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Commercial spotting in the Australian surface fishery, updated to include the 2006/7 fishing season

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Abstract

Data on the sightings of SBT schools in the GAB were collected by experienced tuna spotters during commercial spotting operations between December 2006 and March 2007. Spotting data has now been collected over six fishing seasons (2001-02 to 2006-07). In all seasons, the majority of search effort occurred in December to March, and the areas of highest SBT abundance per nautical mile searched were within a "core fishing area" close to the shelf-break, and around the inshore lumps/reefs. The commercial spotting data was used to produce nominal and standardised fishery-dependent indices of SBT abundance (surface abundance per unit effort – a SAPUE index).

Introduction

In the summer of 2001-02 (called the 2002 season), a pilot study was conducted to investigate the feasibility of using experienced industry-based tuna spotters to collect data on the sightings of SBT during commercial spotting operations in the Great Australian Bight. The data provided a preliminary fishery-dependent index of SBT abundance (surface abundance per unit effort – a SAPUE index) for that fishing season. Recognising the importance of time-series of indicators, we continued to collect and analyse SBT sightings data from commercial tuna spotters over the following 4 fishing seasons (2003-2006). Interpretation of the results are difficult as the data suffers from many of the same problems that affect catch per unit effort (e.g. changes in coverage over time, lack of coverage in areas where commercial fishing is not taking place, and changes in operations over time), but it may provide a qualitative indicator of juvenile SBT abundance in the GAB. It has always been recognised, however, that a line-transect survey with consistent design and protocols from year to year is highly preferable. In 2007, we continued to collect SBT sightings data from commercial spotters. This report summarises the field procedures and data collected, and provides results of analyses for all six seasons (2002-2007).

Field procedures

Data were collected on SBT schools sighted by four spotters engaged between December 2006 and March 2007 (called the 2007 fishing season). In previous seasons, data has been collected from up to 6 spotters, but this year only four spotters were required by Industry. In the 2002 to 2005 fishing seasons, <1% of search effort occurred before December or after March; thus data were only collected from December to March since the 2006 season.

The spotting data were collected following the protocols used in the previous five fishing seasons. Within each plane there was a spotter and pilot. For most flights, the spotter searched the sea surface on both sides of the plane for surface schools of SBT. During some flights, the pilot also searched for schools. A GPS was used to log the position of the plane and record waypoints. Sighting information and environmental conditions were recorded by the spotter and/or pilot in a logbook (not by a separate data recorder). The start and end of "search" periods were recorded, so that transit time to and from the fishing area, or periods of time when the spotter was not searching for fish, could be removed from the analysis. There were no restrictions on the environmental conditions for commercial spotting operations, although they rarely occurred when wind speeds were above 10-15 knots.

When a “sighting” of SBT was made, a waypoint (position and time) was recorded over the school (or schools). The spotter estimated a range for the size of fish in the schools (in kg) and the biomass of each school (in tonnes). It is important to note that many SBT schools are recorded as single schools (34-62% each season). Some schools, however, are recorded in groups of 2-10 or even 50+ schools. Environmental observations were recorded at the start and end of each flight and when the conditions changed significantly during the day. The environmental observations included wind speed and direction, air temperature, cloud, visibility, spotting conditions and swell. The spotter also recorded the type of search effort (restricted or broad scale) undertaken during the flight. The target species of each flight (SBT, skipjack tuna, mackerel, or a combination of these) was also recorded.

Results

Search effort and SBT sightings

Data were collected for 120 commercial spotting flights in the 2006/07 fishing season, which is the greatest collected in a season so far. Consequently, the greatest level of search effort (600 hours) and total biomass (94018 tonnes) were recorded this season. Note, however, that the total biomass recorded does not represent the total biomass of SBT present in the survey area, as many schools were potentially recorded several times (either by different spotters on the same day or over several days).

The relative contribution to the total search effort by spotter is given in Table 1, and details of search effort and SBT sightings are given in Table 2. SBT were recorded on 110 of the 120 commercial flights in 2007 (92%). The location of SBT sightings varied slightly between seasons (Figure 1) but the areas of highest SBT sighted per nautical mile searched remains within the same ‘core fishing area’ and around the inshore lumps/reefs each season.

Figure 2 and Figure 3 show the size frequency of SBT schools and fish recorded by one spotter 1 between 2002 and 2007. Using data from one spotter removes the problem of differences between spotters in their estimates of school and fish size. Spotter 1 was selected because he had collected data on the greatest number of SBT schools each season. The school size frequency data does not show any obvious trend over time; 10-40 tonnes schools dominate in most seasons. The fish size frequency data shows a steady increase in fish <20 kg between 2004 and 2007 and very few fish >30 kg in the last two years (Figure 4).

Table 1. Relative contribution (%) by commercial spotters to the total search effort (time) by fishing season.

Spotter	Fishing season					
	2002	2003	2004	2005	2006	2007
1	61.3	20.2	42.2	39.7	44.2	38.0
2	7.6	11.5	15.2	9.3	11.6	11.1
3	11.7	33.2	19.4	19.5	-	-
4	-	1.2	-	-	-	-
5	5.6	4.4	-	5.0	14.8	22.1
6	13.9	29.5	23.2	26.5	29.5	28.8

Table 2. Search effort and SBT sighted by commercial spotters in the 2002-2007 fishing seasons. Note: the 2005a data does not include 20 flights where with no GPS flight path data was collected (see Basson and Farley 2005).

Fishing season	2002	2003	2004	2005	2005a[2]	2006	2007
No. flights	86	102	118	116	96	102	120
Search effort (hrs)	325	425	521	551	467	452	600
Search effort (hrs) in core	245	341	464	-	418	376	519
No. 0.1° squares searched	854	947	775	-	654	817	665
% 0.1° squares with SBT	20	16	14	-	19	19	21
% flights with SBT recorded	84	82	77	94	93	82	92
Total number of schools	1182	1301	1133	2395	1725	1554	2600
Total biomass[1] recorded	44626	38559	33982	87447	63492	50524	94018
Total biomass[1] recorded (core)	40957	30230	25720	-	52802	36570	75222

[1] The total biomass recorded does not represent the total biomass of SBT present in the survey area, as many schools were potentially recorded several times (either by different spotters on the same day or over several days).

[2] The data given for 2005a does not include 20 flights that had no GPS flight paths data collected (see Basson and Farley 2005).

Figure 1. Search effort (nm flown/0.1° square), locations of SBT sightings, and SAPUE (tonnes/nm/0.1° square) in the GAB by fishing season. SAPUE data are displayed as the % of total effort for the season. Areas of darkest blue in the SAPUE plot indicate zero SAPUE. Note the log scale for effort and SAPUE. The core fishing area is shown by a red square.

