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Commercial spotting in the Australian surface fishery, updated to include the 2005/6 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 over five fishing seasons (2001-02 to 2005-06). 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). The standardised indices were below the 5-season average in the 2002/3 and 2003/4 seasons, but are estimated to have been above average in 2004/5 and close to, or slightly above, average in 2005/6. Interpretation of the results is, however, 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).

Introduction

Between 1993 and 2000, a line-transect aerial survey for juvenile SBT was conducted in the Great Australian Bight (GAB) to estimate fishery independent surface abundance indices for 2-4 year-olds. The survey was not conducted in 2001 to 2004 due to logistical constraints of finding trained spotters, but was re-established in 2005. During the suspension of the line-transect survey, a pilot study was conducted to investigate the feasibility of utilizing experienced industry-based tuna spotters to collect data on the sightings of SBT during commercial spotting operations in the GAB.

The commercial spotting data provided preliminary fishery-dependent indices of SBT abundance (surface abundance per unit effort – a SAPUE index) for the 2002-2005 seasons. However, the indices are difficult to interpret (e.g. different ways of defining type of effort), and suffer from many of the problems which make longline catch per unit effort (CPUE) difficult to interpret (e.g. substantial changes in coverage over time; non-random coverage and areas with no coverage in some years). Although the SAPUE index may provide a qualitative indicator of juvenile SBT abundance in the GAB, it has always been recognised that a line-transect survey with consistent design and protocols from year to year is highly preferable.

Recognising the importance of time-series of indicators, we continued to collect SBT sightings data from commercial tuna spotters over the 2006 fishing season for SAPUE indices. This report summarises the field procedures and data collected during the 2006 season, and provides results of analyses for all five seasons (2002-2006).

2006 fishing season

Data were collected on SBT schools sighted by four experienced tuna spotters engaged in commercial fishing activities in the GAB between December 2005 and March 2006 (called the 2006 fishing season). In previous seasons, data has been collected from up to 6 spotters, but this year only four spotters were required by Industry. Unfortunately, one spotter that did not operate this year, collected significant amounts of data in all of the previous 4 fishing seasons, reducing our capacity to calculate a time series of SAPUE indices by individual.

The spotting data were collected following the protocols used in the previous four fishing seasons. Each plane had a spotter and pilot. For most flights, the spotter searched the sea surface on both sides of the plane for surface schools of SBT, although the pilot also searched for schools during some flights. A GPS was used to log the position of the plane (at 15 second intervals) and record the waypoint position of specific events. These events included the start and end of "search" periods (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), weather stations, and the positions of SBT schools observed. When a "sighting" of SBT was made, the spotter estimated the size range of the fish in the school (in kg) and the size of the school (in tonnes).

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. There were no restrictions on the environmental conditions for commercial spotting operations, although they rarely occurred when wind speeds were above 10-15 knots.

The spotter also recorded the type of search effort (intensive, broad scale or assisting boats) undertaken during the flight. Some spotters, however, find it difficult to distinguish between intensive search effort and time spent assisting vessels during a flight. Given this, the two categories were combined and were termed "restricted" search effort in the SAPUE analysis (below). The target species of each flight (SBT, skipjack tuna, mackerel, or a combination of these) was also recorded. All sighting information and environmental conditions were recorded in a logbook (not by a separate data recorder).

Search effort and SBT sightings

Data were collected for 102 commercial spotting flights in the 2006 fishing season. 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. Note that the data given in Table 2 for 2005 does not include 20 flights that had no GPS flight paths data collected (see Basson and Farley, 2005). Approximately 84 hrs of search effort and 677 tonnes of SBT were recorded during these 20 flights. The flight path data collected indicates that the area searched by spotters (number of 0.1° squares) increased slightly in 2006 compared to 2005. The proportion of 0.1° squares with SBT recorded in 2006 was similar to the 2005 season, but higher than in 2003 and 2004. BBT were recorded on 84 of the 102 commercial flights in 2006 (82%). The location of SBT sightings varied slightly between seasons (Figure 1) but the areas of highest SBT sighted per nautical mile searched were generally within the core fishing area and around the inshore lumps/reefs each season.

Figure 2 and Figure 3 show the size frequency of schools and fish sighted by one spotter during the 2002-2006 fishing seasons. This spotter contributed 40% of the total search effort and 48% of SBT schools recorded over the five fishing seasons. Using data from one spotter removes the problem of differences between spotters in their estimates of school and fish size. The school size frequency data does not show any obvious trends time. However, the fish size frequency data shows a steady increase in the proportion of small (<10 kg) SBT recorded since 2003 (Figure 4), an absence of large (>30kg) fish in 2006 compared to previous seasons.

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

Spotter	Fishing season				
	2002	2003	2004	2005	2006
1	61.3	20.2	42.2	39.7	44.2
2	7.6	11.5	15.2	9.3	11.6
3	11.7	33.2	19.4	19.5	0.0
4	0.0	1.2	0.0	0.0	0.0
5	5.6	4.4	0.0	5.0	14.8
6	13.9	29.5	23.2	26.5	29.5

Table 2. Search effort and SBT sighted by commercial spotters in the 2002-2006 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	2006
No. flights	86	102	118	116	96	102
Total time searched (hrs)	325	425	521	551	467	452
Total time searched in core (hrs)	245	341	464	-	418	376
No. 0.1° squares searched	854	947	775	-	654	817
No. 0.1° squares with SBT	170	151	109	135	124	155
% 0.1° squares with SBT	20	16	14	-	19	19
% flights with no SBT recorded	16	18	23	6	7	18
Total number of schools	1182	1301	1133	1061	1725	1124
Total biomass[1] recorded	44626	38559	33982	2402	63492	50524
Total biomass[1] recorded (core)	40957	30230	25720	87447	52802	36570

[1] Table footnote: 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).

