperative/Competitive Effects – these effects attempt to account for the influence of vessels cooperating or competing within a similar area of the fishery. Variables include the number of vessels within same 1-degree square/day and the number of vessels within the same 1-degree square/month.

Table 4. Listing of variables, together with the model parameter names and category definitions, used to standardize CPUE.

No.	Standardising Variable	Model Parameter	Category Levels	Category Definition
		1. Statistical Effects		
1	Year	Year	1 to 15	1997 to 2011
2	Quarter	Qtr	1	Jan-Mar
			2	Apr-Jun
			3	Jul-Sep
			4	Oct-Dec
3	Region fished	Area	1 to 7	Species specific Refer to Figures
		2. Fishing Strategy Effects		
4	Start Time of set	Start	1	before 4am
			2	4am to 8am
			3	8am to noon
			4	noon to 4pm
			5	4pm to 8pm
			6	8pm to midnight
5	Bait Type Used	Bait	1	squid, dead
			2	yellowftail scad, alive
			3	pilchard, dead
			4	other, dead
			5	other, alive
			6	mixed species, dead
			7	mixed species, alive & dead
6	Hooks-per-Float	HPF	1	HPB <= 5
			2	HPB=6
			3	HPB=7
			4	HPB=8
			5	HPB=9
			6	HPB=10
			7	HPB between 11 and 19
			8	HPB between 20 and 40
7	Percentage of Hooks with Lights	Lights	1	0%
			2	1 to 19 %
			3	20 to 39 %
			4	40 to 59 %
			5	60 to 79 %
			6	80 to 99 %
			7	100%
		3. Environmental/Oceanographic Effects		
8	Sea-Surface Temperature	SST	1	Normalised SST<-1.0
			2	Normalised SST between -1.0 and -0.3
			3	Normalised SST between -0.3 and 0.3
			4	Normalised SST between 0.3 and 1
			5	Normalised SST >1.0
9	Southern-Oscialltion Index	SOI	1 to 5	As for Sea-Surface Temperature
10	Mixed-layer Depth	MLD	1 to 5	As for Sea-Surface Temperature
11	Frontal Density	FRT	2 to 5	As for Sea-Surface Temperature
12	Moon Phase	moon	Continuous	ABS[cos(PI*phase/29)]
		4. Cooperative/Competative Effects		
13	Number of other vessels in same 1-degree square - daily effect	Daily-VES	1	no other vessels
			2	1 other vessel
			3	2 other vessels
			4	3 other vessels
			5	4 other vessels
			6	5 other vessels
			7	6 other vessels
			8	more than 6 other vessels
14	Number of other vessels in same 1-degree square - monthly effect	Monthly-VES	1	less than 3 other vessels
			2	3-5 other vessels
			3	6-8 other vessels
			4	9-11 other vessels
			5	12-14 other vessels
			6	15-17 other vessels
			7	18-20 other vessels
			8	more than 20 other vessels

Most variables were fitted as categorical variables with a given range of values for each variable being associated with a discrete category (e.g. the start times were categorized into six 4-hourly intervals of time). Only moon-phase was fitted as a continuous variable.

Each of the four oceanographic variables were normalized based on the mean and standard deviation of the values across all data included in the analysis, then categorized into one of the five categories depending on whether the absolute value of the normalized variable |z| was less than or greater than 0.3 or 1.0.

Due to the inflated number of zero catch observations (enhanced due to apportioning the catch into size classes) it was considered best practice to standardise the CPUE data as a two stage process: one stage being concerned with the pattern of occurrence of positive catches, and the other stage with the mean size of the positive catch rates. We also assume that both the probability of a positive catch and the size of a positive catch rate can be modelled as linear combinations of the factors listed in Table 4. Once this is done, we can combine the means from the two distributions to give an overall mean abundance index.

A small example helps illustrate this approach. Consider a season for which there are n catch rate observations, C_i. The average catch rate can be expressed as follows:

$$\mu = \frac{1}{n}\sum_{i=1}^{n} C_i = \frac{1}{n_S + n_F}\sum_{i=1}^{n_s} C_i = \frac{n_S}{n_S + n_F}\frac{1}{n_S}\sum_{i=1}^{n_s} C_i = p_S \mu_S$$

where n_S is the number of positive or successful catch rates obtained (C_i>0), n_F is the number of zero or failed catches (C_i =0), p_S is the proportion of positive catches and μ_S is the average of the positive catch rates. This result shows that the overall mean catch rate can be expressed as the combination of the parameters from the distributions used to model the probability of a successful catch and that used to model the non-zero catch rates. A similar approach was used in the estimation of egg production based on plankton surveys (Pennington 1983, Pennington and Berrien 1984) and for estimating indices of fish abundance based on aerial spotter surveys (Lo et al 1992).

Stage 1: Prob(positive catch)

The Binominal distribution is used to model the probability of a non-zero catch where we model each observation as either a success (C_i >0) of a failure (C_i =0), with the probability of either expressed as follows:

$$\Pr(C_i > 0) = p_S \qquad \text{and} \qquad \Pr(C_i = 0) = 1 - p_S$$

Associated with each observation is a vector of covariates or explanatory variables X_j thought likely to influence the probability of a positive catch. Furthermore, we assume that the dependence of p_S occurs through a linear combination $\eta = \sum \beta_j X_j$ of the explanatory variables. In order to ensure that $0 \le p_S \le 1$ we use the logit link function which takes the following form:

$$\eta = \log\left(\frac{p_S}{1 - p_S}\right)$$

The inverse of this relation gives the probability of a positive sighting as a function of the explanatory variables:

$$p_S = \frac{e^{\eta}}{1+e^{\eta}} = \frac{\exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + ...)}{1+\exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + ...)}$$

The following model was then fitted to the data using the SAS GENMOD procedure

MODEL p_S = *intercept* + *f(year,qtr,area)* + *hpb* + *clights* + *bait* +*start_time* +
*soi*area* + *sst*area* + *mld*area*+ *alt*area* + *moon_phase* +
dvescat + *mvescat* / dist=binomial link=logit

where the following two forms of the function *f()* were fitted as separate models:

Model 1: f(year, qrt, area) = year*qtr + qtr*area

Model 2 f(year, qrt, area) = year*qtr*area

and * represents an interaction between the variables shown. The standardised probability for a positive catch, p_S, was then calculated for each spatio-temporal strata (year, quarter and area) against a standard set of model factors.

Stage 2: Mean Size of Positive Catch Rate

Having fitted the above model to the probability of obtaining a positive catch, a separate model was fitted to the distribution of positive catch rates, μ_S. For this purpose a log-Gamma model was adopted, such that the μ_S was assumed to have a gamma distribution with a log link to the vector of covariates or explanatory variables X_j. The data fitted to the model were limited to those observations having a positive catch.

As before, the following model was then fitted to the data using the SAS GENMOD procedure:

MODEL μ_S= *intercept* + *f(year,qtr,area)* + *hpb* + *lights* + *bait* +*start_time* +
*soi*area* + *sst*area* + *mld*area*+ *alt*area* + *moon_phase* +
dvescat + *mvescat* / dist=gamma link=log

where the two functional forms of *f()* described previously were again fitted. A standardised mean positive catch rate, μ_S, was then calculated for each spatio-temporal strata (year, quarter and area) against a standard set of model factors.

Note: the continuous gamma distribution is used here as the fitted catch data is no longer an integer after being multiplied by the proportion of the catch in each size class. However, the aggregate catch over all size classes (denoted ALL in the following) remains an integer and as such the alternative model using the discrete negative binomial distribution, a log link and a log(effort) offset fitted to the catch was consider more appropriate. This distribution also provides a more general form of the assumed variance function ($\mu + k\mu^2$).

5 Abundance Index

The above two models were fitted to the data-sets defined below for each species and the results used to calculate the standardized index, *S*, in each year, quarter and area strata:

$$S(year, qtr, area) = S_{y,q,a} = p_S(\text{year, qtr, area}) * \mu_S(\text{year, qtr, area})$$

An annual index of abundance, *I(year)*, was then determined by first calculating the area-weighted sum of the standardized index across all *NA* areas and then taking the average across all *NQ=4* quarters as follows:

$$I(year) = \sum_{area=1}^{NA} \left[\frac{Size_{area}}{NQ} \sum_{qtr=1}^{NQ} p_S(\text{year, qtr, area}) * \mu_S(\text{year, qtr, area}) \right]$$

where $Size_{area}$ is the spatial size of the individual areas (as measured by the number of 1-degree squares in each area).

Due to the fact that the period used in the analysis begins in mid-1997, for this year the standardized index is only available for the third and fourth quarters. The standardized index in the first and second quarters (for a given area) was therefore modeled by multiplying the mean of the standardized index in the third and fourth quarters in 1997 for that area by the ratio of the index for that quarter and the mean index for the last two quarters across the years 1998 to 2003, i.e.

$$S(1997, qtr = i, area = j) = \overline{S}_{1997,3\&4,j} \cdot \frac{1}{6} \sum_{y=1998}^{2003} \left[\frac{S_{y,i,j}}{\overline{S}_{y,3\&4,j}} \right] \qquad i=1,2$$

where $\overline{S}_{y,3\&4,j}$ represents the mean of the standardized catch-rates in the third and fourth quarters in year *y* and area *j*:

Finally, the annual index for all years was scaled so that the mean of the annual index over the entire time-series was equal to 1.

6 Selection of Area Effects for GLMs

Ideally one would like to construct an annual abundance index based on all areas fished in the fishery. However, as mentioned previously, the changing spatial extend of the ETBF creates a number of problems for the calculation of annual abundance indices. For example, over the past decade some of the highest catch rates of swordfish have been achieved in the off-shore areas of the ETBF east of 160^{o}E. However, in recent years there has been little or no fishing in this region. As such, it is not be possible to estimate the values of p_S, and μ_S, in these areas and include them in the annual abundance index defined above.

The ETBF harvest strategy will require the abundance index for each of the principal target species to be calculated on a regular basis. Furthermore, so that changes in the index are due to changes in the abundance of available fish and not due to changes in the model used to calculate the index, there is a further need to use an index (and related GLMs) that has the potential to remain the same for at least some period into the future (say 3-5 years). Given the large changes observed in the spatial extent of the fishery over the past decade, central to achieving this will be the need to define some core spatial region of the ETBF which remains constant over this period and over which an abundance index for each species can be calculated each year.

6.1 Identification of Core Catch Area

In order to identify a core region for each species over which the abundance index could be calculated, and taking into account the need for such a region to generally coincide with the areas of the fishery which have a continuous history of being fished, the following approach was followed (note, as with the analysis of the size data this analysis was first undertaken in 2009 and again explains why the data was used only to mid-2008):

1) The number of years that each 1-degree square of the ETBF had been fished over the 11 year period between 1 July 2007 to 30 June 2008 was calculated.
2) The percentage of the total ETBF catch of a given species in each year which was caught in those squares which had been fished in all 11 years was calculated. If this percentage exceeded 90% in all years then the core area for this species was taken to be the union of all these 1-degree squares.
3) If the percentages calculated in the previous step were not all greater than 90% then the percentage of the total ETBF catch in each year caught in all squares fished for 10 or more years was calculated. Again, if these percentages exceeded 90% in all years then the core area for this species was taken to be the union of all these 1-degree squares.
4) This step-by-step analysis was continued until the percentage of the total ETBF catch taken in the identified 1-degee squares exceeded 90% in each year and the core area for this species was taken to be the union of all these 1-degree squares.

The number of squares fished, the percentage of squares fished, the percentage of fishing operations, and the percentage of hooks deployed, each year within those squares which have been have been fished n-years (n=1,…,11) over the 11 financial years 1997/08 to 2007/08 are shown in Figure 6, while the percentage of the total annual catch of four species of interest caught within these squares is shown in Figure7.

From Figure 6a it is seen that the number of 1-degree squares fished in any year over this 11 year period has varied between 176 (in 2007/08) and 273 (in 2003/04). A core region comprising 104 squares has been fished in the ETBF each year, while a region of 132 (152) squares consist of those squares which have been fished 10 (9) or more years. In 2007/08 the 104 squares which have been fished in all 11 years comprised 59% of all squares fished that year while in 2002/03 these same squares only comprised 38% of all squares fished (c.f. Figure 6b). In all years more than 82% of fishing operations (FOPS or longline sets) occurred within those 104 squares fished all years, while 88% (91%) of FOPS each year occurred within the 132 (153) squares fished 10 (9) or more years (c.f. Figure 6c). On the other hand, in all years more than 80% of hooks set in the ETBF were deployed within those 104 squares fished all years, while 86% (87%) of hooks each year were deployed within the 132 (153) squares fished 10 (9) or more years (c.f. Figure 6d).