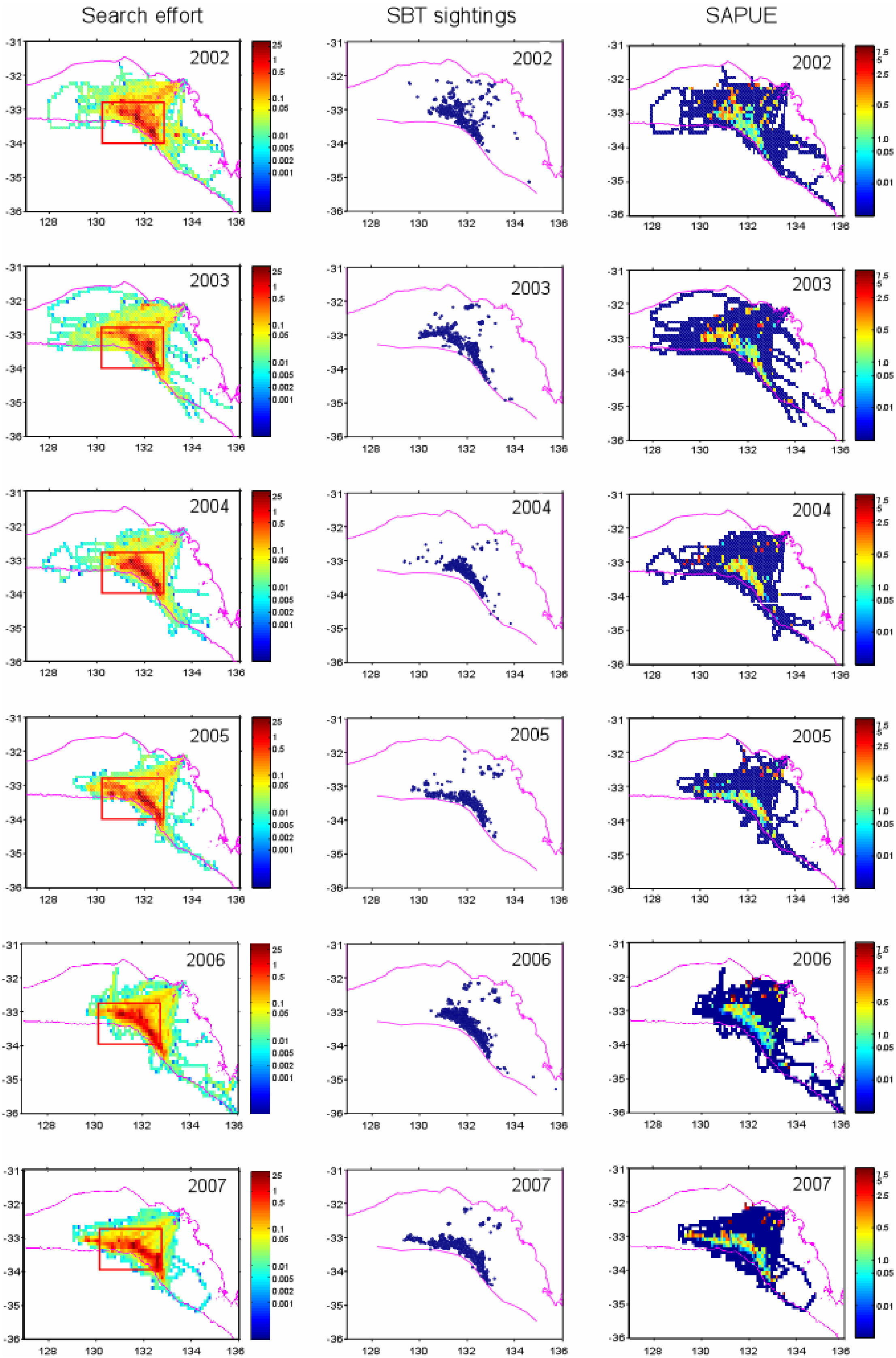


Figure 2. Size frequency of SBT schools recorded by one commercial spotter during the 2002-2007 fishing seasons. (Total number of schools recorded = 4583)

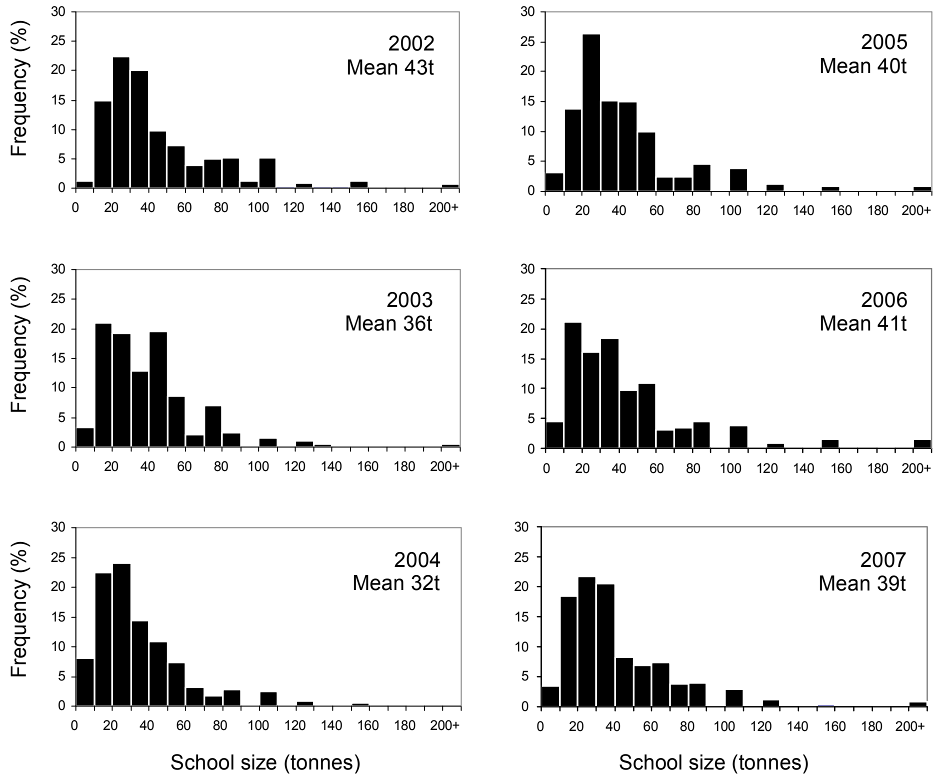


Figure 3. Size frequency of SBT recorded by one commercial spotter during the 2002-2007 fishing seasons. Data are weighted by school size. (Based on mean fish size data collected for 4353 schools).

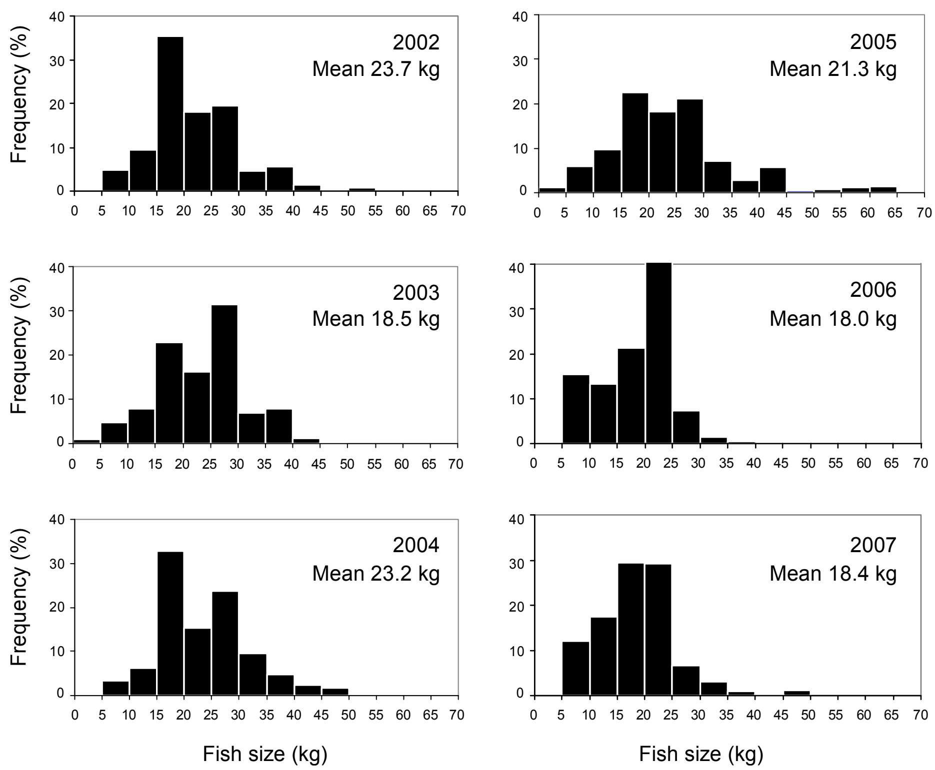
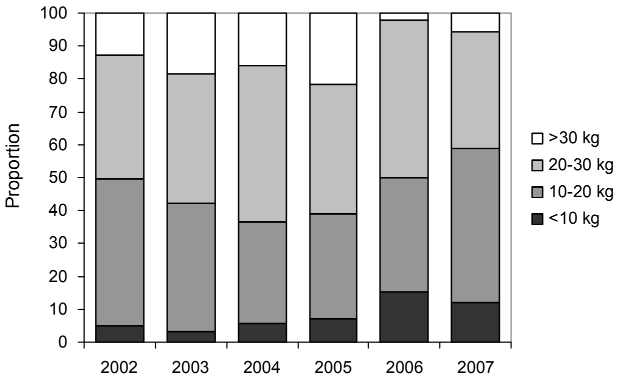


Figure 4. Proportion of SBT by size class recorded by one commercial spotter in the 2002-2007 fishing seasons.