Figure 1. Search effort by spotters (nm flown/0.1° square), locations of SBT sightings, and SBT SAPUE (tonnes/nm/0.1° square) in the GAB by fishing season. For direct comparison, location of effort data are displayed as the percent (%) of total effort for the season. Areas of darkest in the SAPUE plot blue indicate zero SAPUE. Note the log scale for effort and SAPUE. The 'core fishing area' is shown by the red square. Coastline and shelf-break (200m isobath) shown for geographical reference.

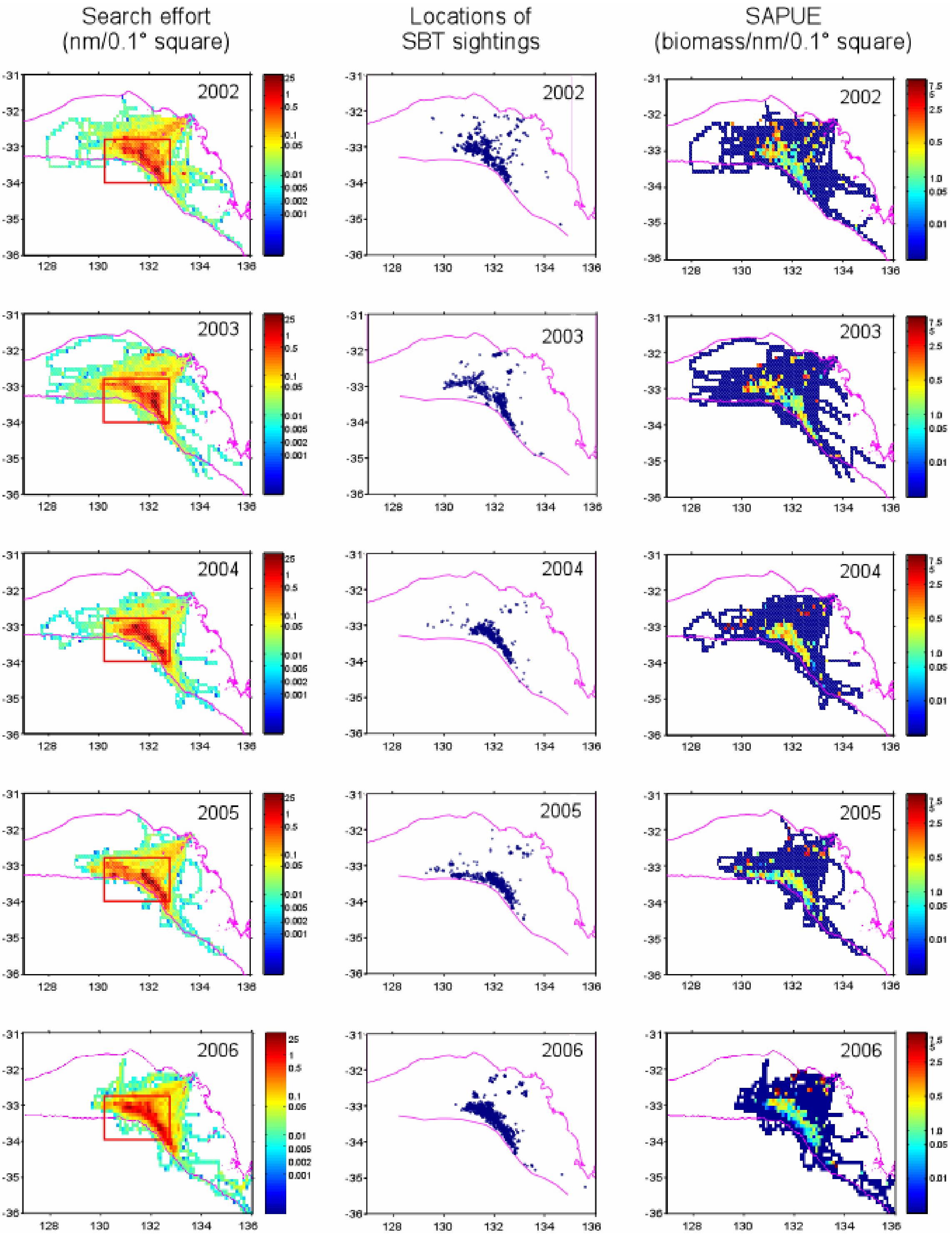


Figure 2. Size frequency of SBT schools recorded by one commercial spotter during the 2002-2006 fishing seasons. (n=3315 schools)