From the distribution of yellowfin catches in the ETBF shown in Figure 7a it is seen that in all years more than 87.8% of the catch was taken within those 104 squares fished all years, while at least 91.9% of the catch each year was taken within the 132 squares fished 10 or more years. Based on the protocol adopted above, the core region in the ETBF for the calculation of the annual abundance index for this species was therefore taken to consist of these 132 squares.

Figure 6. The (a) number of squares fished, (b) percentage of squares fished, (c) percentage of fishing operations, and (d) percentage of hooks deployed, each year within those squares which have been have been fished n-years over the 11 financial years 1997/08 to 2007/08.

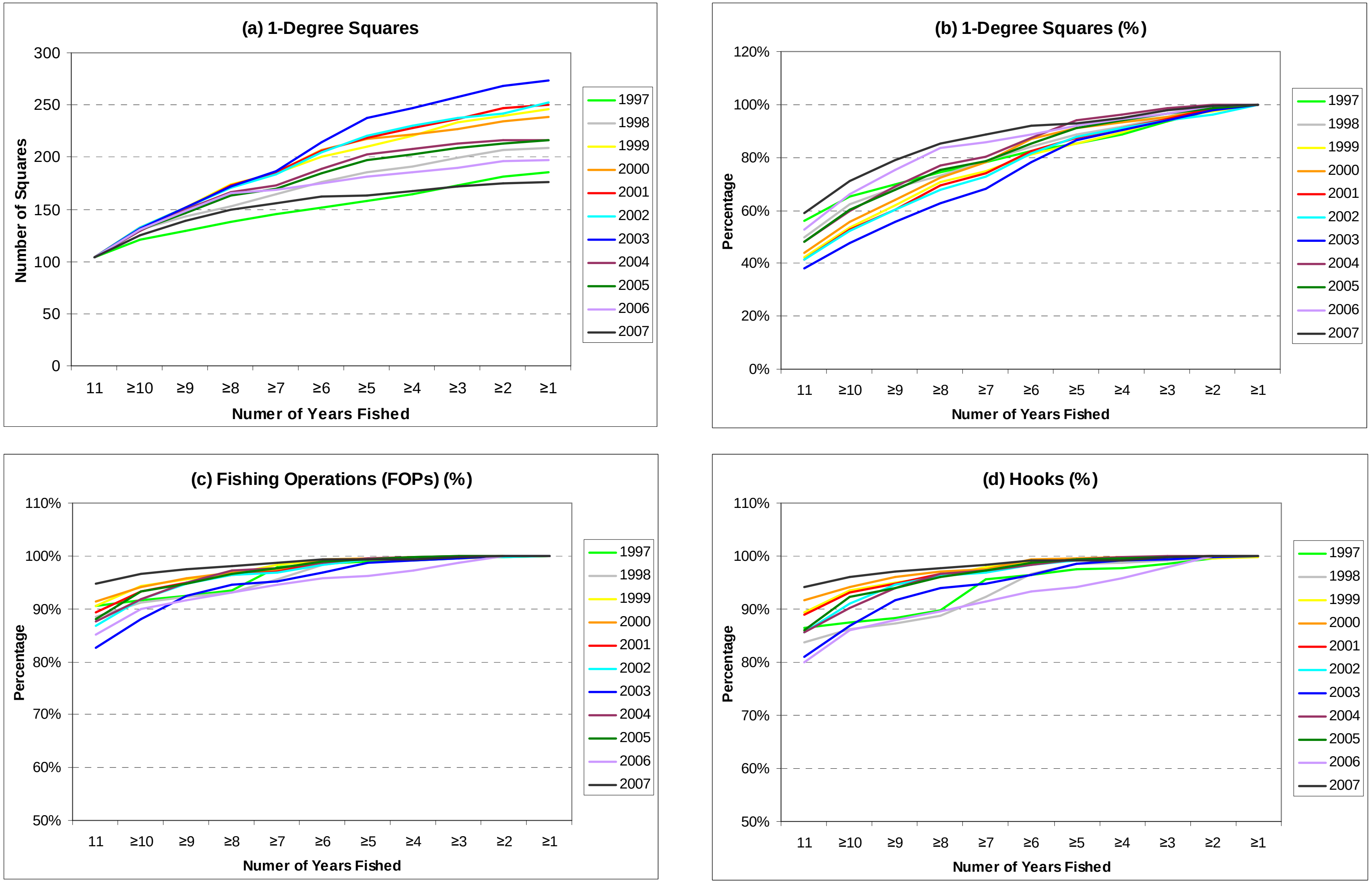


Figure 7. The percentage of the total annual catch of four species caught within those squares which have been have been fished n-years over the 11 financial years 1997/08 to 2007/08.

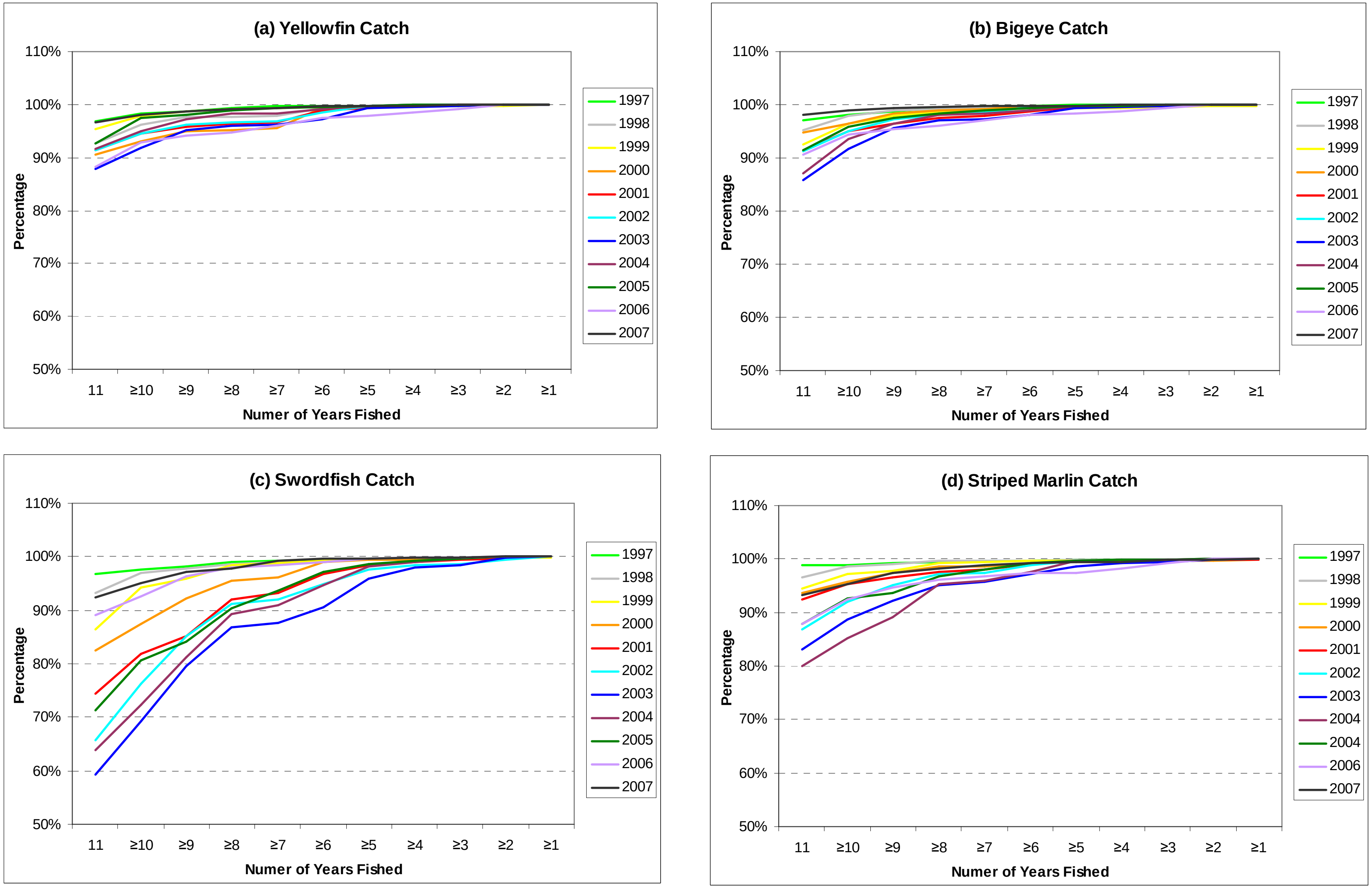
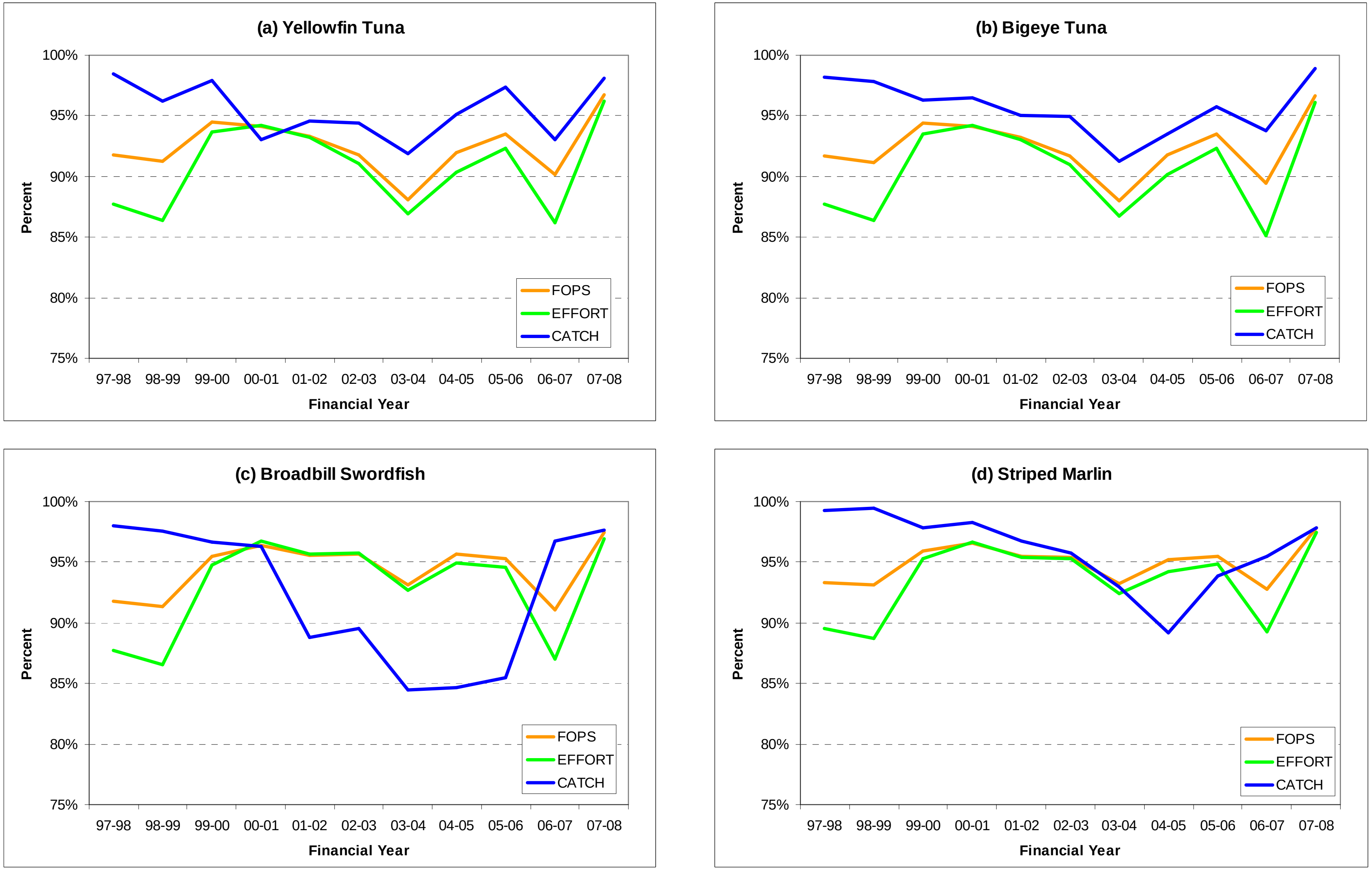


Figure 8. The percentage of the total annual effort and catch caught within the core area identified for each of the four principal target species displayed.



