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Commercial spotting in the Australian surface fishery, updated to include the 2004/5 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 four fishing seasons (2001-02 to 2004-05). 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 SAPUE indices generally showed substantial declines prior to 2004, but increased between 2004 and 2005. Interpretation of the results, however, is difficult as the data suffers from many of the same problems that affect catch per unit effort (eg changes in coverage over time, lack of coverage in areas where commercial fishing is not taking place, and changes in operations over time). No comparison can be made between the SAPUE index and the line-transect aerial survey index (see CCSBT/ESC/0509/22), given that both are relative indices and there is only one year of overlap. More importantly, the commercial spotting data are obtained in a substantially different way directly associated with the fishing operation. We still consider the line-transect aerial survey to be preferable as an approach to an index compared to the commercial spotting.

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 2002-2004 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 2005 fishing season for SAPUE indices. This report summarises the field procedures and data collected during the 2005 season, and provides results of analyses for all four seasons (2002-2005).

Field procedures

Data were collected on SBT schools sighted by five experienced tuna spotters engaged in commercial fishing activities in the GAB between December 2004 and April 2005 (called the 2005 fishing season). The spotter-planes used were four Cessna 337s and one Aero

Commander. 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. (Note, in this section we use the terminology 'spotter', not 'observer').

The spotting data were collected following the protocols used in the previous three fishing seasons (Farley et al., 2004). A GPS was used to log the position of the plane (at 15 second intervals) 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 in the GPS directly over the school. The spotter estimated a range for the size of individual fish in each school (in kg) and the size of each 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. The spotter also recorded the type of search effort (intensive, broad scale or assisting boats) undertaken during the flight, and the target species of the flight (SBT or skipjack tuna). However, some spotters found 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).

Search effort

Data were collected for 116 commercial spotting flights by 5 spotters in the 2005 fishing season. Unfortunately, flight path data collected by one spotting company was disappointing this season. Of 25 flights with sightings data collected, only 5 had complete GPS-logged flight path data from which we could obtain data on the areas and distance searched. Of the remaining 20 flights, 12 had incomplete flight path data (probably because of incorrect placement of the aerial in the plane) and 8 had no data collected. Fortunately, the total search time was recorded for each flight and this data was used as the measure of search effort in the SAPUE analyses. However, the 20 flights were not included in SAPUE estimates for the core fishing area as there was no information on the areas searched during the flights.

Three spotters collected the majority of data in all four fishing seasons (Table 1). The number of flights and total search effort recorded increased over the four seasons, if we include the 20 flights with missing flight path data (Table 2; 2005b). In all seasons, 99-100% of search effort occurred in December to March. The flight path data shows that the area searched by spotters (number of 0.1° squares) has declined over the four seasons, and the proportion of search effort in the core fishing area has increased (Figure 1; Table 2). SBT (or SBT and skipjack combined) were the target species of approximately 85% of flights each season. For flights where skipjack was the target species, all SBT sighted were recorded. Most skipjack flights occurred to the west of the core fishing area.

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

Spotter	Fishing season 2002	2003	2004	2005
A	0	1.2	0	0.0
B	5.6	4.6	0	5.0
C	7.6	11.5	15.2	9.3
D	11.7	33.2	19.4	19.5
E	13.9	29.5	23.2	26.6
F	61.3	20.2	42.2	39.6

Table 2. Search effort and SBT sighted by commercial spotters in the 2002-2005 fishing seasons. The 2005a data does not include 20 flights with no GPS flight path data collected, while the 2005b data does.

Fishing season	2002	2003	2004	2005a	2005b
No. flights	86	102	118	96	116
Total time searched (hrs)	325	425	521	467	551
Total time searched in core (hrs)	245	341	464	418	-
No. 0.1° squares searched	854	947	775	654	-
No. 0.1° squares with SBT	170	151	109	124	135
% 0.1° squares with SBT	20	16	14	19	-
% flights with no SBT recorded	16	18	23	7	6
No. sightings	670	735	780	920	1061
No. schools	1182	1301	1133	1725	2402
Total biomass[1] recorded	44626	38559	33982	63492	87447
Total biomass[1] recorded (core)	40957	30230	25720	52802	-

[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).