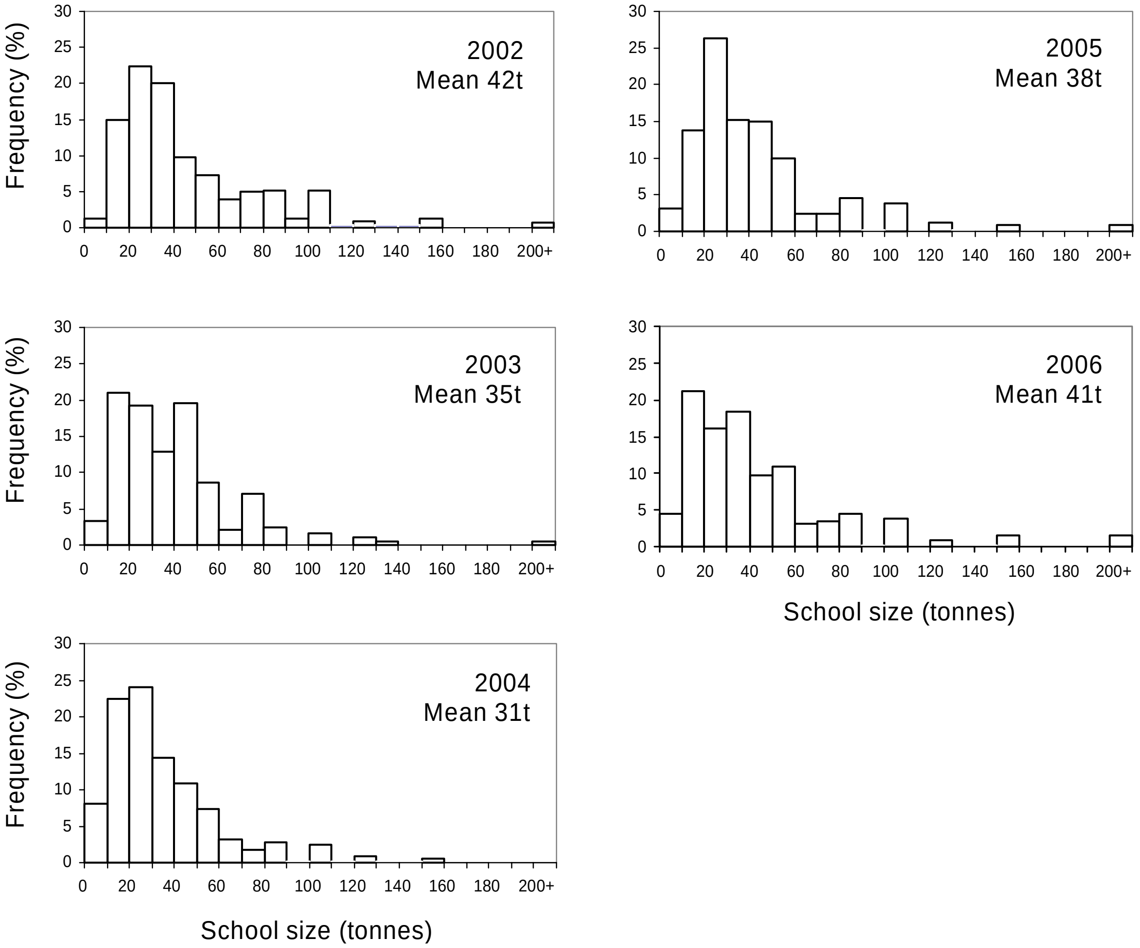


Figure 3. Size frequency of SBT recorded by one commercial spotter during the 2002-2006 fishing seasons. Data are weighted by school size. Graphs based on mean fish size data collected for 3286 schools.

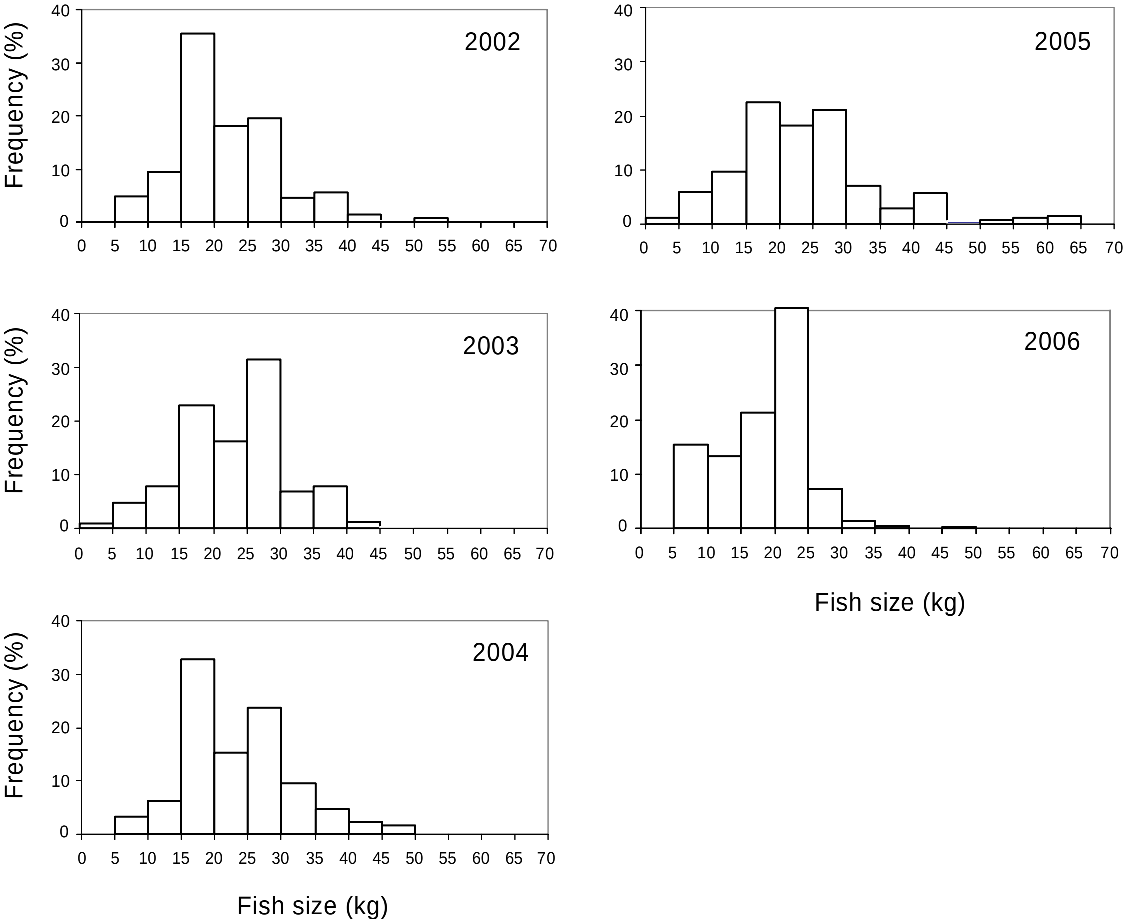
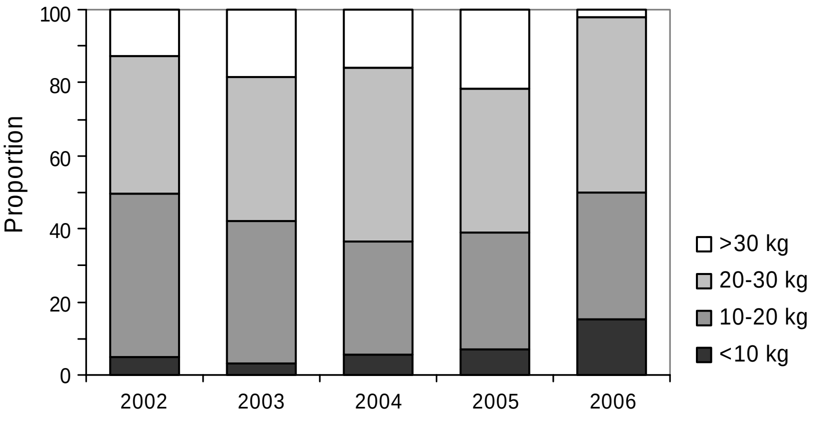