For bigeye tuna, in all years more than 85.8% of the catch was taken within those 104 squares fished all years, while at least 91.6% of the catch each year was taken within the 132 squares fished 10 or more years (c.f. Figure 7b). Hence, the same core region as adopted for yellowfin was also adopted as the core region for bigeye.

The distribution of striped marlin catches in the ETBF, shown in Figure 7d, indicates that the catches are distributed on a slightly greater spatial scale than either yellowfin or bigeye tuna. Across all years, the percentage of the total annual catch found in the 132 squares fished for 10 or more years is between 85-99% whilst at least 92.2% of the catch is taken within the 153 squares fished 9 or more years in all years but one (2004) when 89% of the catch was taken. Modifying the criteria adopted above slightly, we therefore adopt these 153 squares as the core region for striped marlin. (Note, if we had gone to the next level, at least 95% of the catch each year is taken within the 176 squares fished 8 or more years.)

For swordfish, the distribution of catches is seen to be significantly different to those for yellowfin and bigeye tuna (c.f. Figure 7c). This is due to the core fishery being further offshore than for the other species. In all years only 59.4% of the catch was taken within those 104 squares fished all years, while only 69.2% of the catch each year was taken within the 132 squares fished 10 or more years. In order to ensure that more than 90% of the catch in any year is taken, one needs to adopt as the core region the 219 squares fished for 6 or more years. However, as a substantive part of this later region coincides with areas where swordfish are not caught in high numbers, as for striped marlin the criteria for defining the core region was modified slightly. In this instance we adopted as the core region the 114 squares west of 159^{o}E fished for 10 years or more and the 75 squares east of 159^{o}E fished for 5 years or more. This gives a core region of 189 1-degree squares.

6.2 Selection of sub-areas

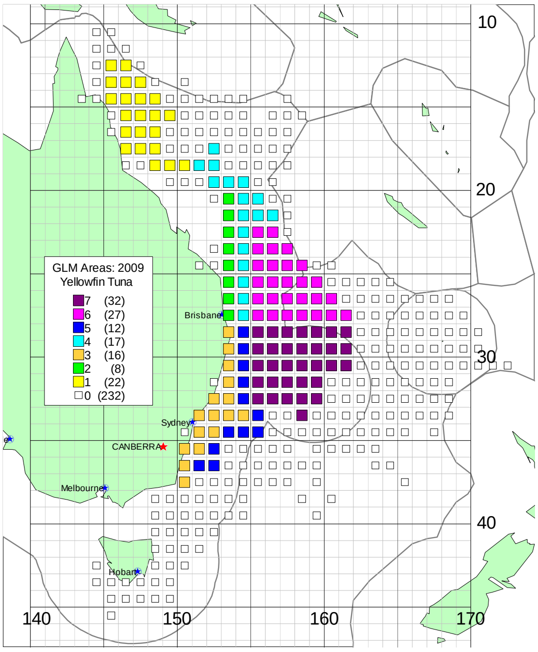
Having selected a core region for each species, this region was sub-divided into a number of sub-regions, or areas, (usually 6 or 7) to serve as Area-effects within the GLM. For each species these areas were selected as follows:

1) the nominal CPUE within each 1-degree square within the core region was calculated for each year (but only where the number of FOPS was 5 or more). The mean of these nominal CPUEs was there calculated over all years and the distribution of these mean CPUEs for each 1-degree square was mapped.
2) the distribution of mean annual CPUEs were binned into 6 categories using the Equal Range mapping criteria in MapInfo. The resulting distributions for each species are shown in Figures 6c-9c.
3) the core region was subdivided into 6 or 7 areas by grouping together 1-degree squares having similar CPUE. In some instances additional 1-degree squares were added to make the area contiguous or several outlying squares were removed. The resulting areas are shown in Figure 9.

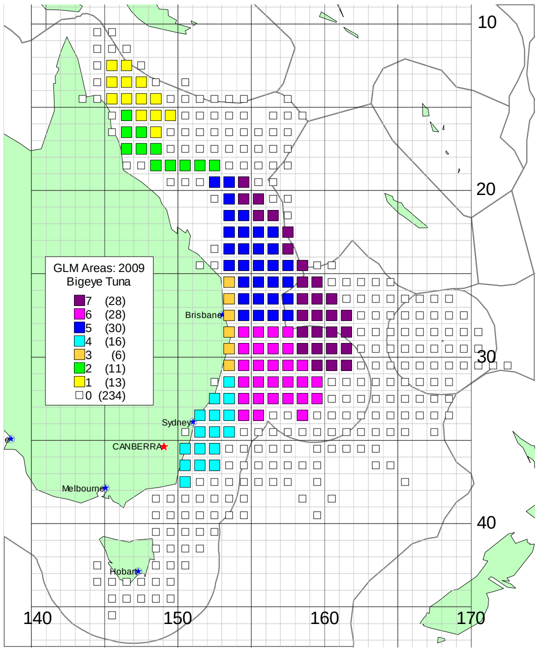
The percentage of total ETBF FOPS, effort and catch of each species taken within the identified areas during each (financial) year are shown in Figure 7a-d while the mean percentages across all years are given in Table 5. Clearly, the objective of identifying a core region for each species in which a significant proportion of the catch each year is taken has been achieved.

Figure 9. Sub-regions of the ETBF selected as area-effects in the GLMs for each species.

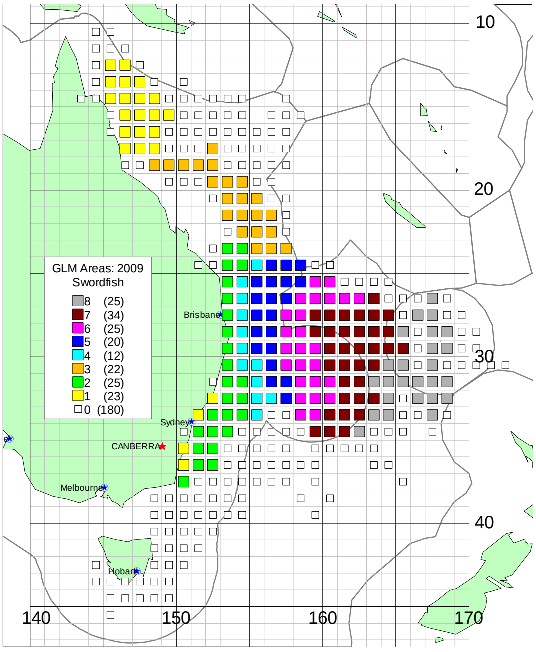
(a) Yellowfin Tuna



(b) Bigeye Tuna



(c) Broadbill Swordfish



(d) Striped marlin

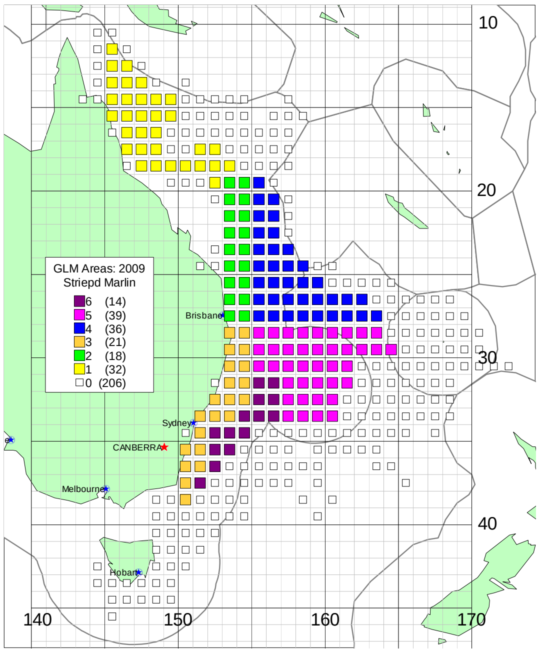


Table 5. Mean percentage of FOPS, effort and catch taken within the GLM areas for each species.

Species	FOPS	Effort	Catch
Yellowfin Tuna	92.5%	90.7%	95.5%
Bigeye Tuna	92.3%	90.6%	95.6%
Broadbill Swordfish	94.5%	93.0%	92.4%
Striped Marlin	94.9%	93.6%	96.1%

7. Selection of Data for GLMs

The data for inclusion in the GLM analyses for each species was limited to the 14.5 year period between 1-July 1997 and 31-December 2011. However, upon closer inspection of the data in each of the sub-areas identified in the previous section it was decided that not all such areas be included in the analyses.

7.1 Selection of GLM Areas

For each species the percentage of the aggregate catch over the entire 14.5 year period taken within each species-specific area is shown in Table 6. For yellowfin tuna 13.2% of the total catch was taken in Area 1 while 36.6% of the total catch was taken in Area 3 – only 4.8% of the total catch was not taken within a GLM-area. As close to 5% of the catch was taken in all Areas, data from all areas was included in the associated GLM analyses. On the other hand, as less than 1% of the total bigeye catch was taken in Area 1, and as this Area could be considered as being a non-core bigeye region of the ETBF, only the data from Areas 2-7 were included in the associated GLM analyses for this species. For a similar reason, only the data from Areas 2-6 were included in the associated GLM analyses for striped marlin. (Note, while an attempt is being made to limit the data in each analysis to the core catch regions for any species, another reason for not including areas with small catches is that there will be a high proportion of sets with a zero catch of this species and this may cause problems in the subsequent analyses).

Table6. For the indicated species, the percentage of the total catch aggregated over the 11 financial years taken within each area (Catch) and for each area the percentage of all FOPS in that area for which the catch is zero (Zero).

	Yellowfin Tuna		Bigeye Tuna		Broadbill Swordfish		Striped Marlin	
Area	**% Catch**	**% Zero**	**% Catch**	**% Zero**	**% Catch**	**% Zero**	**% Catch**	**% Zero**
1	13.2%	19.0%	0.8%	67.7%	1.0%	83.5%	2.2%	94.9%
2	10.9%	9.2%	18.0%	45.4%	12.8%	54.8%	18.9%	59.7%
3	36.6%	13.7%	3.3%	63.9%	6.5%	34.1%	18.3%	67.4%
4	14.7%	16.6%	11.7%	55.4%	13.3%	36.4%	17.5%	67.5%
5	6.1%	20.0%	40.1%	31.8%	25.9%	13.7%	27.4%	55.8%
6	8.7%	25.0%	14.4%	33.8%	18.2%	5.9%	11.3%	59.4%
7	4.9%	23.7%	7.6%	34.0%	15.8%	2.7%	1.0%	75.8%
8					4.6%	0.0%		
Non-Core	4.8%	38.9%	4.1%	55.8%	1.9%	70.9%	3.4%	75.1%
	100.0%		100.0%		100.0%		100.0%	

For swordfish, again due to the small proportion of the total catch taken in Area 1 (and the corresponding high proportion of zero catches) this Area was not included in the associated GLM analyses. On the other hand, while close to 5% of the total catch has been taken in Area 8, unfortunately this area has a poor data coverage, with 35 of the 58 (Year, Quarter) strata having less than 10 FOPS (of which 22 strata have no FOPS). With no way of estimating the abundance index in this Area during these latter quarters, this Area was also excluded from the GLM analyses.

In summary then, for each species the final set of data selected satisfied the following criteria:

- The date of all selected sets was within the 14.5 year period between 1 July 1997 to 31 December2011),
- The location of all selected sets was within the selected spatial GLM areas chosen for that specific species,
- All variables used in the models were available (i.e. associated number or hooks, number of hook-per-float, bait-type, number of light-sticks, start-set-time and associated environmental data were all non-null). Those sets (around 50) where the number of hooks-per-floats is less than 3 or greater than 40 were removed due to possible data errors, and,
- All sets where the number of hooks≤200 were also removed from the data set - again due to the possibility of data errors and to avoid those sets (generally in the Coral Sea) where a small number of hooks are deployed to target aggregations of tuna during certain period of the year (generally October and November).