SBT sightings

SBT were recorded on 109 of the 116 commercial flights in 2005 (94%). The location of SBT sightings varied between seasons, being closer to the shelf-break in 2005 than in the previous seasons. The areas of highest SBT abundance per nautical mile searched were within the core fishing area and around the inshore lumps/reefs (Figure 1).

Figure 2 and Figure 3 show the size frequency of schools and fish sighted by one spotter during the 2002-2005 fishing seasons. This spotter contributed 40% of the total search effort and 42% of sightings data over the four fishing seasons. Using data from one spotter removes the problem of differences between spotters in their estimates of school and fish size. In 2005, a slightly greater proportion of very small (< 10 kg) and large (>30 kg) SBT were recorded compared to previous seasons (Figure 4). There does not appear to be any obvious trends in the size of schools or fish sighted over the four seasons by this spotter.

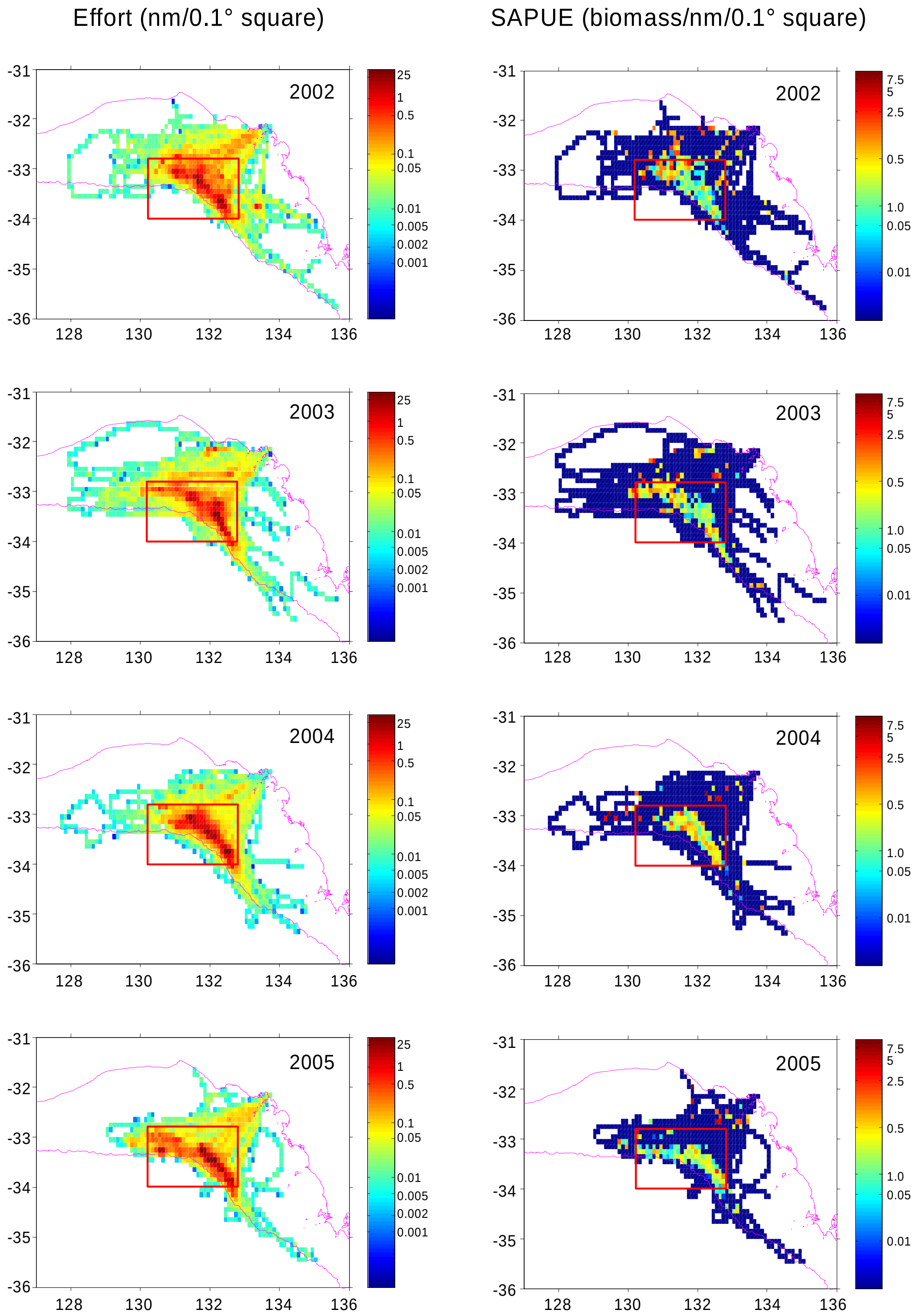

Figure 1. Search effort by spotters (nm flown/0.1° square) and SBT SAPUE (tonnes/nm/0.1° square) in the GAB by fishing season. The 'core fishing area' is shown by the square. Coastline and shelf-break (200m isobath) shown for geographical reference. For direct comparison, location of effort data are displayed as the percent (%) of total effort for the season. In the effort plots, the greatest search effort occurred within the core fishing area (darkest squares). In the SAPUE plots, the darkest squares indicate zero SAPUE, and lighter squares indicates higher SAPUE. Note the log scale for effort and SAPUE.

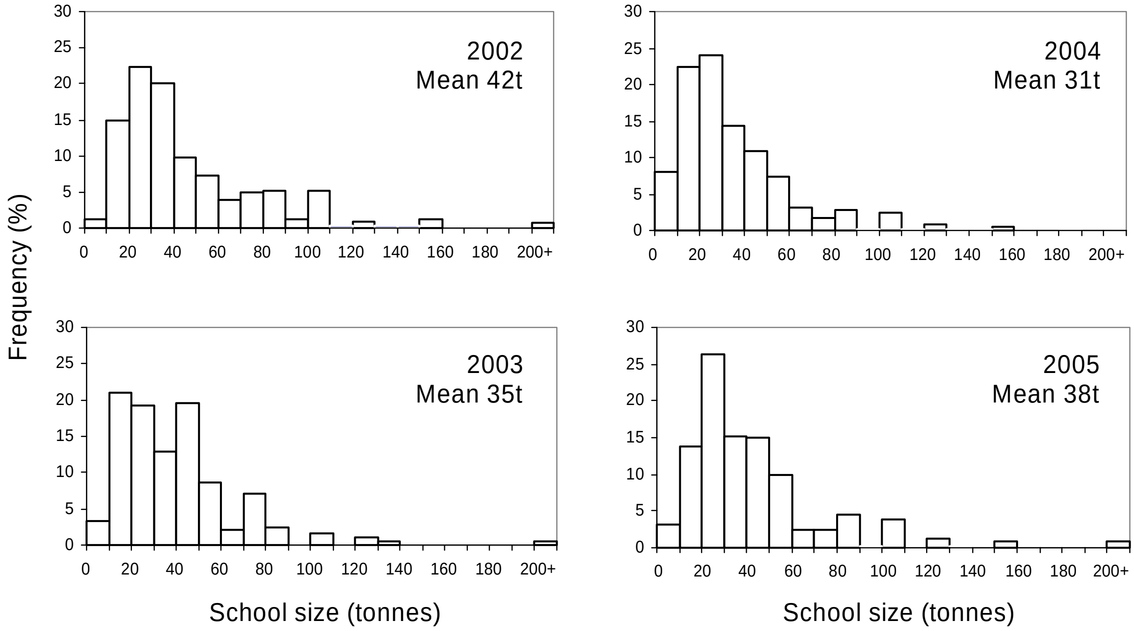

Figure 2. Size frequency of SBT schools recorded by one commercial spotter during the 2002-2005 fishing seasons. (n=2507 schools)