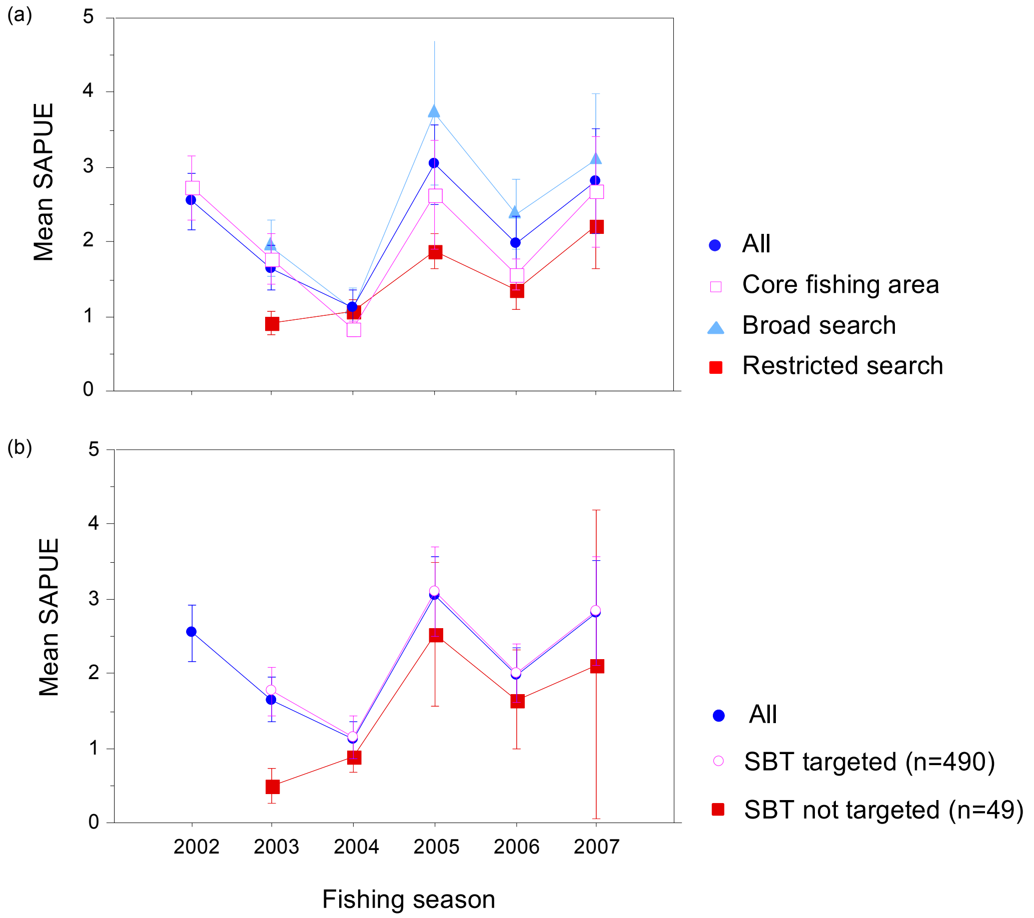


Nominal SAPUE

The duration of "search" sectors during flights were calculated using the GPS logged position and time. Logbook data on SBT sightings were summarised to give the total number of sightings, schools, and total biomass per plane per day. Data were extracted to ensure consistency between seasons (e.g. flights in November and April, outside the main fishing season and with relatively low coverage, were excluded; flights with less than 30 minutes of search effort were excluded because these were considered too short to have a meaningful SAPUE estimate). As these data were removed for all seasons, it should not affect the relative index of abundance. Nominal (unstandardised) indices of juvenile SBT abundance (surface abundance per unit effort – SAPUE) were calculated, based on the mean of biomass sighted (*B*) per unit of search effort (*D*) (Klaer et al. 2002; Farley and Bestley 2002). The SAPUE indices were calculated by geographic area (whole GAB and core fishing area), by search type (broad and restricted), and for flights where SBT was/was not targeted. The core fishing area was selected based on search effort and biomass sighted. Substantial amounts of SBT were sighted between 130.2 and 132.9°E and 32.7 and 34.0°S. Approximately 75% of the total biomass and 81% of the total search effort was recorded in this core area. Note, however, that this dataset includes sightings from one flight (in 2007) which was conducted in a different way from any of the other commercial flights. We discuss this further below.

Four nominal SAPUE indices of juvenile abundance are shown in Figure 5a. Since the type of search effort (broad/restricted) and target species were not recorded in 2002, only two of the indices can be calculated for all six seasons. Three of the indices showed declines prior to 2004 then all four fluctuated similarly between 2005 and 2007, and showed increases between 2006 and 2007. Figure 5b shows the comparison of mean SAPUE by season for flights where SBT was and was not targeted. Not surprisingly, mean SAPUE was lower for flights where SBT was not targeted, but as there were very few non SBT flights (n=49), it makes little difference to the overall SAPUE indices obtained by month.

Figure 5. Nominal SAPUE indices (+/-se) for the 2002-2007 fishing seasons (a) irrespective of target species, and (b) by species targeted. The large standard error for 2007 in (b) is for the 'SBT not targeted' point. Classifying search effort as either broad or restricted, and recording the target species, started in 2003 (i.e. the 2002/2003 fishing season). Note that only flights in Dec to Jan were included, and when search effort was >30 minutes.

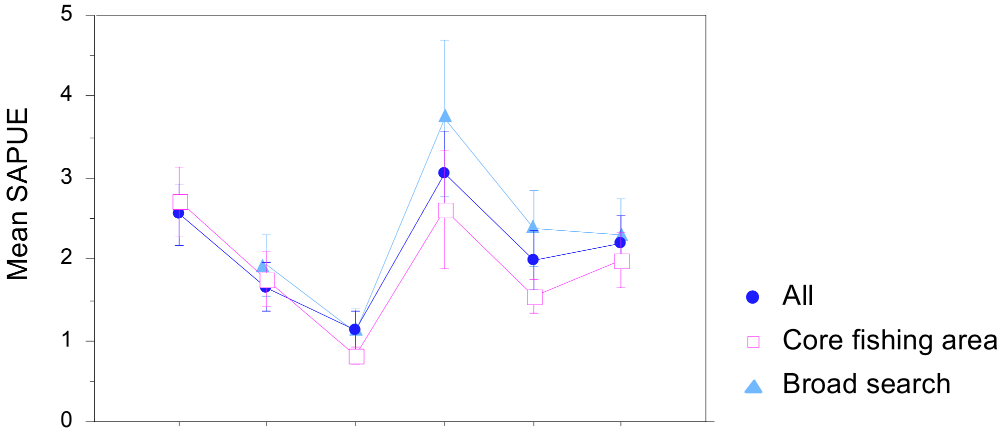


It is important to note here that three of the four highest SBT biomass levels recorded in a flight were recorded in 2007, and all on the same day. Given that the temperature, visibility and overall spotting conditions recorded that day were all well above average for the season, while wind speed and cloud cover were well below average, it is not surprising that higher than average SBT biomass levels were recorded. However, the SBT biomass recorded on one of these flights was over twice that recorded by the next highest flight that day, with only half the search effort, giving a SAPUE of 76.7 tonnes/nm. This very high SAPUE appears to be due to a different spotting method used during the flight. That is, the flight seems to be a 'stock take' flight similar to, but more extreme, than those conducted for a BRS project in 2004/05. The spotter recorded the majority of SBT schools in groups of between 12 to 50+ with an average biomass for the group, and was thus able to search a large area in a relatively short time. Although the practice of grouping schools is quite common for commercial spotters (27% of schools are recorded in groups of ≥10), the extent to which this was done on this flight was significantly higher (92%).

If this flight is removed from the analysis, on the basis that it was different from the regular commercial flights, the nominal SAPUE indices for 2007 are reduced (Fig. 6). This change in the index based on a single flight highlights the problems of using commercial spotting data, and the lack of consistent search methods, to develop an index of juvenile abundance. The nominal indices should therefore be interpreted with caution, and we still consider the line-transect aerial survey to be preferable as an approach to an index compared to the commercial spotting.

Further analyses of the SAPUE data are required to standardise for environmental conditions and spotters. This is considered below.

Figure 6. Nominal SAPUE indices (+/-se) for the 2002-2007 fishing seasons after a 'stock-take' flight is removed from the 2007 data. The 'restricted' index is not included as it is unchanged from Fig 5a.



Standardised SAPUE

There are now six years worth of commercial spotting data which can potentially be standardised to obtain an index of juvenile abundance (ages 2-4 primarily) in the GAB between December and March. Although data from 5 companies are available, summaries of the number of days flown in each month and season show that two of the companies flew a limited number of days and only in some months (Table 3). This is understandable because these companies take a relatively small proportion of the surface fishery catch, and it should be remembered that the commercial spotting is directly and strongly linked to the commercial fishing operations. This is also important from the point of view of interpretation of the data. The commercial spotting data can therefore suffer from many of the same hard-to-quantify biases that affect catch per unit effort, for example, changes in coverage over time, lack of coverage in areas where commercial fishing is not taking place –for whatever reasons – and changes in operations over time. From a statistical perspective, the aerial survey, which uses a line transect design and consistent protocols, is far preferable as an approach to an index compared to the commercial spotting. However, these additional (commercial spotting) data can potentially provide further insights given the relatively large amount of effort (hours flown).