Table 7. Listing of the number of records (individual fishing sets) within each data set fitted for each species. Also shown are the maximum CPUE values (limits) used to screen out possible outliers in the data, the number of Year-Quarter-Area strata (Y.Q.A) for which there were data, and the percentage of zero catch observations in the binomial GLM.

Size Class	Item	Yellowfin Tuna	Bigeye Tuna	Broadbill Swordfish	Striped Marlin
	Number of Years	14.5	14.5	14.5	14.5
	Number of Areas (Squares)	7 (134)	6 (119)	7 (161)	5 (114)
	Number of Quarters	4	4	4	4
	Maximum number of Y.Q.A. strata	406	348	406	290
SMALL	CPUE limit	175	150	22	15
PRIME	CPUE limit	170	150	40	40
LARGE	CPUE limit	80	70	23	30
ALL	CPUE limit	300	240	60	60
(a) Prob(Non-Zero Catch) - BINOMIAL Distribution					
SMALL	Number of sets	120,885	117,707	123,419	102,988
	Zero catch sets (%)	36.4%	50.2%	43.4%	67.4%
PRIME	Number of sets	120,883	117,709	123,422	102,988
	Zero catch sets (%)	21.0%	43.3%	41.1%	64.2%
LARGE	Number of sets	120,886	117,706	123,422	102,985
	Zero catch sets (%)	20.4%	44.4%	44.2%	66.9%
ALL	Number of sets	120,881	117,705	123,420	102,982
	Zero catch sets (%)	18.3%	41.0%	40.1%	62.5%
(b) Size of Non-Zero Catch - GAMMA Distribution					
SMALL	Number of sets	76,835	58,571	69,788	33,542
PRIME	Number of sets	95,446	66,684	72,725	36,852
LARGE	Number of sets	96,254	65,450	68,827	34,129
ALL	Number of sets	98,747	69,397	73,937	38,620

- Finally, for each species and size class an upper limit was set on the CPUE to remove a small number of sets (generally less than 10) having anomalous high catch rates, again due to possible data errors.

A listing of the number of records (individual fishing sets) within each data set fitted for each species and size class, together with a number of other features of the data, is given in Table 7.

7. Treatment of Discarded Fish

The catch used in the GLM analyses is a combination of the number of fish retained and the number of fish discarded, both of which are recorded in the logbooks. However, unlike the large amount of size data that exists for the retained component of the catch, and which is used to apportion the retained catch by size category, no such data exists for the discarded component of the catch. In past analyses it has been assumed that the principal reason for discarding fish was that they were small (and of little market value) and so the discarded component of the catch was added to the Small size class component of the catch. However, more recently the observer data has been analysed in order to gain a better understanding of the reasons for discarding fish and the size of these fish. In particular, the following three sets of data recorded by observers were analysed.

1) *Size of discarded fish*:
   Observers, in some instances, have recorded the lengths of discarded fish. Histograms of these lengths were provided in Campbell (2008) and after using an appropriate length-to-weight relationship these data were used to ascertain the proportion of these fish within each the three size-classes used in the GLM analyses.

2) *Life status of discarded fish*:
   Observers record the life-status of all fish bought onto the vessel and the life life-status of the discarded component has been summarised previously by Campbell (2008) and Anon (2010a). Life-status can be divided into three board categories - 'dead & damaged', dead, and 'alive' – and it is inferred that the proportion of the discarded catch classified as 'dead & damaged' has been depredated on the line after capture. As stated in the Anon (2010a) "in theory it would be logical to assume the reminder of discarded catch is likely to be fish that are alive and are too small or have no economic value at the time of landing." If one assumes then that the 'dead' or 'alive' components of the discarded fish are all small, then the combined proportion of discards classified as 'dead' or 'alive' as can be taken as some measure of the proportion of all discards which are Small.

3) *Reason for discarding*:
   While the reason for discarding a fish is not normally recorded by observers, in some instances the comments provided by observers do note a reason. An analysis of these comments, and a summary of the reasons noted for discarding - classified as 'juvenile', 'predated' and 'other', was provided in Anon (2010a). The proportion of fish discarded as juvenile can again be taken as a minimum indicator of the proportion of discards which could be classified as Small, noting that small fish may also be predated upon and be included in the 'other' category.

Table 8. Summary of the observer data on discarding of swordfish and striped marlin: (a) the proportion of discards within each size class used in the GLM analyses, (b) the life-status of discarded fish, and (c) the reasons for discarding a fish.

	Yellowfin	Bigeye	Swordfish	Striped Marlin
(a) Proportion by Size Class of Discarded Fish				
SMALL	84.1%	83.8%	91.0%	18.2%
PRIME	10.6%	9.1%	5.2%	0.0%
LARGE	5.3%	7.1%	3.7%	81.8%
No Fish	170	99	134	9
(b) Life Status of Discarded Fish				
0. Dead & Damaged	714	250	168	12
1. Dead, in rigour	39	9	15	4
2. Dead, flexible	18	5	55	3
3. Alive, just	8	12	18	0
4. Alive, sluggish	46	31	27	1
5. Alive, vigorous	315	235	53	6
No Fish	1140	542	336	26
Dead & Damaged	62.6%	46.1%	50.0%	46.2%
Dead or Alive	37.4%	53.9%	50.0%	53.8%
c) Reason for discarding: Percent described as juvenile				
2003	2.0%	11.0%	40.0%	25.0%
2004	10.0%	16.0%	12.0%	0.0%
2005	13.0%	8.0%	14.0%	9.0%
2006	1.0%	3.0%	91.0%	31.0%
2007	13.0%	15.0%	18.0%	0.0%
No Fish	Unknown	Unknown	Unknown	Unknown
Mean	7.8%	10.6%	35.0%	13.0%

A summary of the observer data on discards described above for the five principal target species targeted within the ETBF is provided in Table 8. The data on the size of discarded fish provides the most direct means of measuring the proportion of discarded fish falling within each size class, though the number of fish for which this information has been collected is not large (134 swordfish and only 9 striped marlin). On the other hand, each of the other two indicators of the proportion of discarded fish which can be classified as Small (proportion dead or alive, or discarded due to be juvenile) rely on a number of assumptions about i) whether only small fish are discarded if not depredated, and ii) what proportion of the 'predated' and 'other' categories used to classify reasons for discarding a fish can also be classified as small fish.

Based on the above analyses of discards, the proportion of fish discarded within each category was taken to be given by the data summarised by (a) in Table 8. For example, for swordfish the catch for each size category is then defined as follows:

Catch(Small) = Retained_Catch*Proportion_Small + Discarded_Catch*0.910
Catch(Prime) = Retained_Catch*Proportion_Prime + Discarded_Catch*0.053
Catch(Large) = Retained_Catch*Proportion_Large + Discarded_Catch*0.037

Due to the small sample size of fish for striped marlin, and given the similar size of these species, the catch definition of this species was taken to be the same as for swordfish.

8. Results and Discussion

The results of the GLM analysis for each of the four species (yellowfin tuna, bigeye tuna, broadbill swordfish and striped marlin) and for each of the four size classes (Small, Prime, Large and combined (denoted ALL)) are given in the following sub-sections. However, due to the large number of analyses conducted not all results are displayed. The BIC goodness-of-fit criteria was also utilized to discern the more parsimonious of the two models using the different functional form of the function f(year, qtr,area) and for the ALL size-class results this criteria indicated that Model 1 was preferred (except for the negative binomial model for yellowfin tuna). As such, except for the figures displaying the annual trends for the standardized indices all other results correspond to the use of Model l.

For striped marlin two additional analyses were undertaken in order to provide standardized indices corresponding to two of the respective regions used in the updated stock assessment for this species undertaken by SPC-OFP this year. These two regions have a border at 20°S and as such the data used in the GLMs were divided into two data sets corresponding to fishing activities north and south of this border. Separate analyses (but similar to those undertaken on the combined data) were then undertaken on each of these data sets. As the stock assessment does not include size-based stock indices, these models were only fitted to the combined (ALL) size class. The results are shown in Figures STM-5 and STM-6.

Finally, several diagnostics related to checking the fit of the ALL size-class data to the negative binomial model are also shown (see McCullagh and Nelder 1983). These include two indicators of the normality of the distribution of the standardized deviance residuals, a plot of the residuals against the year effect in the linear predictor, and a plot of the absolute residual against the fitted values (which gives an informal check on the adequacy of the assumed variance function). For these latter two checks the null pattern shows no trend while an ill-chosen effect or variance function will result in a trend in the mean. The slightly positive trend seen in this last plot for several species indicates that the assumed variance function is increasing too slowly with the mean so that the choice of $V(\mu)$proportional to μ^2 may need to be replaced by $V(\mu)$proportional to μ^k where $k>2$. This is most likely due to the highly skewed distribution of the catch-rates. Evidence of some departure of the distributions of residuals from normality also indicates that further investigations are warranted to find models that provide a more appropriate fit to the data.

8.1 Yellowfin Tuna

Annual Indices

Table YFT-1 Annual standardised CPUE indices for yellowfin tuna based on the results from Model 1. Note: The Small, Prime, Large and All columns give indices based on fitting the GLM to the respective catch data for small, prime, large and all sized yellowfin tuna. The result in the Combined column is equal to Small+Prime+Large and can be compared with the result for ALL sizes.

Year	Year	Small	Prime	Large	Combined	All
97	1997	1.04	1.04	0.77	0.95	0.86
98	1998	0.74	1.12	0.98	0.98	1.01
99	1999	0.17	0.81	1.37	0.84	0.84
00	2000	0.95	0.90	0.65	0.83	0.88
01	2001	0.65	1.09	1.18	1.01	0.93
02	2002	1.50	0.97	0.88	1.07	1.06
03	2003	1.96	1.24	1.02	1.35	1.22
04	2004	1.31	1.00	0.74	0.99	0.89
05	2005	0.64	0.63	1.22	0.83	0.85
06	2006	1.43	1.16	0.65	1.06	1.22
07	2007	1.14	0.86	0.87	0.93	0.98
08	2008	1.91	1.09	0.97	1.25	1.26
09	2009	0.62	0.88	0.66	0.74	0.78
10	2010	0.45	0.82	1.07	0.81	0.86
11	2011	0.50	1.38	2.00	1.36	1.37
Mean	Mean	1.00	1.00	1.00	1.00	1.00

Figure YFT-1. Annual nominal and standardised CPUE indices for each size-class for yellowfin tuna.

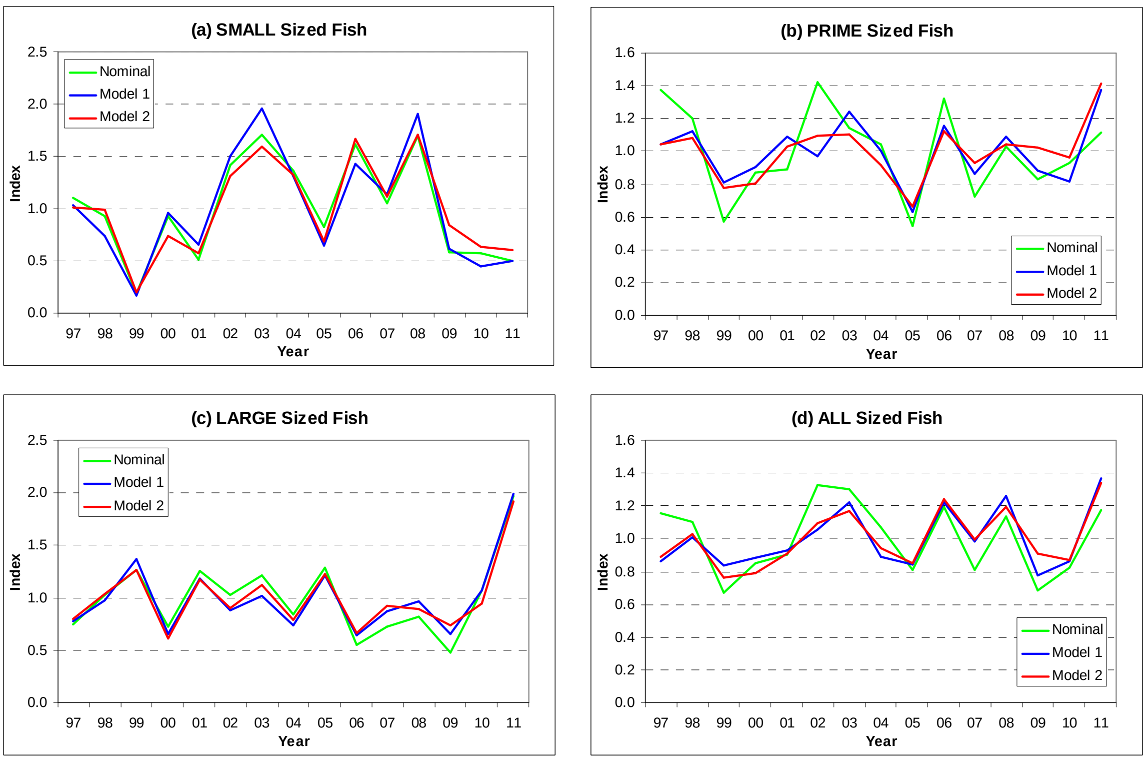


Figure YFT-2. Time-series of quarterly standardised for yellowfin tuna based on the results from Model 1 fitted to the ALL size-class data.