Figure 4. Proportion of SBT by size class recorded by one commercial spotter in the 2002-2006 fishing seasons.



Nominal SAPUE

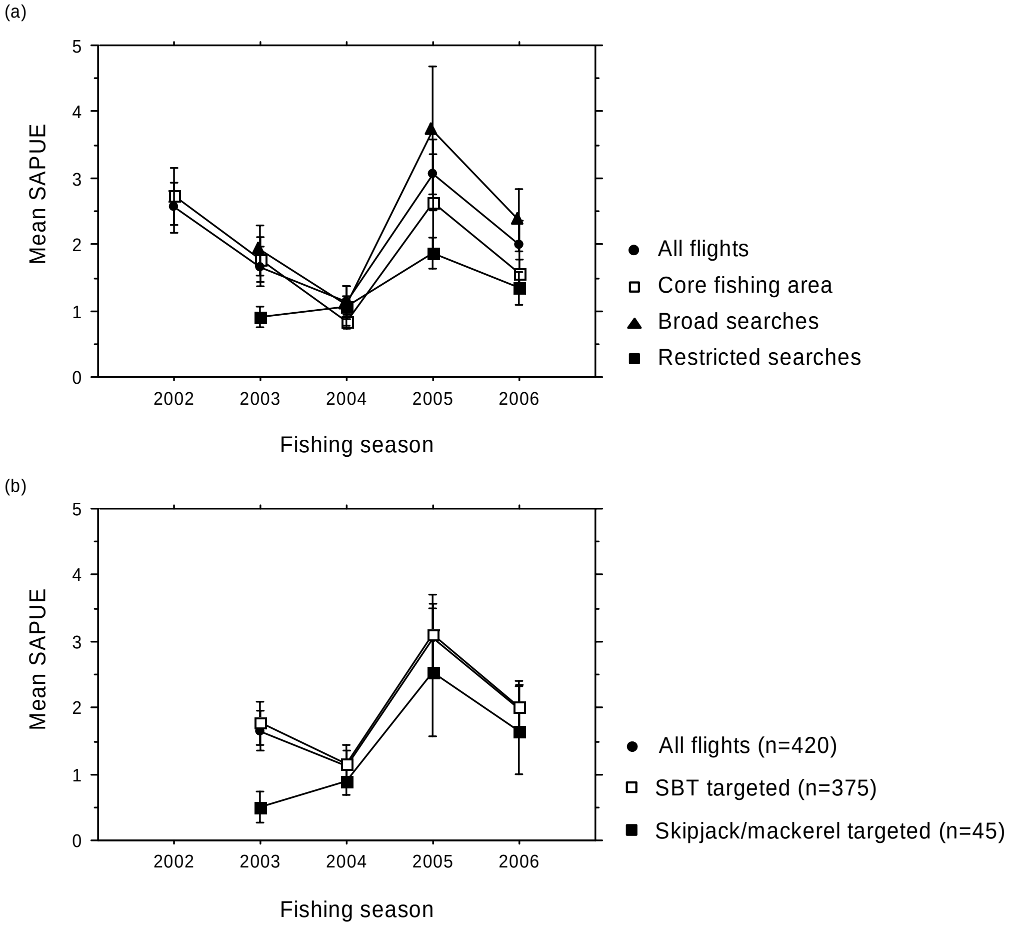
The duration of "search" sectors during flights were calculated using the GPS logged position and time. Search time was used as a measure of effort rather than search distance because GPS positions were not collected for all flights in 2005, while the total search time was. Farley and Bestley (2002) found that nominal SAPUE indices based on search time and distance are strongly linearly related ($r^2 = 0.998$) suggesting that either can be used.

Logbook data on SBT sightings were summarised to produce a daily total number of sightings, schools, and total biomass per plane. 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). This was done by spotter for each fishing season.