Table 3. Number of days flown by spotter, year and month within year. Note that the 'season' is the same as the 'year' for all months except December; for example December 2001 will fall in the 2002 Season.

Year	Month	spotter1	spotter2	spotter3	spotter5	spotter6
2001	Dec	14		8		4
2002	Jan	7	5	5		7
2002	Feb	7	3	3	4	4
2002	Mar	11				
2002	Dec			10		10
2003	Jan	10	6	9	5	10
2003	Feb	2	3	6	1	4
2003	Mar	5		6		4
2003	Dec			11		10
2004	Jan	9	7	5		11
2004	Feb	15	10	9		6
2004	Mar	16		2		4
2004	Dec			4		3
2005	Jan	11	7	9	1	7
2005	Feb	9	2	10	6	16
2005	Mar	19		2		8
2005	Dec	9			3	4
2006	Jan	8	4		3	8
2006	Feb	9	8		9	9
2006	Mar	12			4	10
2006	Dec	6			2	7
2007	Jan	15	7		10	14
2007	Feb	9	6		7	7
2007	Mar	12			11	6

Based on the information in Table 3 for the seasons 2002 through to 2007, we only included data from companies 1, 3 and 6 in the standardisation analyses in the past. Data from all months (Dec, Jan, Feb and March) were included in the analyses. As noted last year, there was a change in the 2006 season (Table 3). The effort for spotter 3 (also referred to as company 3 in previous working papers[1]) dropped to zero, but that for spotter 5 increased. This causes several difficulties for the analysis. It is no longer satisfactory to leave out data for spotter 5, but it is also now more difficult to fit models with an interaction term between spotter and season due to the unbalanced data. In 2007, spotter 3 again did no spotting, though spotter 5 continued and contributed a relatively large number of days' data to the database. We therefore explore several combinations of spotters in the standardisation analyses.

Environmental variables

As noted in the past (e.g. CCSBT-ESC/0409/19) sighting conditions and surfacing behaviour are influenced by weather and environmental variables. The environmental variables recorded by season are summarised in Table 4 and Figure 7. Note that the aerial survey

[1] Although we use the terms 'company' and 'spotter' interchangeably, the data pertains to a particular spotter.

transects are only flown during certain conditions, so that summaries of environmental conditions recorded during the aerial survey and during commercial spotting operations would tend to differ. The data show that during the 2007 commercial spotting flights, the average wind speed, swell height, air temperature and cloud cover were lower than in 2006, and spotting conditions and visibility were slightly higher. Overall, however, the environmental data were not particularly unusual compared to previous seasons.

Although the mean temperature in the 2005 and 2006 seasons were quite similar (21.1 and 22.1 degrees C respectively), we noted last year (CCSBT/ESC/0609/17) that the monthly temperatures were very different. Figure 8 shows the monthly mean temperatures from the data over the past 6 seasons. In 2006, the difference between the January and February temperatures was the greatest seen so far. The January average temperature was the highest recorded (the highest overall and the highest January temperature), and the February temperature was the lowest of the February temperatures in the dataset. This was also noted in the temperature data used with the line transect aerial survey (CCSBT/ESC/0609/16). The monthly temperature pattern for the 2007 season was more similar to those in 2004 and 2005, and not particularly unusual.

Analyses of the aerial survey data found that moon illumination was a significant term and it is plausible that this could affect surfacing behaviour. Moon illumination was therefore also considered in the standardisation analysis.

Table 4. Average environmental conditions during search effort on commercial flights by season (Dec-Mar only). Note visibility was not recorded in 2002.

Fishing season	Wind speed (knots)	Swell height (0-3)	Air temp (°C)	Cloud cover (/8)	Spotting condition (/5)	Visibility (nm)
2002	7.05	1.46	17.91	4.48	2.64	
2003	6.94	1.21	23.35	3.66	2.79	5.54
2004	7.91	1.65	19.73	3.94	2.64	7.77
2005	6.99	1.59	21.14	4.23	2.55	8.95
2006	7.59	1.95	22.11	4.01	2.75	7.64
2007	6.69	1.49	21.10	3.60	2.78	7.92

Figure 7. Boxplots summarizing the environmental conditions present during search effort on commercial flights by season (Dec-Mar only). The horizontal band through a box indicates the median, the length of a box represents the inter-quartile range, and the vertical lines extend to the minimum and maximum values. The dashed line running across each plot shows the overall average across all survey years. Note visibility was not recorded in 2002.

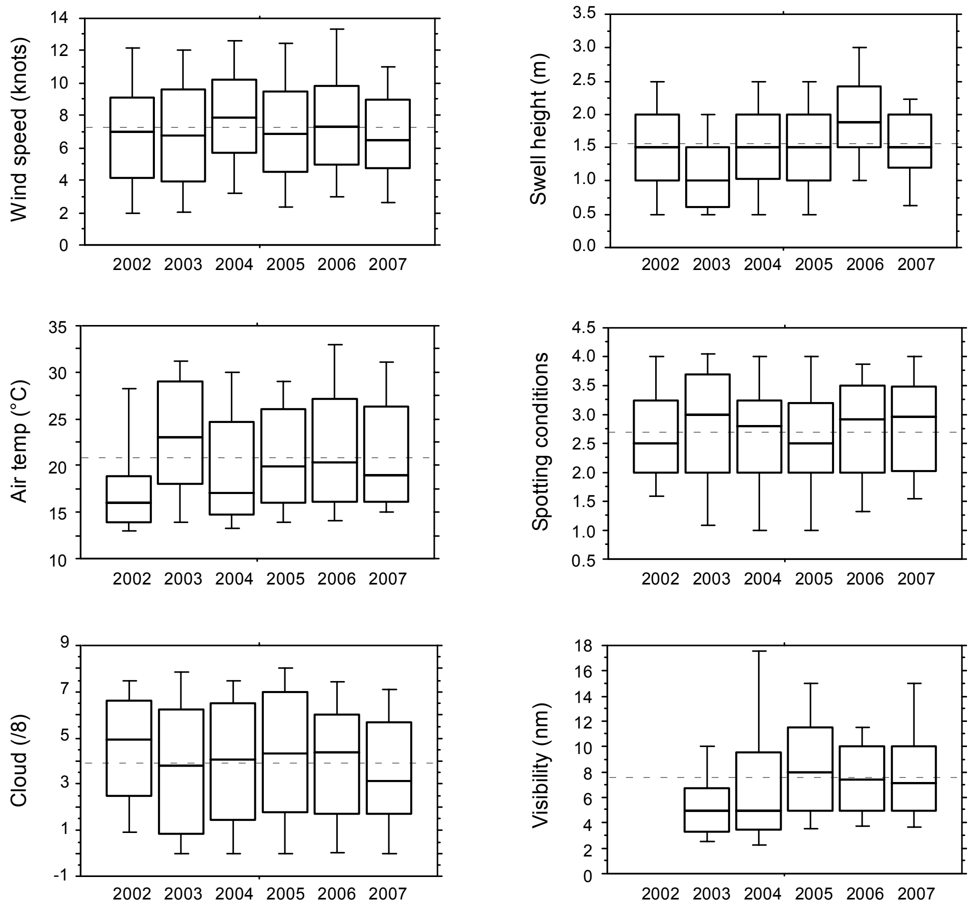
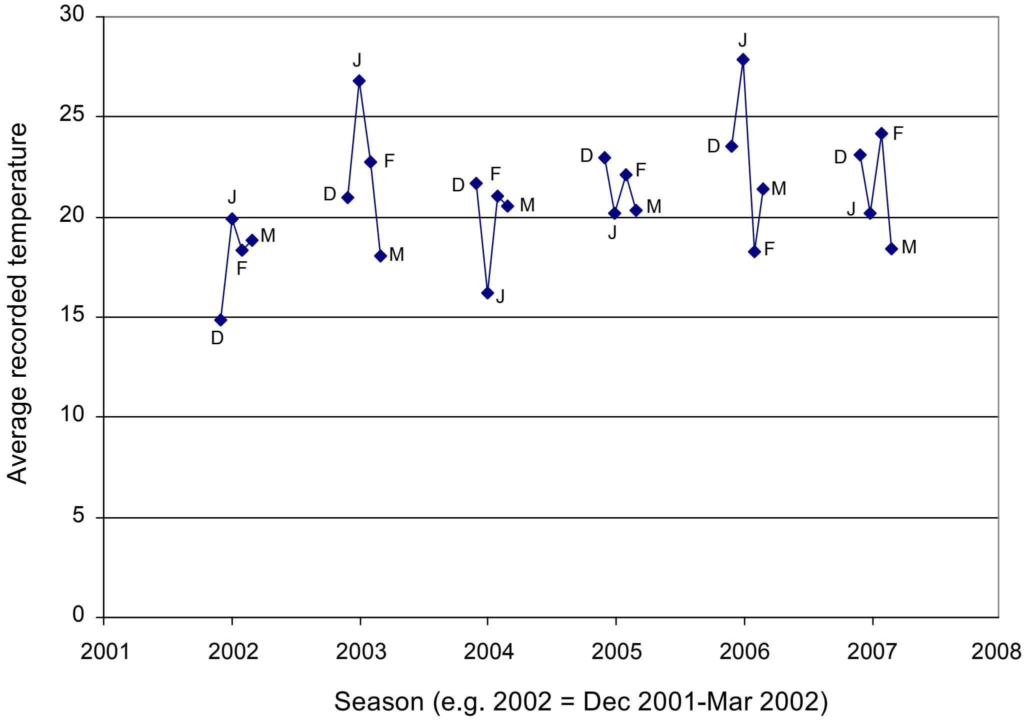