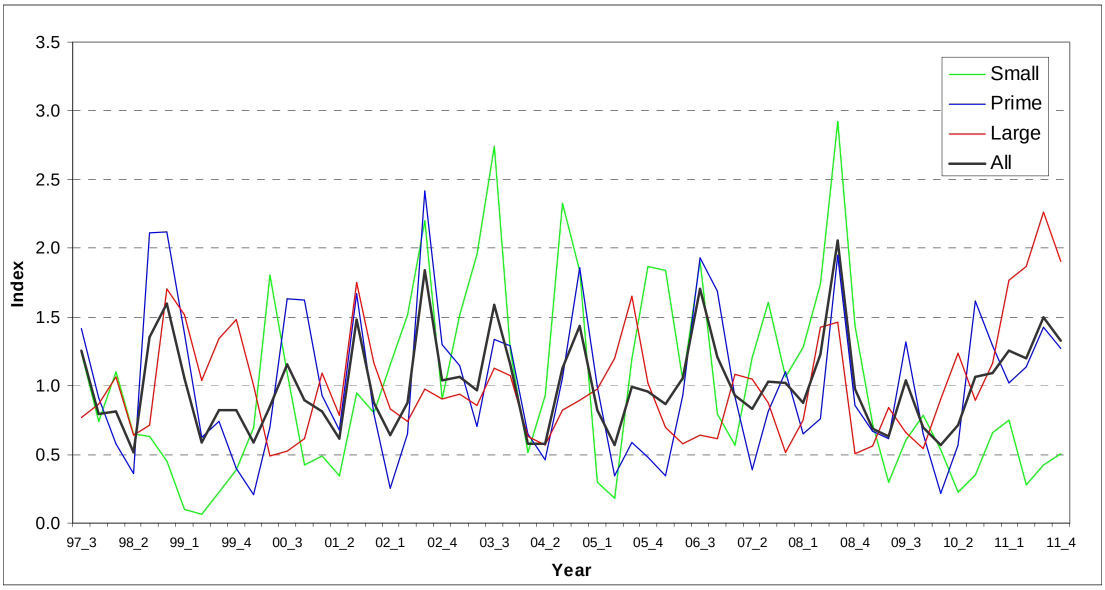
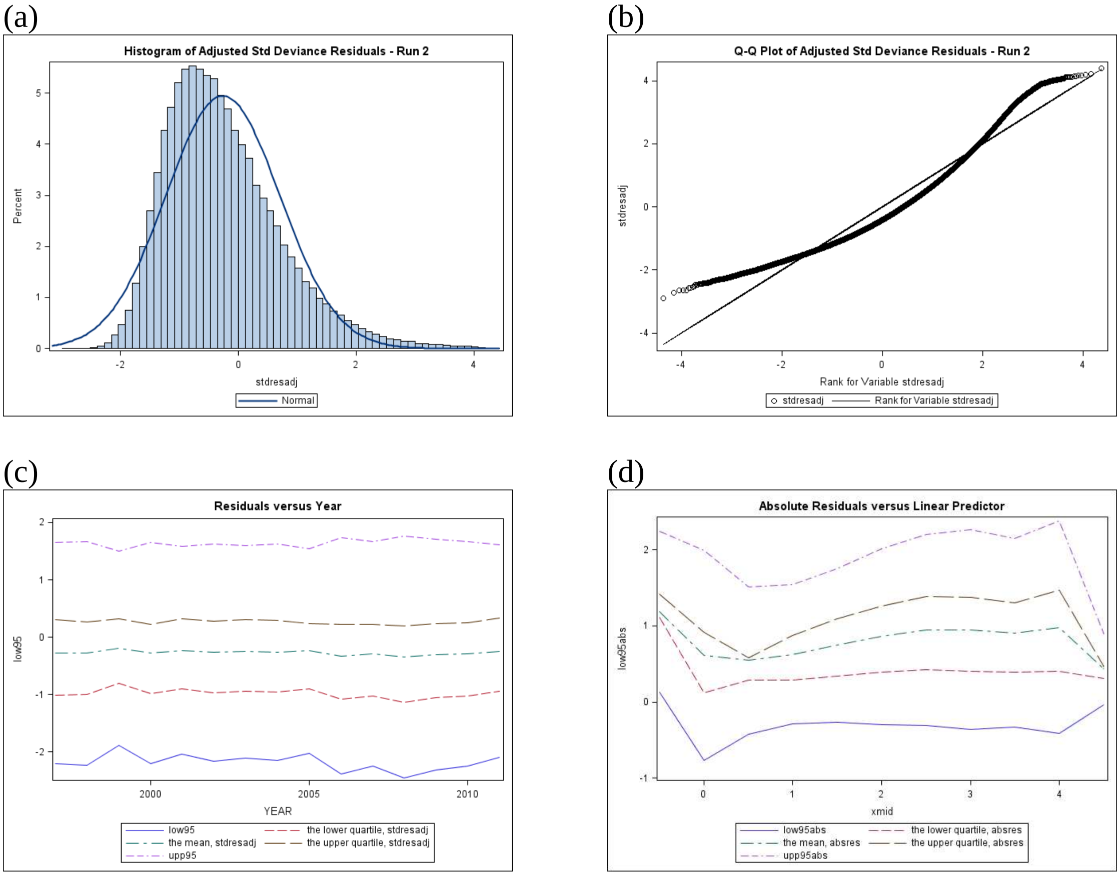


Table YFT-2. Goodness-of-fit criteria (both GLMs) and Type-3 analysis for Model 1 fitted to the ALL size-class data for yellowfin tuna.

	ALL Yellowfin Tuna						
	Log Likelihood	AIC	BIC		Log Likelihood	AIC	BIC
Model 1	-52639	105749	108029		-292178	584829	587071
Model 2	-51580	104279	109703		-289226	579572	584892

Effect	df	Chi-Sq	ChiSq/df	Pr>ChiSq		df	Chi-Sq	ChiSq/df	Pr>ChiSq
Year*Qtr	54	2871	53.2	<0.0001		54	3981	73.7	<0.0001
Qtr*Area	18	297	16.5	<0.0001		18	1355	75.3	<0.0001
Lights	6	45	7.5	<0.0001		6	134	22.3	<0.0001
Bait-Type	8	497	62.1	<0.0001		8	752	94.0	<0.0001
Start-Time	5	45	9.0	<0.0001		5	1515	303.0	<0.0001
HPF	7	167	23.9	<0.0001		7	1859	265.6	<0.0001
Moon-phase	1	311	311.0	<0.0001		1	414	414.0	<0.0001
Area*SOI	28	198	7.1	<0.0001		28	383	13.7	<0.0001
Area*SST	28	195	7.0	<0.0001		28	400	14.3	<0.0001
Area*MLD	28	291	10.4	<0.0001		28	372	13.3	<0.0001
Area*ALT	28	175	6.3	<0.0001		28	346	12.4	<0.0001
Daily-VES	7	128	18.3	<0.0001		7	185	26.4	<0.0001
Monthly-VES	7	32	4.6	0.0068		7	27	3.9	0.0003

Figure YFT-3. Checks of the fit of Model 1 to the negative binomial GLM for the ALL size-class data for yellowfin tuna: (a) distribution of residuals, (b) Q-Q plot of residuals, (c) distribution of residuals against year effect, and (d) distribution of absolute residuals against linear predictor. Residual is standardised deviance residual.



8.2 Bigeye Tuna

Annual Indices

Table BET-1. Annual standardised CPUE indices for bigeye tuna based on the results from Model 1. Note: The Small, Prime, Large and All columns give indices based on fitting the GLM to the respective catch data for small, prime, large and all sized bigeye tuna. The result in the Combined column is equal to Small+Prime+Large and can be compared with the result for ALL sizes.

Year	Year	Small	Prime	Large	Combined	All
97	1997	0.74	2.13	1.61	1.63	1.52
98	1998	0.68	1.23	1.82	1.24	1.24
99	1999	0.24	0.74	1.58	0.83	0.88
00	2000	1.45	0.41	1.02	0.84	0.82
01	2001	0.82	1.43	0.76	1.10	1.07
02	2002	1.57	0.54	0.79	0.87	0.85
03	2003	1.36	0.96	0.46	0.94	0.87
04	2004	1.36	0.80	0.66	0.91	0.85
05	2005	0.38	0.99	0.91	0.81	0.84
06	2006	1.77	0.35	0.73	0.82	0.83
07	2007	1.07	2.12	0.57	1.45	1.52
08	2008	0.99	1.29	1.47	1.26	1.29
09	2009	0.96	0.52	0.88	0.73	0.77
10	2010	0.49	0.87	0.75	0.74	0.76
11	2011	1.13	0.61	1.00	0.85	0.86
Mean	Mean	1.00	1.00	1.00	1.00	1.00

Figure BET-1. Annual nominal and standardised CPUE indices for each size-class for bigeye tuna.

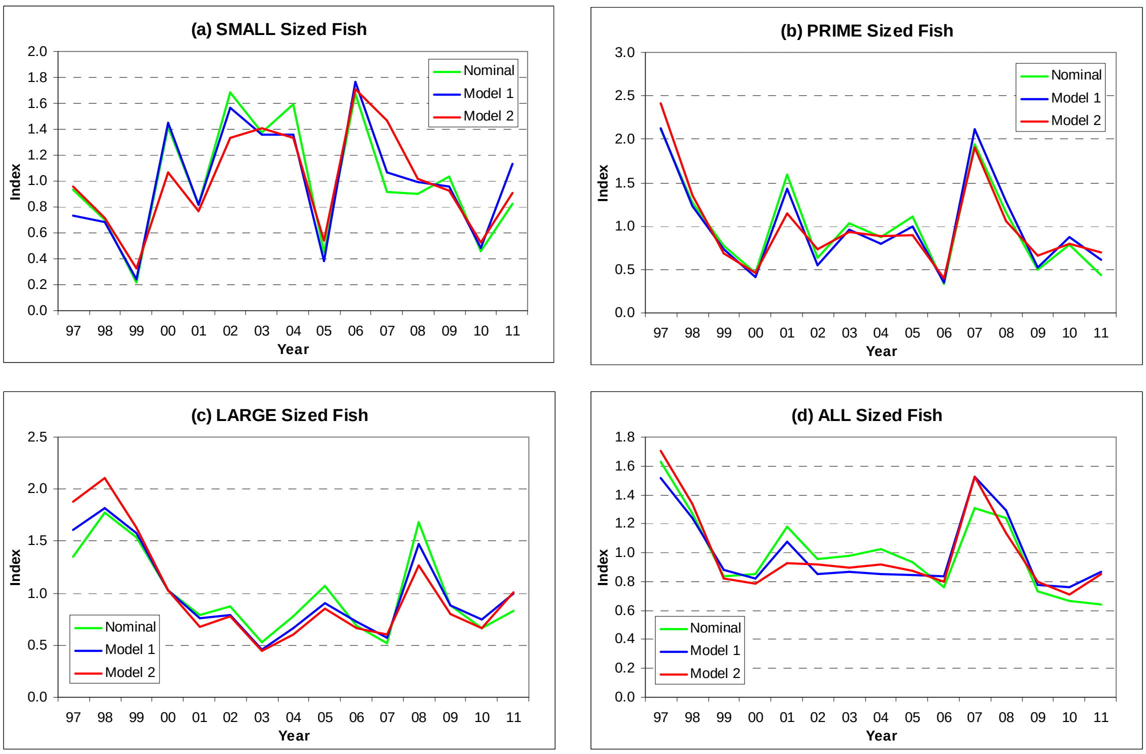


Figure BET-2. Time-series of quarterly standardised CPUE for bigeye tuna based on the results from Model 1 fitted to the ALL size-class data.