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. SAPUE indices were calculated by geographic area (whole GAB and core fishing area), by search type recorded by the spotters (broad and restricted), and for flights where SBT was targeted. The core fishing area was selected based on search effort and biomass sighted. Substantial amounts of SBT were sighted between 130.2 and 132.8°E and 32.8 and 34.0°S. Approximately 75% of the total biomass and 81% of the total search effort was recorded in this core area.

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 five seasons. Three of the indices showed substantial declines prior to 2004, then all four increased in 2005 and decreased in 2006. For 2005, the broad search category includes sightings from intentional post-fishing flights to search for SBT schools as part of a stock-take project run by BRS. The nominal index based on the broad search effort should therefore be interpreted with caution in 2005. Figure 5b shows a comparison of mean SAPUE by season for all flights, flights where SBT was targeted, and flights where SBT was not specifically targeted. Not surprisingly, mean SAPUE was lower for flights where SBT was not targeted, but as there were very few non SBT flights (n=45), it makes little difference to the overall SAPUE indices obtained by month.

Figure 5. Nominal SAPUE indices (+/-se) for the 2002-2006 fishing seasons (a) irrespective of target species, and (b) by species targeted. Classifying search effort as either broad or restricted, and recording the target species, started in 2003 (i.e. the 2002/2003 fishing season)



Standardised SAPUE

There are now five 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, season and month within season

Season	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

Based on the information in Table 3 for the seasons 2002 through to 2005, 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. It is clear from Table 3 (and Table 1 above) that there was a change in the 2006 season. The effort for spotter 3 (also referred to as company 3[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.

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 average environmental variables recorded by season are summarised in Figure 6 and Table 4. Note that the aerial survey transects are only flown during certain conditions, so that summaries of environmental conditions recorded during the line transect aerial survey (CCSBT/ESC/0609/16) and during commercial spotting operations would tend to differ. During the 2006 flights, the mean air temperature, wind speed, swell height, and overall spotting conditions were higher than in 2005, but 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), it is interesting to note that the monthly temperatures were very different. Figure 7 shows the monthly mean temperatures from the data over the past 5 seasons. In 2006, the difference between the January and February temperatures was the

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

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).

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

Figure 6. Box-plot of environmental variables recorded by the commercial spotters for flights during the 2002-2006 fishing seasons (Dec-Mar only). Centre line and outside edge of each box indicate the median and 25th/75th percentile around the median respectively.

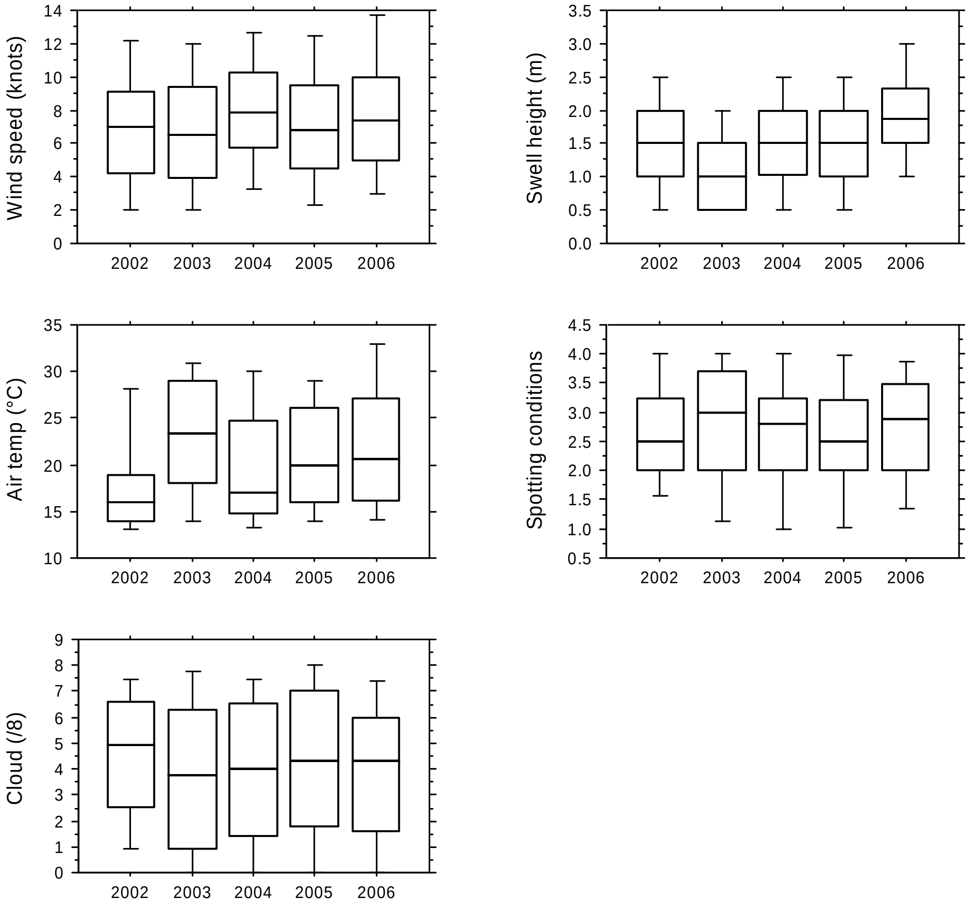
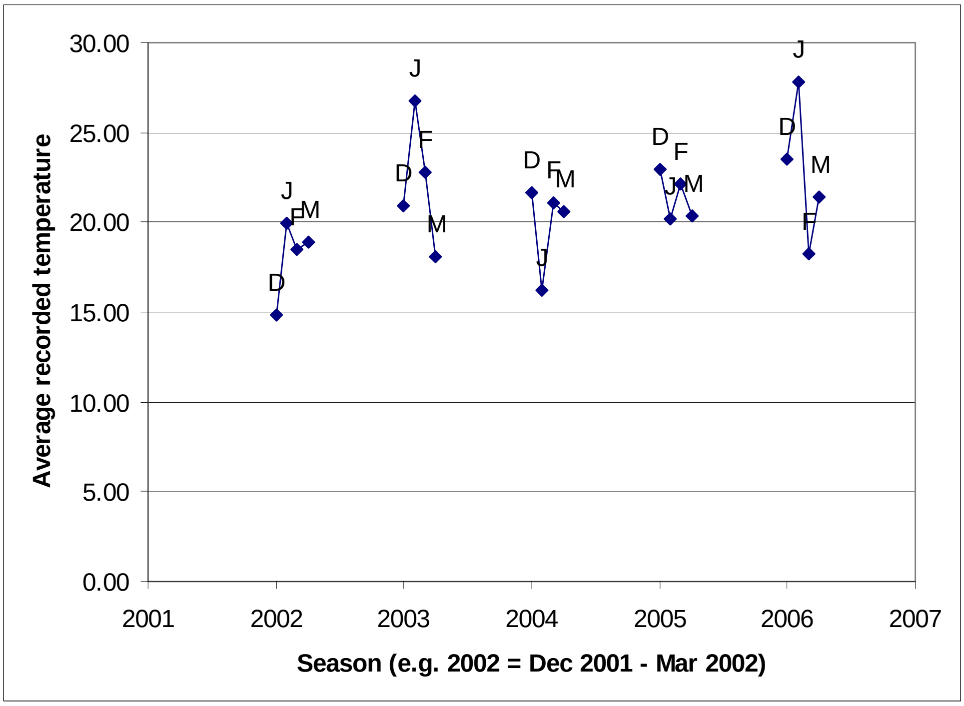