Figure 8. Average monthly temperatures (December to March) from the spotting data for the past 5 seasons.



The sightings data

As indicated in the past, there are many different ways in which the sightings data could be compiled for analysis. The best way would be to compile the data at as fine a time and spatial scale, to give some chance of partly adjusting for the lack of spread of spatial coverage and the autocorrelation in the observations. This task would, however, be seriously complex and given that an aerial survey was again conducted this season, it is not warranted. Instead, we have followed the approach used in the past. The data are compiled as the biomass sighted and effort in hours flown on each day by each spotter. The associated environmental variables are taken as the means for that day and spotter. The data were compiled as a set for the entire area and all the analyses were done on the ‘whole area’ dataset.

Table 5 shows a summary of the number of days flown with no biomass sighted. This information can be treated as a simple ‘presence’/’absence’ index. The percentage days with no sightings was below average in 2005 and 2007.

Table 5. Number of days flown with no biomass sighted and days with some biomass sighted, for all companies combined and all months. Since different levels of effort are associated with each day, the %effort in hours associated with days when no biomass was sighted is also shown.

Season	Zero biomass days	Positive biomass days	Total days	% days with Zero biomass	% effort (hours) associated with zero biomass
2002	10	72	82	12.2	10.0
2003	15	76	91	16.5	11.9
2004	25	90	115	21.7	15.7
2005	6	108	114	5.3	4.1
2006	16	84	100	16.0	11.5
2007	9	110	119	7.6	4.8

Modelling approach

We used the same modelling approach as last year and essentially updated those analyses with data from the 2007 season. The main intention of modelling of these data is to standardise the raw index (e.g. average biomass per unit effort sighted) for differences between spotters and different environmental, weather and spotting conditions from year to year. Some of the variables (e.g. moon illumination) most likely only affect surfacing behaviour of tuna, whereas others (e.g. wind, swell) may affect both spotting ability and surfacing behaviour. The "regression model" used must be able to cope with the zero observations, and with the strong dependency of the variance on the mean. A convenient way to do this is to fit GLMs using the Tweedie family of distributions (Jørgensen, 1997; see also Candy 2004) with a log-link, so that different factors combine multiplicatively. The mean-variance relationship in Tweedie distributions follows a power-law with adjustable exponent Φ, and for $\Phi<2$ there is no problem with zero observations. When fitting the models, the exponent Φ was entered ($1< \Phi <2$). Note that the value of $\Phi=1$ coincides with the Poisson distribution, and a value of $\Phi=2$ with the Gamma distribution. Different values of Φ were tried and the deviance residuals were checked to ensure that they were relatively similar over the range of predicted values.

All analyses were done in R using library(Tweedie) to enable use of "family=tweedie()" in the standard GLM routine. The Akaike information criterion (AIC) statistic was primarily used to compare model fits and bootstrapping was used to explore the estimated variance of parameter estimates.

In the past, data and model exploration, suggested that all the environmental covariates in the dataset were important, though swell was only marginally relevant – including or excluding it had little effect on results or on the AIC statistic. In general, records with missing values for any of the environmental variables in the model are excluded. However, spotter 5 often did not record swell, and if those records are excluded, the dataset (particularly in the most recent 2 seasons) is much smaller. We therefore also explore a model which does not include 'swell' as a covariate, and includes records which has missing values only for 'swell'. Limited exploration was performed this year, but indications are that the same set of covariates are still relevant. All results are based on the following model with swell either included or excluded:

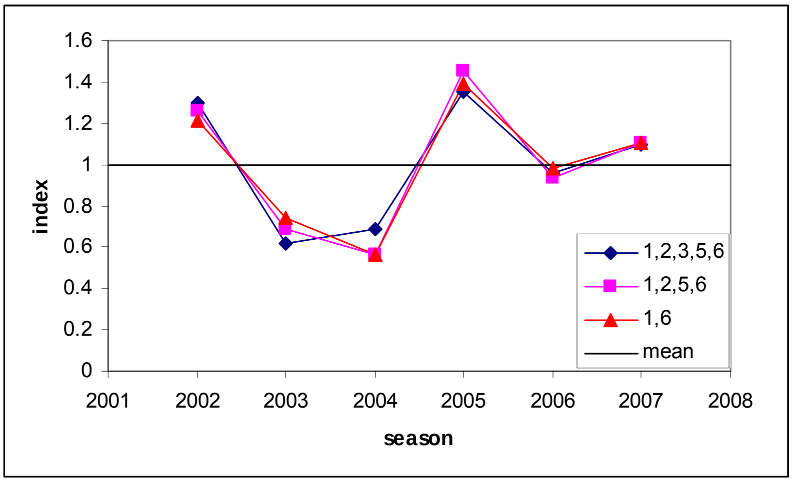
Full model without interaction:
biomass ~ as.factor(season) + as.factor(company) + as.factor(month) + wind + spotcon + swell + cloud + temperature + moonillum + offset(log(effort))

In the past, an interaction term between spotter and season appeared to be important, though it does make interpretation of results rather difficult because this model implies a different index time-series for each spotter. As noted above, the change in effort for spotters 3 and 5 in the 2006 season has lead to an unbalanced dataset. We consider that it is still not meaningful to use the model with interaction term to obtain a standardised index of abundance for the whole period[2]. All results are therefore for the no-interaction model. We did, however, look at the sensitivity of the index to using data for different groups of spotters.

Results

First consider results for the model which includes swell as a covariate, and excludes all records with missing values for swell. Results for three datasets are shown in Figure 9: (i) all spotters, (ii) spotters 1,2,5 and 6, and (iii) only spotters 1 and 6. Swell does appear to be significant in all three models (Table A1, Appendix), though less so than some of the other environmental variables (e.g. wind, spotting condition or cloud cover). The main difference between point-estimates of the index occurs when spotter 3 is not included; the relative values for 2003 and 2004 change, but other values are almost unaffected by the inclusion or exclusion of spotters 2 and/or 5.

Figure 9. Time-trends of the standardised SAPUE indices (surface abundance per unit effort) scaled to the mean for (i) all spotters (1,2,3,5,6), (ii) spotters 1,2,5, and 6 and (iii) only spotters 1 and 6. Season refers to the 2nd year e.g. 2006 indicates the 2005/06 season. Results are for the full model without interaction terms.

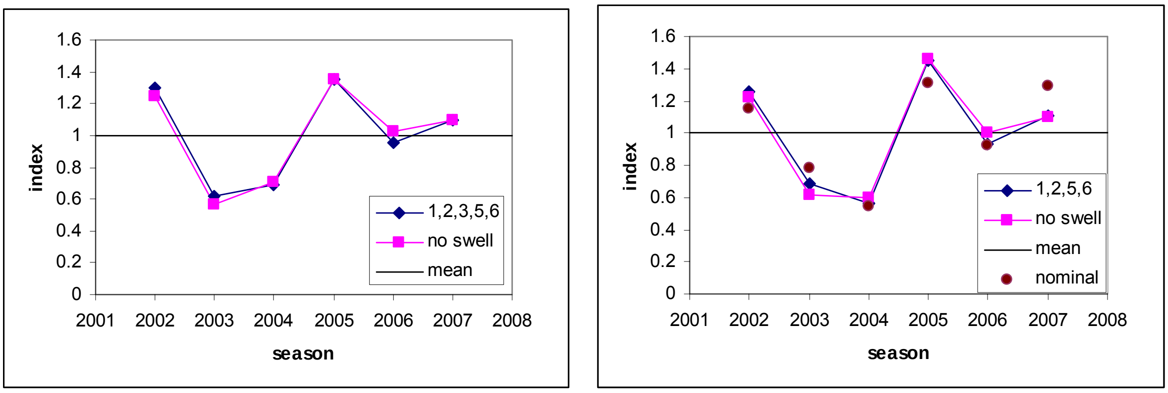


[2] The index is constructed by predicting the biomass per unit effort at average values for covariates and a given reference level (for factor variables) using the model. In this case, however, the predictions are not reliable because the model matrix is rank deficient.