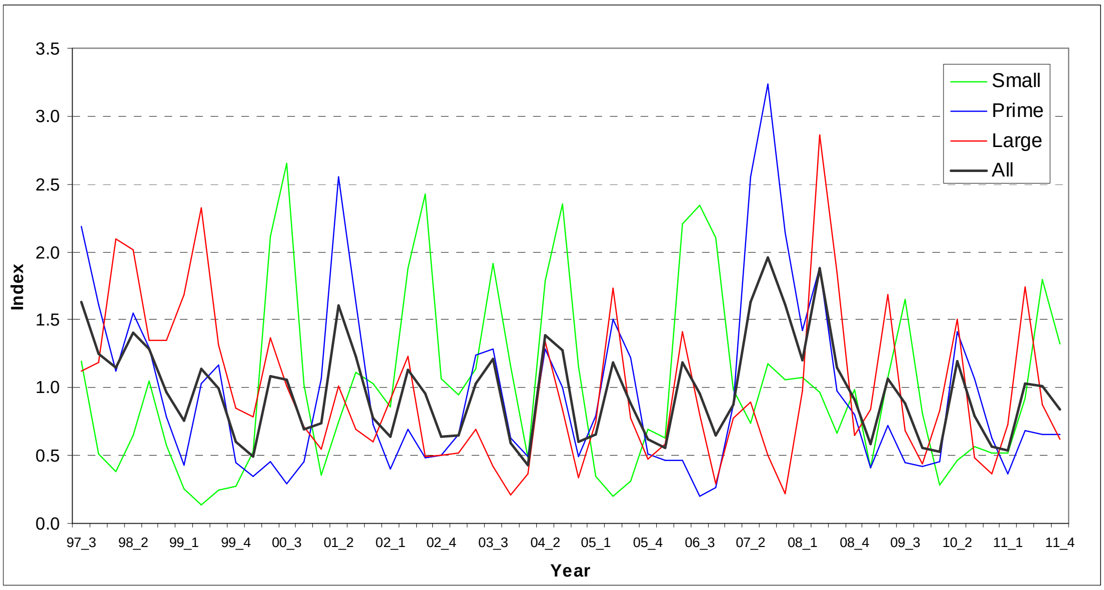


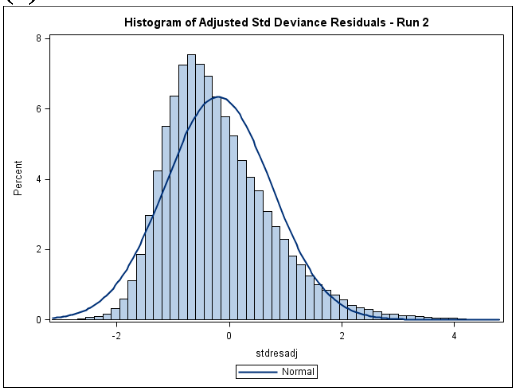
Table BET-2. Goodness-of-fit criteria (both models) and Type-3 analysis for Model 1 fitted to the ALL size-class data for bigeye tuna.

	Binomial Model				Gamma Model		
	Log Likelihood	AIC	BIC		Log Likelihood	AIC	BIC
Model 1	-67543	135516	**137596**		-166789	334010	**335985**
Model 2	-66323	133617	138310		-165843	332659	337104

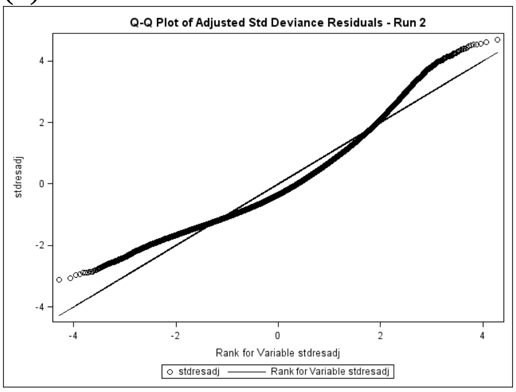
Effect	df	Chi-Square	ChiSq/df	Pr>ChiSq		df	Chi-Square	ChiSq/df	Pr>ChiSq
Year*Qtr	54	1441	26.7	<0.0001		54	2924	54.1	<0.0001
Qtr*Area	15	1329	88.6	<0.0001		15	2710	180.7	<0.0001
Lights	6	1089	181.5	<0.0001		6	631	105.2	<0.0001
Bait-Type	8	179	22.4	<0.0001		8	200	25.0	<0.0001
Start-Time	5	1133	226.6	<0.0001		5	604	120.8	<0.0001
HPF	7	1027	146.7	<0.0001		7	98.5	14.1	<0.0001
Moon-phase	1	984	984.0	<0.0001		1	1225	1225.0	<0.0001
Area*SOI	24	373	15.5	<0.0001		24	333	13.9	<0.0001
Area*SST	24	173	7.2	<0.0001		24	204	8.5	<0.0001
Area*MLD	24	256	10.7	<0.0001		24	182	7.6	<0.0001
Area*ALT	24	278	11.6	<0.0001		18	350	19.4	<0.0001
Daily-VES	7	355	50.7	<0.0001		7	283	40.4	<0.0001
Monthly-VES	7	91.4	13.1	<0.0001		7	140	20.0	<0.0001

Figure BET-3. Checks of the fit of Model 1 to the negative binomial GLM for the ALL size-class data for bigeye tuna: (a) distribution of residuals, (b) Q-Q plot of residuals, (c) distribution of residuals against year effect, and (d) distribution of absolute residuals against linear predictor. Residual is standardised deviance residual.

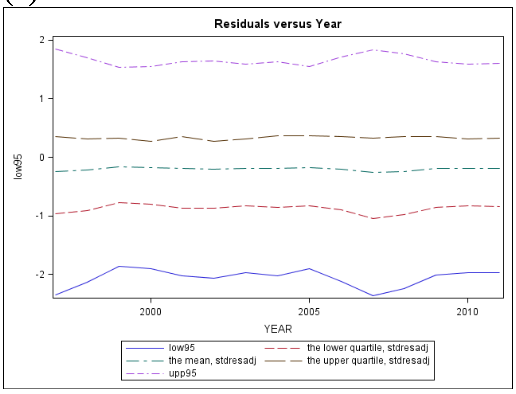
(a)



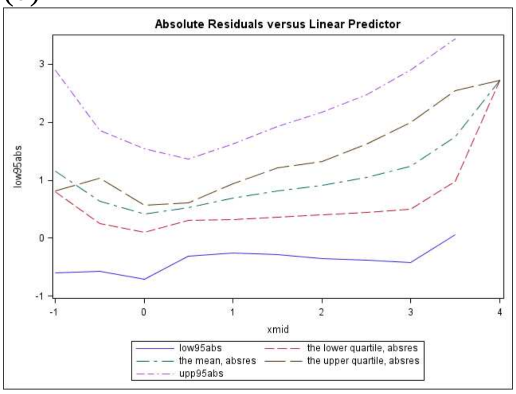
(b)



(c)



(d)



8.3 Broadbill Swordfish

Annual Indices

Table SWO-1. Annual standardised CPUE indices for broadbill swordfish based on the results from Model 1. Note: The Small, Prime, Large and All columns give indices based on fitting the GLM to the respective catch data for small, prime, large and all sized broadbill swordfish. The result in the Combined column is equal to Small+Prime+Large and can be compared with the result for ALL sizes.

Year	Year	Small	Prime	Large	Combined	All
97	1997	0.86	2.06	2.69	1.98	1.93
98	1998	0.75	1.46	1.63	1.35	1.27
99	1999	1.03	1.09	1.40	1.16	1.14
00	2000	0.74	1.08	1.21	1.04	1.01
01	2001	0.71	0.97	0.84	0.88	0.86
02	2002	1.16	0.73	0.70	0.82	0.84
03	2003	0.70	0.55	0.59	0.59	0.60
04	2004	0.96	0.74	0.57	0.74	0.76
05	2005	0.94	0.68	0.65	0.73	0.73
06	2006	1.34	0.79	0.70	0.89	0.91
07	2007	1.63	0.95	0.78	1.05	1.10
08	2008	0.98	1.12	0.92	1.04	1.06
09	2009	1.10	0.94	0.70	0.91	0.93
10	2010	1.13	0.87	0.72	0.89	0.92
11	2011	0.97	0.95	0.90	0.94	0.94
Mean	Mean	1.00	1.00	1.00	1.00	1.00

Figure SWO-1. Annual nominal and standardised CPUE indices for each size-class for broadbill swordfish.

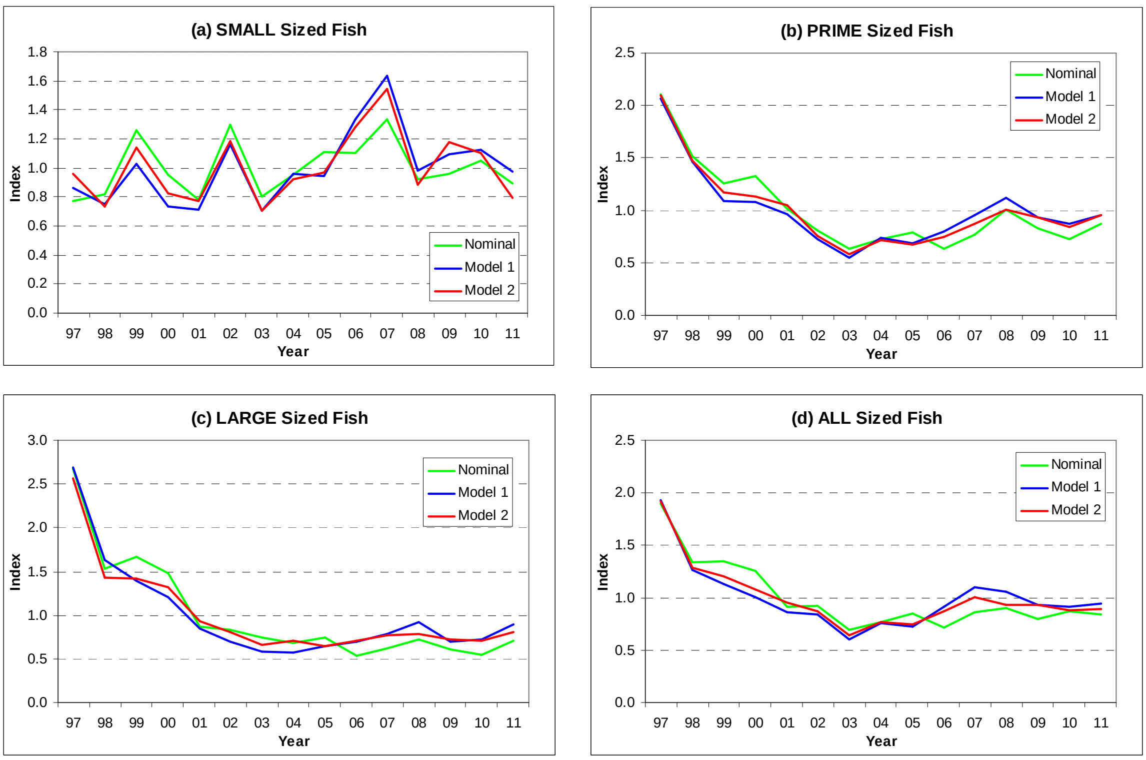


Figure SWO-2. Time-series of quarterly standardised CPUE for broadbill swordfish based on the results from Model 1 fitted to the ALL size-class data.