Table 4. Mean values of environmental variables. Note visibility was not recorded in 2002.

Season	Wind speed	Spotting condition	Swell height	Cloud cover	Temperature	Visibility
2002	7.05	2.64	1.46	4.48	17.91	
2003	6.94	2.79	1.21	3.66	23.35	5.54
2004	7.91	2.64	1.65	3.94	19.73	7.77
2005	6.99	2.55	1.59	4.23	21.14	8.95
2006	7.59	2.75	1.95	4.01	22.11	7.64

Figure 7. 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 conducted this season, it 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 company. The associated environmental variables are taken as the means for that day and company. The data were compiled as a set for the entire area and all the analyses were done on the ‘whole area’ dataset. In the past we have also done analyses for just the “core” area (where most of the spotting effort occurs), but this was omitted this year simply because of limited time given the overall workload on SBT.

Table 5 shows a summary of the number of days flown with no biomass sighted. It is interesting to note that the percentage days with no sightings was much lower in 2005 than any of the other years, and that it was relatively high in both 2004 and 2003.

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

Modelling approach

We used the same modelling approach as last year and essentially updated those analyses with data from the 2006 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 k, and for $k<2$ there is no problem with zero observations. When fitting the models, the exponent k was entered ($1<k<2$). Note that the value of $k=1$ coincides with the Poisson distribution, and a value of 2 with the Gamma distribution. Different values of k 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.

Results

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. Only limited exploration was performed this year, but indications are that the same set of variables are still relevant. An interaction between company and season appeared to be important in the past, and we previously considered two models:

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

Model with interaction:
biomass ~ as.factor(season) + as.factor(company) + as.factor(month) + wind + spotcon + swell + cloud + temperature + moonillum + **as.factor(season):as.factor(company)** + offset(log(effort))

As noted above, the change in effort for spotters 3 and 5 in the 2006 season has lead to an unbalanced dataset. This means that it is currently not meaningful to use the model with interaction term to obtain a standardised index of abundance for the whole period[2]. We therefore only present results for the no-interaction model. We did, however, look at the sensitivity of the index to using data for spotters 1,3,5 and 6, or using only data for spotters 1 and 6.

Figure 8 shows that point estimates are only very slightly sensitive to this in 2005 and 2006. The nominal values of SAPUE are also plotted, showing that the standardisation has the strongest effect on the index in 2003 and 2004 seasons.

Figure 8. Time-trends of the standardised SAPUE indices (surface abundance per unit effort) scaled to the mean for (i) companies 1, 3, 5 and 6, and (ii) companies 1 and 6 from the no-interaction model, and (iii) nominal SAPUE. Season refers to the 2nd year e.g. 2006 indicates the 2005/06 season.