Whether swell is included or excluded (Figure 10), also has only a relatively small effect, and shows that the inclusion or exclusion of spotter 3 actually has more of an effect on the point estimates, though this effect is still much smaller than the inter-annual differences in the index value. The difference between the nominal and standardised value in 2007 is due to the fact that the weather was generally good in this season. As pointed out above (Figure 7), the spotting conditions were generally above average, and wind and cloud cover were below average.

The coefficients of variation (CVs) of the season-coefficients are also hardly affected by the inclusion or exclusion of swell as a covariate, irrespective of the fact that there are more records when swell is excluded. It is important to recall that it is not just the model that is different when swell is excluded, but also the dataset. In particular, the flight in 2007 that appears to have been done more like a 'stock-take' flight, and discussed in the section on 'Nominal SAPUE' is included in the model/data which excludes swell. The residual for this data point is in fact obvious in the diagnostics (Appendix, Figure A 2, third panel); the point with highest observed biomass. The comparisons of estimated index values from different model/data combinations, however, suggest that this single point is not having a disproportionate effect on the standardised results.

Figure 10. Time-trends of the standardised SAPUE indices (surface abundance per unit effort) scaled to the mean for (a, left panel) all spotters, with and without swell, and (b, right panel) spotters 1,2,5 and 6 (i.e. excluding spotter 3) with and without swell. The nominal (unstandardised) index is also shown on this panel. Season refers to the 2nd year e.g. 2006 indicates the 2005/06 season.



Given that spotter 3 has ceased spotting, and that the inclusion or exclusion of that spotter has only a relatively small effect on the time-series (compared to the inter-annual differences), we continue with the two models which use only the data for spotters 1,2,5 and 6. Although spotter 2 has only contributed records in January and February, there are data for all 6 seasons, and results currently appear not to be sensitive to whether data from this spotter are included or excluded. Diagnostics for the two models (spotters 1,2,5,6 with or without swell as a covariate) show that residuals are reasonably well-behaved, though the qq-plots are rather poor, and not linear as expected (see Appendix, Figure A 1 and Figure A 2). This is unlikely to badly affect the point-estimates of coefficients, but does indicate a 'fat' tail in the data. In a relative analysis such as this, where the focus is on year-to-year comparisons, poor qq-plots do not generally imply bias in the point-estimates, but do point to the need to validate standard errors. This is done by bootstrap analyses, discussed below.

We explored the effect of using a different assumption about the mean-variance relationship through different values of the Tweedie parameter, Φ. Figure A 3 (Appendix) shows the deviance residuals (square root of the absolute values) plotted against the fitted values for a range of values of Φ. The smoother through the data shows that a value of around 1.5 is most appropriate, since the smoother is 'flattest' (slope closest to 0) for this assumption. Lower values of Φ lead to a slight positive slope, and higher values lead to a slight negative slope.

A comparison between estimated standard errors from the GLM model and estimates from bootstrap analysis, as described in Basson and Farley (2005; CCSBT-ESC/0509/23), was again made. In the past both 'day' and 'week' were used as resampling units, and results were generally very similar for the two resampling units. We have only updated this analysis for 'day' as a resampling unit. Results from 500 bootstrap replicates (Table 6) show that the model estimates of standard deviations are no smaller than the bootstrap estimates. Bootstrap estimates of standard errors are obtained directly from the 500 estimates of each of the season-coefficients, and the intercept.

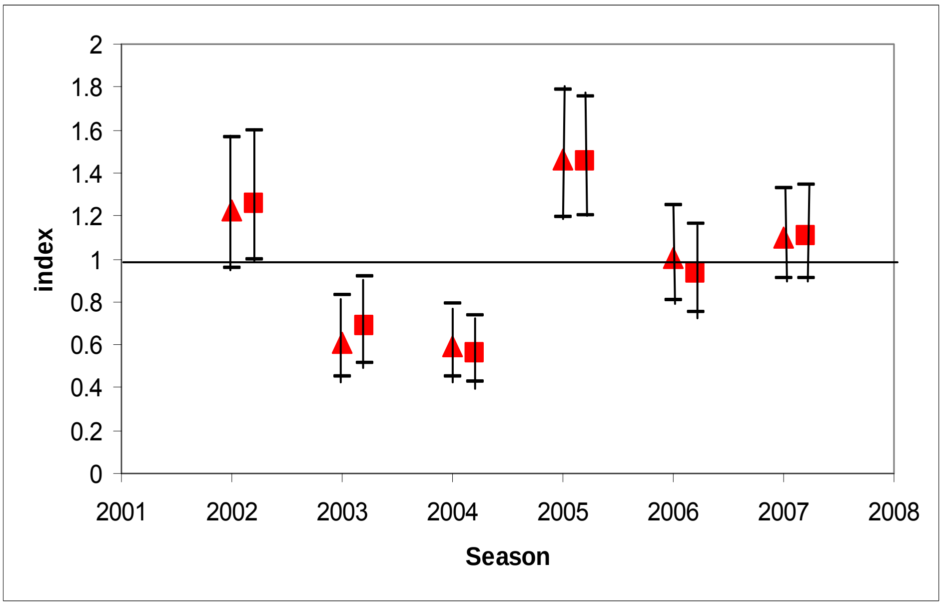
We have therefore assumed that the standard errors from the model can be used to indicate the uncertainty in the index. Note, though, that the standard errors describe only the uncertainty about the season level given the available data; there is an extra layer of uncertainty, about how many SBT were in the GAB outside the area covered by the SAPUE, that the model cannot reveal.

Table 6. Estimates of standard errors for some model coefficients from the GLM model (with spotters 1,2,5 and 6 included) and standard deviations of the coefficients from 500 bootstrap replicates with 'day' as the resampling unit.

	Swell Included		Swell Excluded	
	Estimated Standard error	Bootstrap Standard error	Estimated standard error	Bootstrap standard error
Intercept	0.47	0.42	0.44	0.41
season 2003	0.21	0.16	0.22	0.20
season 2004	0.19	0.18	0.20	0.19
season 2005	0.18	0.16	0.19	0.18
season 2006	0.18	0.18	0.19	0.20
season 2007	0.17	0.15	0.17	0.17

Figure 11 shows results of the standardised index for the four spotters (1,2,5 and 6) over the past 6 seasons, and the two models: one with swell included as a covariate (and records with missing values for swell excluded), and the other with swell excluded as a covariate (but records with missing values for swell included). The ranges were obtained by taking the predicted values + or – 2 standard deviations on the log scale and then converting to the normal scale. Note though, that the standard deviations themselves take into account the fact that the index has been scaled to the mean.

Figure 11. Estimates of standardised relative surface abundance, scaled to the mean over the period, for models with companies 1,2, 5 and 6 for (i) swell included as a covariate (triangles) and (ii) swell excluded as a covariate (squares). All months were included (December – March). The median and exp(predicted value + or – 2 standard errors) are shown. Values are scaled to the mean over the period, so the horizontal line at 1 indicates the mean.



Summary

We present results of a standardised 'surface abundance per unit effort' (SAPUE) index, based on fitting a general linear model to the data. The model does not have any interaction terms, although past analyses suggested that an interaction between spotter and season is important. Due to the changes in spotter effort in the 2006 season, the dataset has become unbalanced, making it difficult to obtain a reliable index of abundance for the model with interaction between spotter and season. We have, however, considered the sensitivity of results to different combinations of spotters in the analysis, and to the inclusion or exclusion of 'swell' as a covariate. The reason for this is that one of the spotters has a large number of missing values for this covariate, reducing the dataset if these records are excluded.