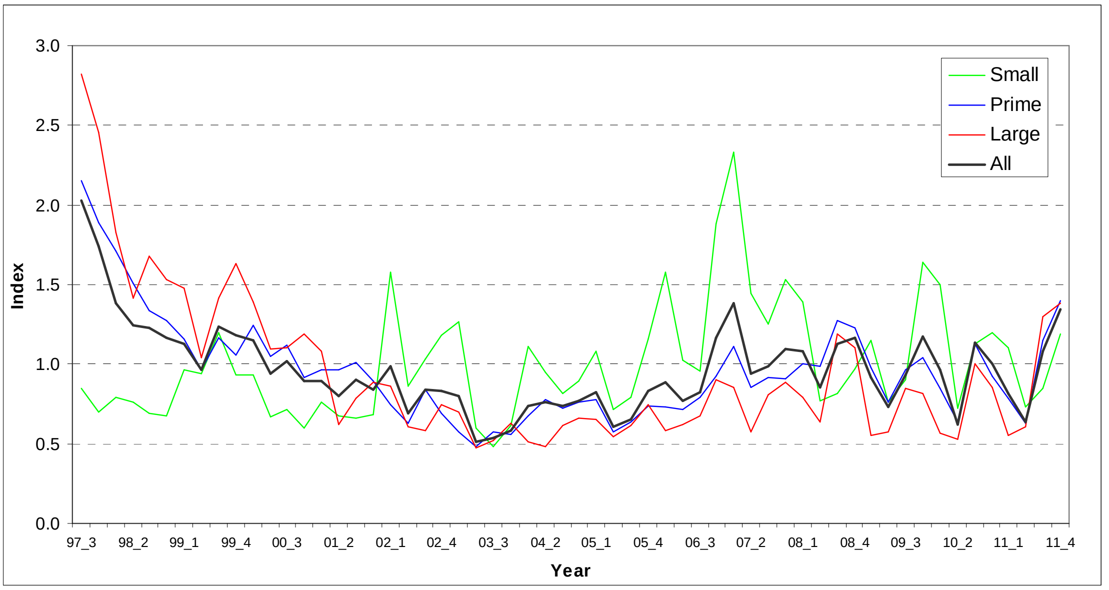


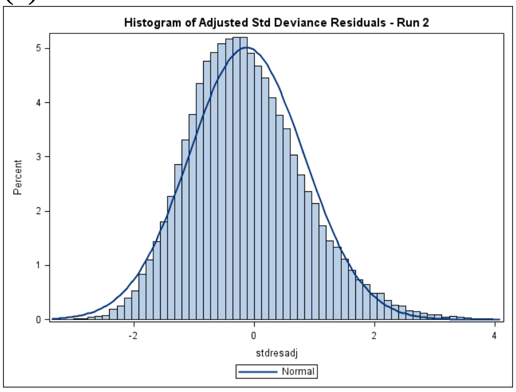
Table SWO-2. Goodness-of-fit criteria (both models) and Type-3 analysis for Model 1 fitted to the ALL size-class data for broadbill swordfish.

	Binomial Model			Negative Binomial Model		
	Log Likelihood	AIC	BIC	Log Likelihood	AIC	BIC
Model 1	-52431	105332	**107617**	-170012	340497	**342671**
Model 2	-51770	104657	110083	-169008	339134	344283

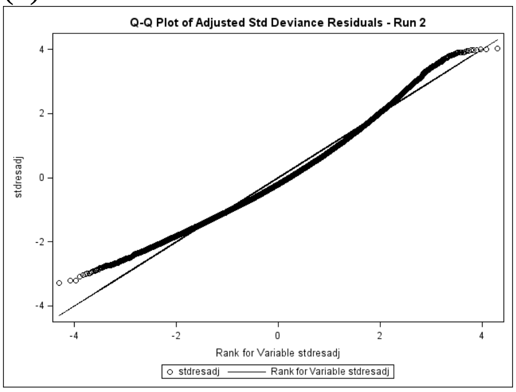
Effect	df	Chi-Sq	ChiSq/df	Pr>ChiSq	df	Chi-Sq	ChiSq/df	Pr>ChiSq
Year*Qtr	54	1325	24.5	<0.0001	54	6425	119	<0.0001
Qtr*Area	18	513	28.5	<0.0001	18	771	42.8	<0.0001
Lights	6	1833	305.5	<0.0001	6	1415	235.8	<0.0001
Bait-Type	8	581	72.6	<0.0001	8	488	61.0	<0.0001
Start-Time	5	2529	505.8	<0.0001	5	1973	394.6	<0.0001
HPF	7	53.1	7.6	<0.0001	7	1383	197.6	<0.0001
Moon-phase	1	991	991.0	<0.0001	1	2056	2056	<0.0001
Area*SOI	28	221	7.9	<0.0001	28	268	9.6	<0.0001
Area*SST	28	81.7	2.9	<0.0001	28	133	4.8	<0.0001
Area*MLD	28	151	5.4	<0.0001	28	332	11.9	<0.0001
Area*ALT	28	191	6.8	<0.0001	21	248	11.8	<0.0001
Daily-VES	7	37.2	5.3	<0.0001	7	32.6	4.7	<0.0001
Monthly-VES	7	86.6	12.4	<0.0001	7	167	23.9	<0.0001

Figure SWO-3. Checks of the fit of Model 1 to the negative binomial GLM for the ALL size-class data for broadbill swordfish: (a) distribution of residuals, (b) Q-Q plot of residuals, (c) distribution of residuals against year effect, and (d) distribution of absolute residuals against linear predictor. Residual is standardised deviance residual.

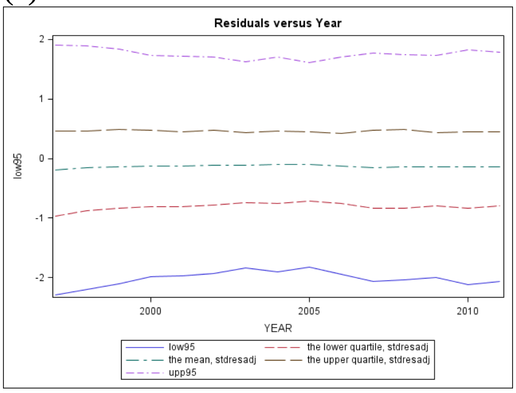
(a)



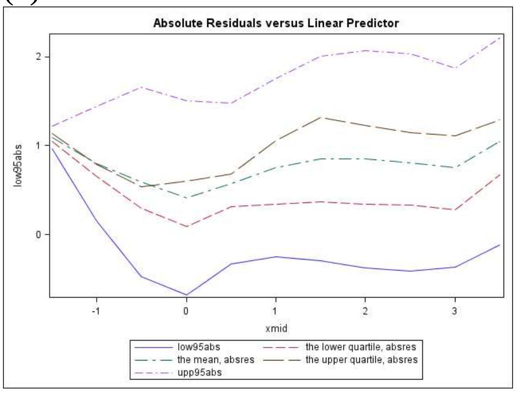
(b)



(c)



(d)



8.4 Striped Marlin

Annual Indices

Table STM-1. Annual standardised CPUE indices for striped marlin based on the results from Model 1. Note: The Small, Prime, Large and All columns give indices based on fitting the GLM to the respective catch data for small, prime, large and all sized striped marlin. The result in the Combined column is equal to Small+Prime+Large and can be compared with the result for ALL sizes.

Year	Year	Small	Prime	Large	Combined	All
97	1997	1.34	0.74	0.64	0.86	0.79
98	1998	1.58	1.37	1.02	1.33	1.36
99	1999	1.21	1.44	1.30	1.35	1.36
00	2000	1.25	1.40	1.43	1.37	1.41
01	2001	1.26	1.55	1.14	1.38	1.39
02	2002	1.08	0.89	1.23	1.02	1.02
03	2003	1.41	0.98	0.80	1.04	1.04
04	2004	0.84	0.90	1.08	0.93	0.96
05	2005	0.73	0.62	0.74	0.68	0.69
06	2006	0.95	0.94	0.92	0.94	0.93
07	2007	0.83	0.88	0.94	0.88	0.85
08	2008	1.08	1.08	0.97	1.05	1.04
09	2009	0.44	0.87	0.89	0.77	0.77
10	2010	0.42	0.64	0.97	0.67	0.65
11	2011	0.59	0.69	0.92	0.73	0.74
Mean	Mean	1.00	1.00	1.00	1.00	1.00

Figure STM-1. Annual nominal and standardised CPUE indices for each size-class for striped marlin.

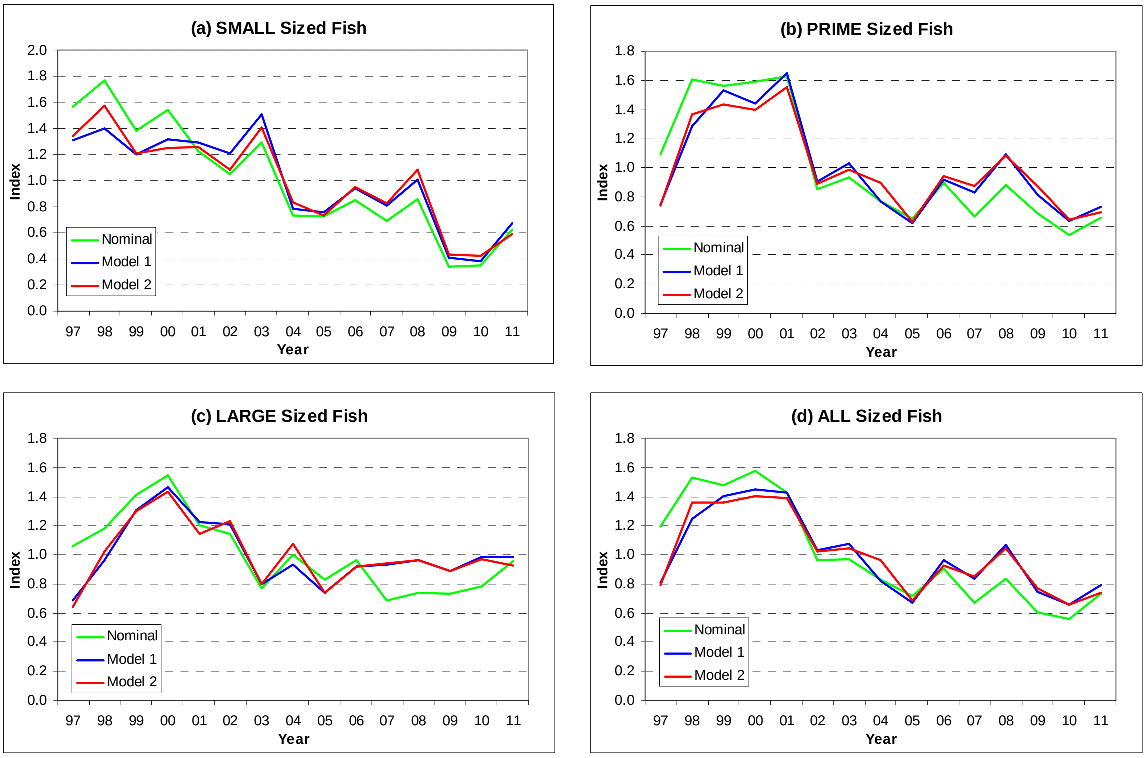


Figure STM-2. Time-series of quarterly standardised CPUE for striped marlin based on the results from Model 1 fitted to the ALL size-class data.