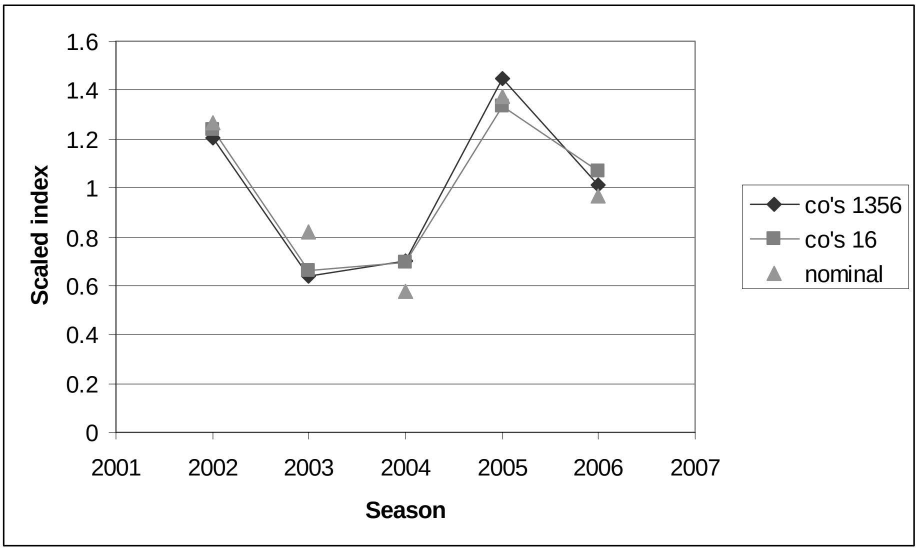


Table A1 (Appendix 1) shows that swell is now significant in the model for spotters 1,3,5 and 6, but not for that with only spotter 1 and 6. This term was not significant in last years analysis. Diagnostics show that residuals are reasonably well-behaved, but the qq-plots are still rather poor (not linear as expected). This is unlikely to badly affect the point-estimates of coefficients, but does indicate a ‘fat’ tail in the data. Lower values of k improve the qq

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[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.

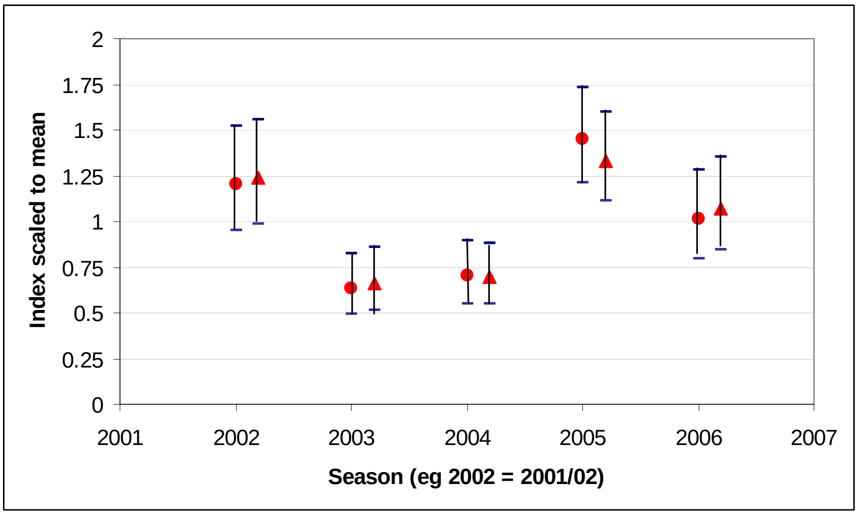
plot at the lower end, but makes it worse at the upper end. Higher values of k makes the qq-plot even more non-linear than seen in the plots for k=1.5. In a relative analysis such as this, where the focus is on year-to-year comparisons, poor qq-plots do not generally imply bias in the point-estimates, but do point to the need to validate standard errors. This was investigated via bootstrap analysis as described in Basson and Farley (2005; CCSBT-ESC/0509/23). Results for 500 bootstraps with 'day' and 'week' as resampling units again show that the model estimates of standard deviations are no smaller than the bootstrap estimates (Table 6). 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.

Figure 9 shows results for the four spotters (1,3,5 and 6) over the past 4 seasons (2005 refers to the December 2004 to March 2005). The ranges were obtained by taking the predicted values + or – 2 standard deviations on the log scale and then converting to the normal scale.

Table 6. Estimates of standard errors for some model coefficients from the GLM model (with companies 1,3,5 and 6 included) and standard deviations of the coefficients from bootstraps with either 'day' or 'week' as the resampling unit.

	Estimated Standard error of coefficient	Bootstrap estimate of the standard deviation of the coefficient (500 replicates)	
		day	week
Intercept	0.52	0.50	0.48
as.factor(season)2003	0.20	0.15	0.18
as.factor(season)2004	0.19	0.16	0.20
as.factor(season)2005	0.18	0.15	0.16
as.factor(season)2006	0.19	0.17	0.18

Figure 9. Estimates of standardised relative surface abundance (scaled to the mean over the period) for (i) the model with companies 1,3, 5 and 6 (circle), and (ii) the model with only companies 1 and 6 (triangle). All months were included (December – March). The median and exp(predicted value + or – 2 standard errors) are shown.



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Summary

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 therefore only present results for the model without interaction, noting however, that past analyses have indicated that the model with interaction is to be preferred over one without interaction between spotter (or company) and season. Instead, we have considered the sensitivity of results to two different combinations of spotters in the analysis: (a) spotters 1,3,5 and 6 included in the analysis, and (b) only spotters 1 and 6 are included. Spotters 1 and 6 have consistently had high levels of effort over the entire period.

Results are again somewhat sensitive to the spotter, though the general patterns of the indices are similar. The estimated index is lowest in 2003 and 2004 (Figure 9). The 2005 estimate is the highest and that for 2006 is close to, or slightly above, the average over the past 5 seasons. It is, however, 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. 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 two years of overlap between the SAPUE index and the line-transect aerial survey index (see CCSBT/ESC/0509/22 and update this year, CCSBT/ESC/0609/16). 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.