Results are again somewhat sensitive to the spotter (spotter 3 in particular), though the general temporal patterns of the indices are similar. The estimated index is lowest in 2003 and 2004 (Figure 9). The 2005 estimate is the highest and those for 2006 and 2007 are both close to, or slightly above, the average over the past 6 seasons. It is interesting to note that in Basson and Farley (2005) the estimate for 2002 was the highest in the series (over 2002-2005) for two of the spotters.

We note again that the index reflects the abundance of 2, 3 and 4 year olds combined. The two low years would therefore represent the 1999, 2000 and 2001 year-classes (as 4,3,2-year olds in 2003) and the 2000, 2001 and 2002 year classes (as 4,3,2-year olds in 2004). In 2005, there also appeared to be many 1-year olds in the bight. This was noticed by industry and mentioned to us, but it was also apparent through the relatively large number of below 10kg fish that were sampled for length from the farming operations. It is unclear and unknown whether the index in 2005 reflects a substantial proportion of age 1 fish or not, compared to other years. (Note that the estimates of fish size from 1 spotter shows an increase in small fish in 2006).

The above analysis does not take into account the position of the sighting and this could potentially be one reason why different patterns emerge for the different spotters when an interaction model is fitted to the data (e.g. as done in Basson and Farley, 2005), or when different combinations of spotters are used in the analysis. However, the fishing and commercial operations occur in a relatively small area in the GAB, which may suggest that the difference may be due to more complex processes that are not being captured in the current models.

There are now three years of overlap between the SAPUE index and the line-transect aerial survey index (see the update this year in CCSBT/ESC/0709/12). Direct comparison is still, however, difficult and should be done with caution. Most importantly, the commercial spotting data are obtained in a substantially different way directly associated with the fishing operation, and covers a much smaller spatial area than the line-transect survey. We still consider the line-transect aerial survey to be preferable as an approach to an index of juvenile abundance, compared to the commercial spotting.

Acknowledgements

There are many people we would like to recognise for their help and support during this project. We would especially like to thank the commercial spotters and pilots for their willingness to collect and record sightings data each fishing season. We also thank the tuna fishing companies in Port Lincoln for their support of the project. This study was funded by AFMA, DAFF, Australian Industry, and CSIRO Marine and Atmospheric Research.

References

Basson, M., Farley, J. 2005. Commercial spotting in the Australian surface fishery, updated to include the 2004/5 fishing season. CCSBT-ESC/0509/23.

Farley, J. and Bestley, S. 2002. Aerial survey indices of abundance: comparison of estimates from line transect and “unit of spotting effort” survey approaches. RMWS/02/01.

Klaer, N., Cowling , A., and Polacheck, T. 2002. Commercial aerial spotting for southern bluefin tuna in the Great Australian Bight by fishing season 1982-2000. Report R99/1498.

Appendix

Table A 1. Estimates of coefficients, standard errors and related 'significance' quantities for three models including swell as a covariate, and two models which do not include swell.

Spotters 1,2,3,5,6, with swell included

```
Call:
glm(formula = biomass ~ as.factor(season) + as.factor(spotter) +
    as.factor(month) + wind + spotcon + swell + cloud + temperature +
    moonillum + offset(log(SearchEffort)), family = mvb.tweedie(1.5,
    0), data = workdat)

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)            0.203226   0.431442   0.471 0.637797
as.factor(season)2003 -0.744417   0.184491  -4.035 6.22e-05 ***
as.factor(season)2004 -0.635654   0.175250  -3.627 0.000313 ***
as.factor(season)2005  0.040629   0.166206   0.244 0.806973
as.factor(season)2006 -0.305934   0.180892  -1.691 0.091348 .
as.factor(season)2007 -0.170354   0.170230  -1.001 0.317392
as.factor(spotter)2   -1.664860   0.190169  -8.755  < 2e-16 ***
as.factor(spotter)3    0.217845   0.155772   1.398 0.162523
as.factor(spotter)5   -0.039925   0.226037  -0.177 0.859862
as.factor(spotter)6   -0.713243   0.119330  -5.977 4.06e-09 ***
as.factor(month)2     -0.213198   0.116562  -1.829 0.067927 .
as.factor(month)3     -0.865349   0.144639  -5.983 3.93e-09 ***
as.factor(month)12     0.106954   0.132618   0.806 0.420311
wind                  -0.116312   0.020799  -5.592 3.52e-08 ***
spotcon                0.325198   0.076025   4.278 2.22e-05 ***
swell                  0.221001   0.068699   3.217 0.001371 **
cloud                 -0.040026   0.019116  -2.094 0.036719 *
temperature            0.038554   0.008105   4.757 2.51e-06 ***
moonillum             -0.295976   0.129431  -2.287 0.022586 *
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

    Null deviance: 22980  on 575  degrees of freedom
Residual deviance: 10760  on 557  degrees of freedom
AIC: 7425.6
```

SPOTTERS 1,3,5,6 with swell included

```
Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)           -0.325445   0.468476  -0.695  0.48760
as.factor(season)2003 -0.604892   0.208225  -2.905  0.00385 **
as.factor(season)2004 -0.805551   0.193522  -4.163 3.75e-05 ***
as.factor(season)2005  0.142625   0.177860   0.802  0.42302
as.factor(season)2006 -0.300260   0.181329  -1.656  0.09842 .
as.factor(season)2007 -0.132470   0.171068  -0.774  0.43910
as.factor(spotter)2   -1.645231   0.182825  -8.999  < 2e-16 ***
as.factor(spotter)5   -0.021748   0.219852  -0.099  0.92124
as.factor(spotter)6   -0.705089   0.116097  -6.073 2.60e-09 ***
as.factor(month)2     -0.180757   0.123507  -1.464  0.14399
as.factor(month)3     -0.824287   0.146272  -5.635 3.03e-08 ***
as.factor(month)12     0.208986   0.147416   1.418  0.15696
wind                  -0.098539   0.022589  -4.362 1.59e-05 ***
spotcon                0.441334   0.091564   4.820 1.95e-06 ***
swell                  0.233646   0.073280   3.188  0.00153 **
cloud                 -0.031464   0.020819  -1.511  0.13140
```

```
temperature            0.036231   0.008511   4.257 2.51e-05 ***
moonillum             -0.307663   0.136599  -2.252  0.02477 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Spotters 1 and 6, with swell included

```
Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)           -0.009891   0.491729  -0.020 0.983962
as.factor(season)2003 -0.491607   0.220327  -2.231 0.026259 *
as.factor(season)2004 -0.766689   0.199469  -3.844 0.000143 ***
as.factor(season)2005  0.131681   0.183873   0.716 0.474348
as.factor(season)2006 -0.217384   0.189169  -1.149 0.251231
as.factor(season)2007 -0.094211   0.175164  -0.538 0.591005
as.factor(spotter)6   -0.738311   0.113750  -6.491 2.73e-10 ***
as.factor(month)2     -0.154259   0.133026  -1.160 0.246948
as.factor(month)3     -0.803408   0.146018  -5.502 7.00e-08 ***
as.factor(month)12     0.216209   0.148360   1.457 0.145871
wind                  -0.115925   0.024361  -4.759 2.80e-06 ***
spotcon                0.374728   0.098802   3.793 0.000174 ***
swell                  0.173309   0.079668   2.175 0.030229 *
cloud                 -0.035727   0.021171  -1.688 0.092339 .
temperature            0.038966   0.009084   4.289 2.29e-05 ***
moonillum             -0.292706   0.143491  -2.040 0.042067 *

***************************************************************************
```

Spotters 1,2,3,5,6, swell EXCLUDED

```
Call:
glm(formula = biomass ~ as.factor(season) + as.factor(spotter) +
    as.factor(month) + wind + spotcon + cloud + temperature +
    moonillum + offset(log(SearchEffort)), family = mvb.tweedie(1.5,
    0), data = workdat.all)