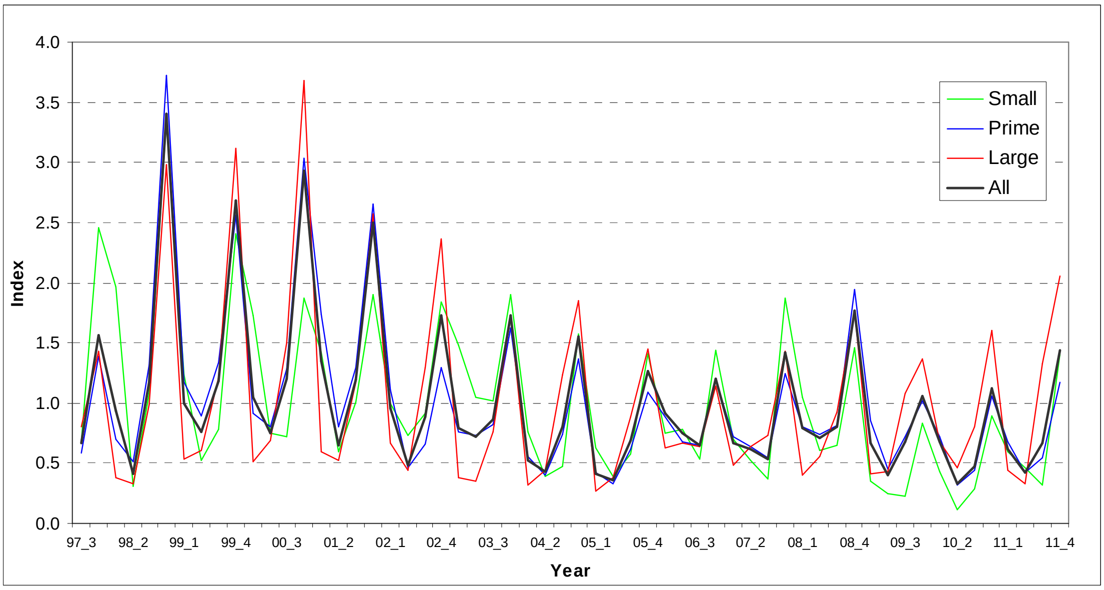
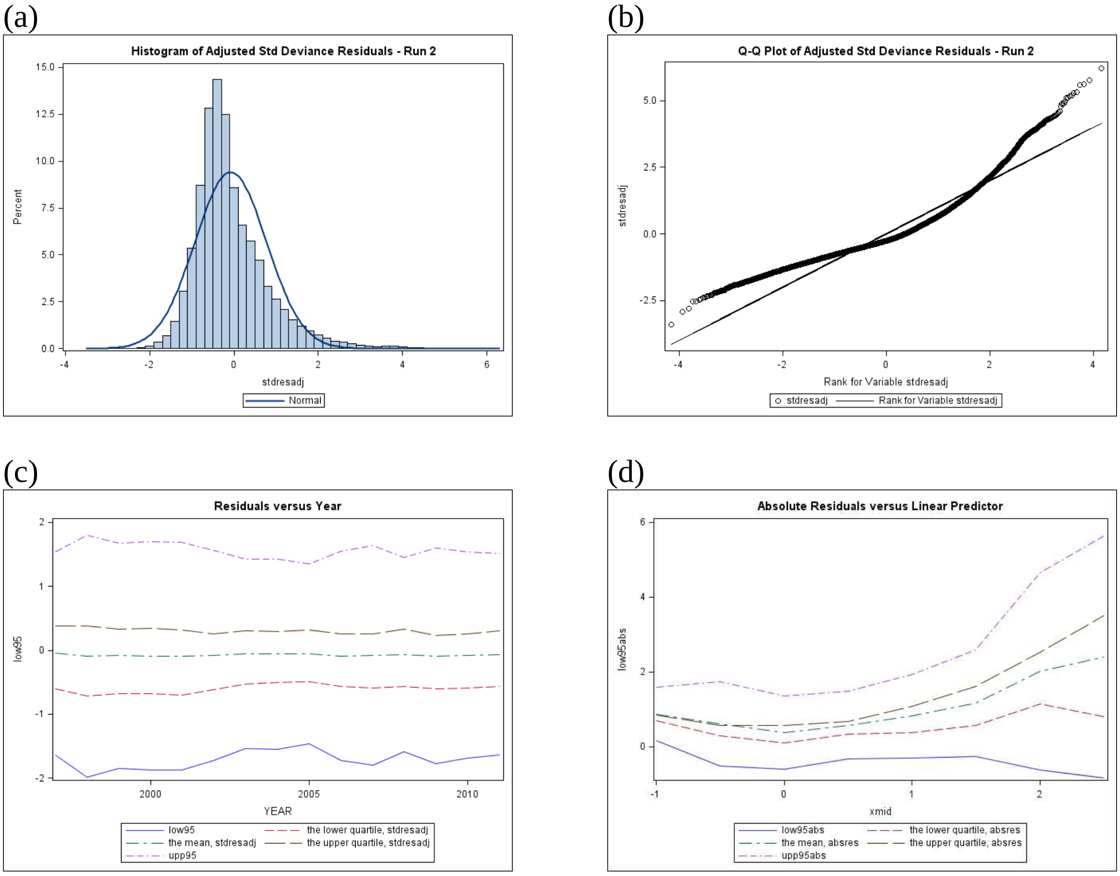


Table STM-2. Goodness-of-fit criteria (both models) and Type-3 analysis for Model 1 fitted to the ALL size-class data for striped marlin.

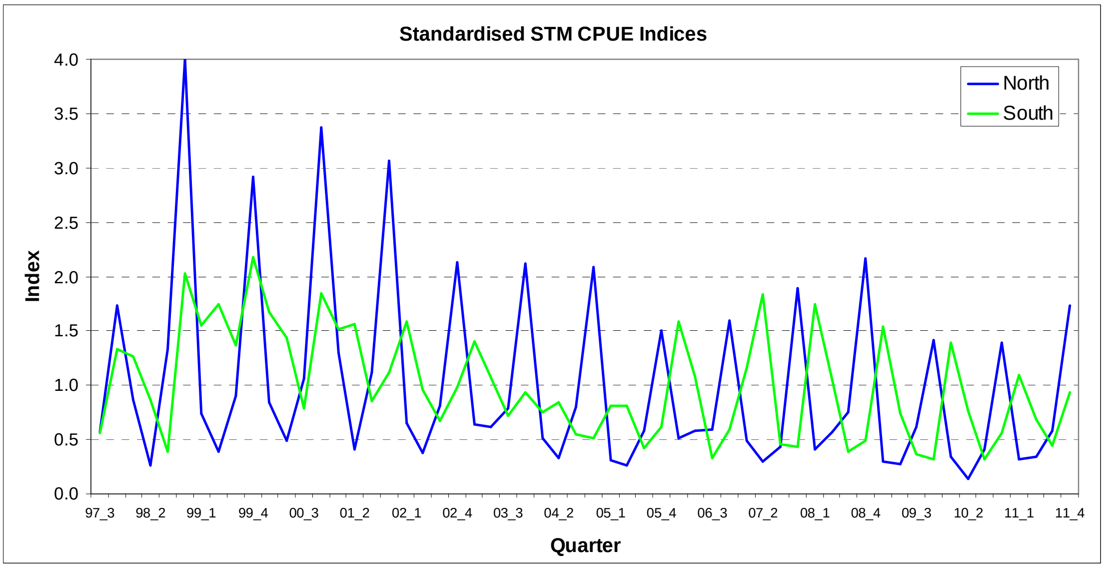
	Binomial Model			Negative Binomial Model		
	Log Likelihood	AIC	BIC	Log Likelihood	AIC	BIC
Model 1	-62250	124890	**126750**	-62696	125785	**127463**
Model 2	-61631	124085	128007	-62194	125213	128739

Effect	df	Chi-Sq	ChiSq/df	Pr>ChiSq	df	Chi-Sq	ChiSq/df	Pr>ChiSq
Year*Qtr	54	1209	22.4	<0.0001	54	1659	30.7	<0.0001
Qtr*Area	12	2591	215.9	<0.0001	12	1107	92.3	<0.0001
Lights	6	46	7.7	<0.0001	6	96	16.0	<0.0001
Bait-Type	8	77	9.6	<0.0001	8	369	46.1	<0.0001
Start-Time	5	509	101.8	<0.0001	5	229	45.8	<0.0001
HPF	7	69	9.9	<0.0001	7	671	95.9	<0.0001
Moon-phase	1	40	40.0	<0.0001	1	4.28	4.28	0.0385
Area*SOI	20	179	9.0	<0.0001	20	152	7.6	<0.0001
Area*SST	20	250	12.5	<0.0001	20	287	14.4	<0.0001
Area*MLD	20	216	10.8	<0.0001	20	129	6.5	<0.0001
Area*FRT	15	67	4.5	0.1292	15	175	11.7	<0.0001
Daily-VES	7	18	2.6	0.0118	7	43.7	6.2	<0.0001
Monthly-VES	7	36	5.1	0.0004	7	25.3	3.6	0.0007

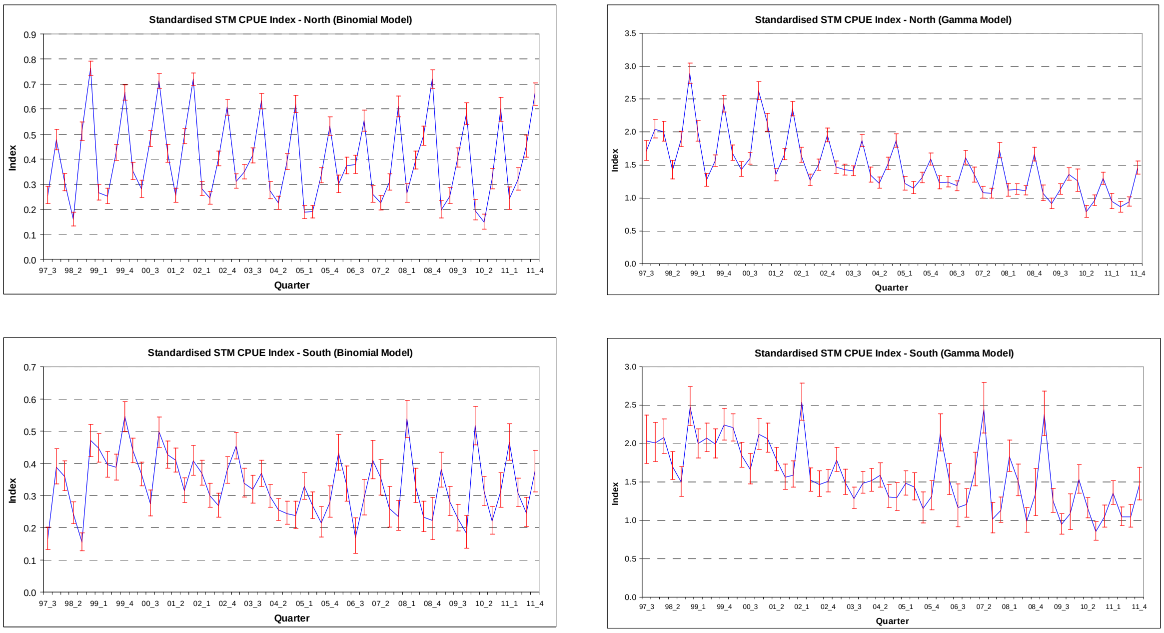
Figure STM-3. Checks of the fit of Model 1 to the negative binomial GLM for the ALL size-class data for striped marlin: (a) distribution of residuals, (b) Q-Q plot of residuals, (c) distribution of residuals against year effect, and (d) distribution of absolute residuals against linear predictor. Residual is standardised deviance residual.



STM-4. Time-series of quarterly standardised CPUE for striped marlin based on the results from Model 1 fitted to the ALL size-class data for the northern and southern regions of the ETBF.



STM-5. LS means and related standard errors for the fit of Model 1 to the binomial and negative binomial GLMs fitted to the ALL size-class data for the northern and southern regions of the ETBF.



9. References

Anon. (2010) Report on discarding in the Eastern Tuna and Billfish Fishery (2003-2007). Working paper presented to the meeting of the Tropical Tuna Resource Assessment Group, held 25-28 July 2010, Brisbane.
Campbell, R. (2008) Non-retention of principal target species in the ETBF. Working paper presented to the meeting of the ETBF Resource Assessment Group, held 29-30 July 2008, Hobart.

Campbell, R. (2009) Size-based standardised CPUE for target species caught in the ETBF longline fishery. Working paper presented to the ETBF Resource Assessment Group meeting, held 25-26 June 2009, Hobart.

Campbell, R (2010) Initial implementation of the ETBF harvest strategy and calculation of recommended biological commercial catches for the principal target species in 2011. Working paper presented to the meeting of the Tropical Tuna Resource Assessment Group, held 28 July 2010, Brisbane.

Campbell, R, K. Williams and D. Waddingham (2012) Summary of size data collected from the Eastern Tuna and Billfish Fishery and associated indicators: FY 97/98 to FY 10/11. Information p aper presented to the meeting of the ETBF Resource Assessment Group, held 5-6 June 2012, Brisbane.

Lo, N.C., Jacobson, L.D. and Squire, J.L. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat.Sci., 49, 2515-2526.

McCullagh, P. and J.A. Nelder (1989) Generalized Linear Models (second edition). Monographs on Statistics and Applied Probability 37. 511p.

Pennington, M. 1983. Efficient estimators of abundance for fish and plankton surveys. Biometrics, 39, 281-286.

Pennington, M. and Berrien, P. 1984. Measuring the precision of estimates of total egg production based on plankton surveys. J. Plankton Res.., 6, 869-879.