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Appendix 1

Table A1. Summary of results of model without interaction terms, spotters 1,3,5 and 6

```
summary(mod1356.2006)   Call:
glm(formula = biomass ~ as.factor(season) + as.factor(company) +
    as.factor(month) + wind + spotcon + swell + cloud + temperature +
    moonillum + offset(log(effort)), family = mvb.tweedie(1.5,
    0), data = workdat, subset = (company != 2))

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-12.176   -3.976   -1.278    1.228   17.566

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)             0.439172   0.515750   0.852 0.394970
as.factor(season)2003 -0.635966   0.195565  -3.252 0.001240 **
as.factor(season)2004 -0.540132   0.185308  -2.915 0.003752 **
as.factor(season)2005  0.185064   0.176496   1.049 0.294997
as.factor(season)2006 -0.172670   0.192724  -0.896 0.370802
as.factor(company)3     0.141998   0.163793   0.867 0.386476
as.factor(company)5    -0.068265   0.232464  -0.294 0.769165
as.factor(company)6    -0.855584   0.139061  -6.153 1.79e-09 ***
as.factor(month)2      -0.164520   0.138330  -1.189 0.234988
as.factor(month)3      -0.880789   0.164220  -5.363 1.36e-07 ***
as.factor(month)12      0.101596   0.152207   0.667 0.504834
wind                   -0.120624   0.023576  -5.116 4.77e-07 ***
spotcon                 0.329350   0.090702   3.631 0.000317 ***
swell                   0.213664   0.080157   2.666 0.007985 **
cloud                  -0.049198   0.021833  -2.253 0.024752 *
temperature             0.029967   0.009788   3.062 0.002343 **
moonillum              -0.399632   0.151068  -2.645 0.008469 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
(Dispersion parameter for Tweedie family taken to be 24.27861)

    Null deviance: 17323.5  on 432  degrees of freedom
Residual deviance:  8289.2  on 416  degrees of freedom
AIC: 5619.8
Number of Fisher Scoring iterations: 6
```

Figure A1. Default plot of diagnostics for model with spotters 1,3,5,6. (x-label is the call as in the table above)

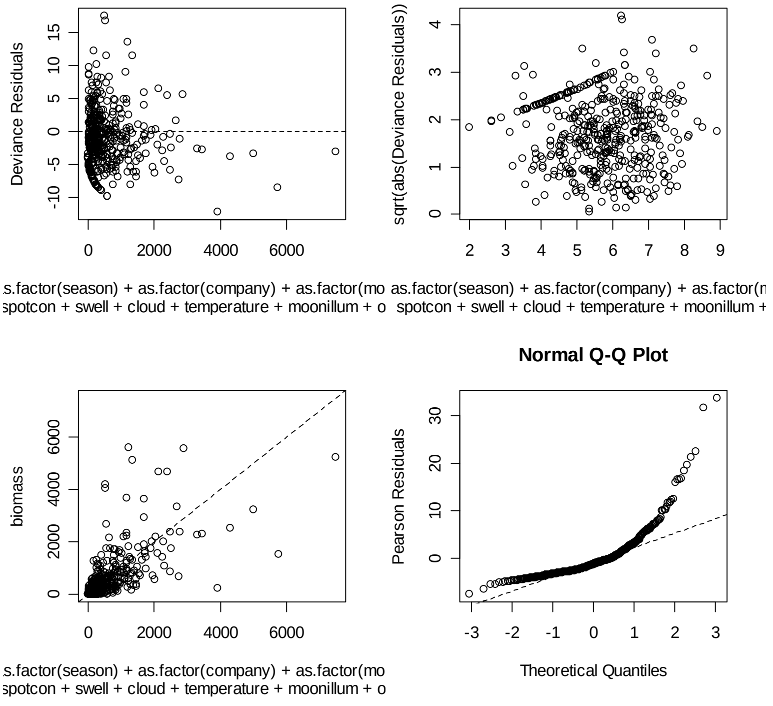

Table A2. Summary of results of model without interaction terms, spotters 1 and 6 only

```
summary(try16)   Call:
glm(formula = biomass ~ as.factor(season) + as.factor(company) +
```

```
    as.factor(month) + wind + spotcon + swell + cloud + temperature + 
    moonillum + offset(log(effort)), family = mvb.tweedie(1.5, 
    0), data = workdat, subset = (company != 2 & company != 5))

Deviance Residuals: 
    Min       1Q   Median       3Q      Max  
-11.345   -3.892   -1.239    1.308   17.772  

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)    
(Intercept)            0.831697   0.516181   1.611 0.107938    
as.factor(season)2003 -0.627238   0.193241  -3.246 0.001273 ** 
as.factor(season)2004 -0.575465   0.180794  -3.183 0.001575 ** 
as.factor(season)2005  0.072873   0.173598   0.420 0.674881    
as.factor(season)2006 -0.148366   0.192716  -0.770 0.441845    
as.factor(company)3    0.100061   0.161339   0.620 0.535499    
as.factor(company)6   -0.878226   0.134529  -6.528 2.09e-10 ***
as.factor(month)2     -0.128368   0.138465  -0.927 0.354460    
as.factor(month)3     -0.862196   0.161745  -5.331 1.66e-07 ***
as.factor(month)12     0.079316   0.151096   0.525 0.599925    
wind                  -0.134536   0.023921  -5.624 3.57e-08 ***
spotcon                0.255716   0.091203   2.804 0.005304 ** 
swell                  0.130272   0.082926   1.571 0.117011    
cloud                 -0.048884   0.021349  -2.290 0.022569 *  
temperature            0.032957   0.009806   3.361 0.000854 ***
moonillum             -0.372386   0.151599  -2.456 0.014472 *  
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 
(Dispersion parameter for Tweedie family taken to be 22.59940)

    Null deviance: 15772.9  on 403  degrees of freedom
Residual deviance:  7441.8  on 388  degrees of freedom
AIC: 5219.5
Number of Fisher Scoring iterations: 6
```

Figure A2. Default plot of diagnostics for model with spotters 1 and 6 (x-label is the call as in the table above)