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)            0.985711   0.393409   2.506  0.01249 *
as.factor(season)2003 -0.791281   0.191868  -4.124 4.26e-05 ***
as.factor(season)2004 -0.565583   0.181898  -3.109  0.00197 **
as.factor(season)2005  0.081830   0.172042   0.476  0.63451
as.factor(season)2006 -0.198639   0.183287  -1.084  0.27892
as.factor(season)2007 -0.128601   0.168453  -0.763  0.44552
as.factor(spotter)2   -1.715257   0.197584  -8.681  < 2e-16 ***
as.factor(spotter)3    0.129579   0.159434   0.813  0.41670
as.factor(spotter)5    0.062152   0.162658   0.382  0.70252
as.factor(spotter)6   -0.765539   0.123769  -6.185 1.16e-09 ***
as.factor(month)2     -0.301193   0.117941  -2.554  0.01091 *
as.factor(month)3     -1.013589   0.144038  -7.037 5.48e-12 ***
as.factor(month)12     0.051354   0.135388   0.379  0.70459
wind                  -0.132950   0.020931  -6.352 4.26e-10 ***
spotcon                0.245276   0.074781   3.280  0.00110 **
cloud                 -0.044256   0.019594  -2.259  0.02427 *
temperature            0.036231   0.007836   4.624 4.63e-06 ***
moonillum             -0.265300   0.130713  -2.030  0.04284 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Spotters 1,2,5,6 swell EXCLUDED

```
Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)            0.538327   0.440503   1.222 0.222258
as.factor(season)2003 -0.693527   0.218813  -3.169 0.001621 **
as.factor(season)2004 -0.720824   0.203946  -3.534 0.000447 ***
as.factor(season)2005  0.177846   0.187398   0.949 0.343064
as.factor(season)2006 -0.196498   0.186713  -1.052 0.293124
as.factor(season)2007 -0.105627   0.173295  -0.610 0.542456
as.factor(spotter)2   -1.695289   0.193131  -8.778  < 2e-16 ***
as.factor(spotter)5    0.065997   0.159135   0.415 0.678523
as.factor(spotter)6   -0.760273   0.122115  -6.226 1.02e-09 ***
as.factor(month)2     -0.271350   0.126234  -2.150 0.032070 *
as.factor(month)3     -0.984782   0.147435  -6.679 6.43e-11 ***
as.factor(month)12     0.165858   0.151851   1.092 0.275256
wind                  -0.118545   0.022810  -5.197 2.96e-07 ***
spotcon                0.346549   0.090583   3.826 0.000147 ***
cloud                 -0.036528   0.021583  -1.692 0.091179 .
temperature            0.034679   0.008284   4.186 3.36e-05 ***
moonillum             -0.274617   0.139476  -1.969 0.049516 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

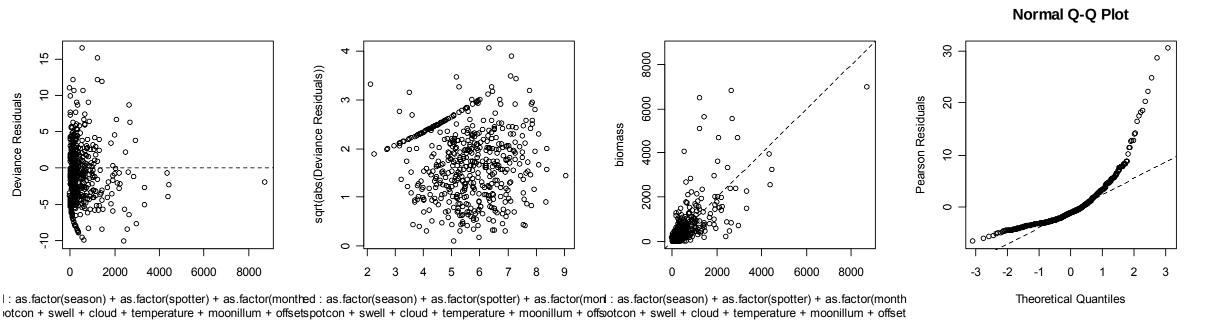


Figure A 1. Diagnostics for the model with spotters 1,2,5,6 and swell included. The x-axis text on the first and third panels is the call to the model indicating that predicted values are being plotted.

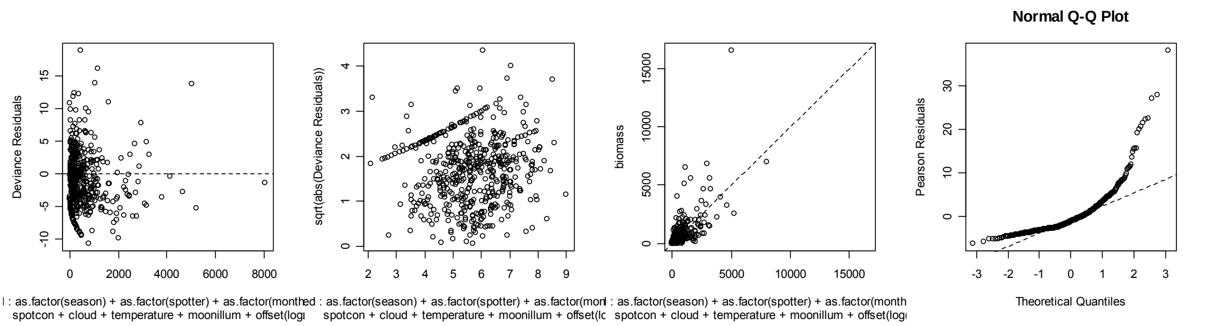


Figure A 2. Diagnostics for the model with spotters 1,2,5,6 and swell EXCLUDED. The x-axis text on the first and third panels is the call to the model indicating that predicted values are being plotted.

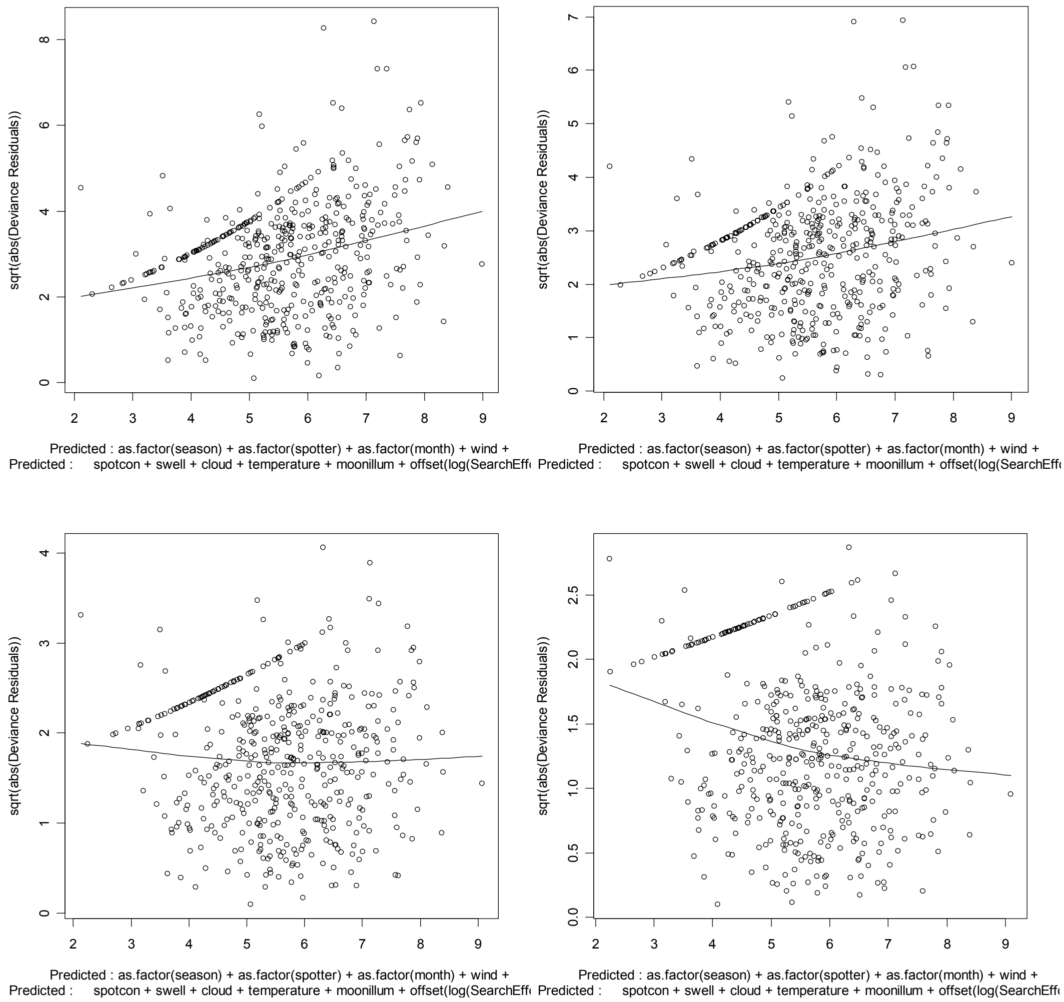


Figure A 3. Deviance residuals (square root of the absolute values) plotted against fitted values for the model with spotters 1,2,5,6 and swell included, with Tweedie parameter: (a, top left) Φ=1.1, (b, top right) Φ=1.2, (c, bottom left) Φ=1.5 and (d, bottom right) Φ=1.7. The solid line is a loess smooth fitted through the data. See main text for details.