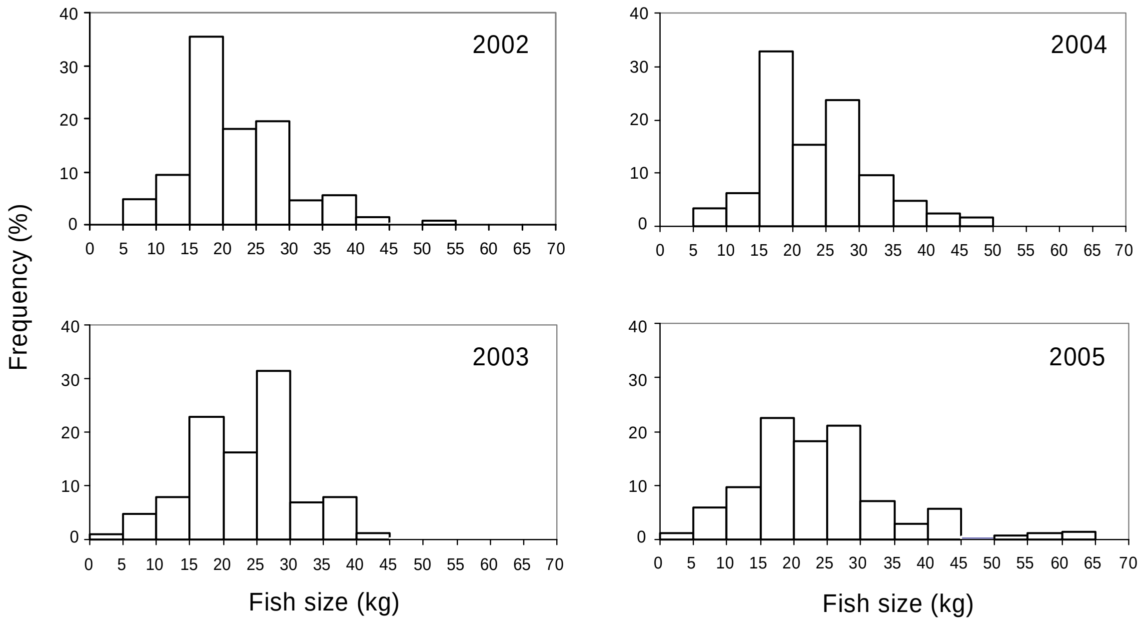

Figure 3. Size frequency of SBT recorded by one commercial spotter during the 2002-2005 fishing seasons. Data are weighted by school size. Graphs based on mean fish size data collected for 2507 schools.

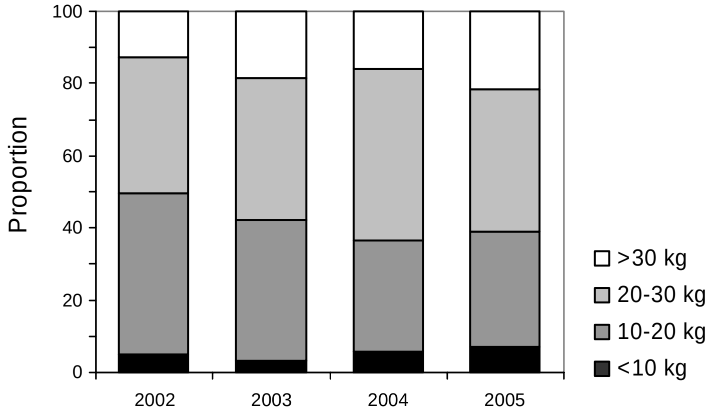

Figure 4. Proportion of SBT by size class recorded by one commercial spotter in the 2002-2005 fishing seasons.

Environmental conditions

In 2005, the mean wind speed and cloud cover during spotting operations were lowest in December and January. By mid-March, spotting conditions deteriorated due to increased wind speed and cloud cover. The mean air temperature in 2005 was relatively high in all months (>20°C). The environmental variables recorded by season for commercial flights are summarised in Figure 5. Previous analyses (Farley et. al. 2004) have shown that SAPUE was generally high when wind speed, swell height and cloud cover were low.

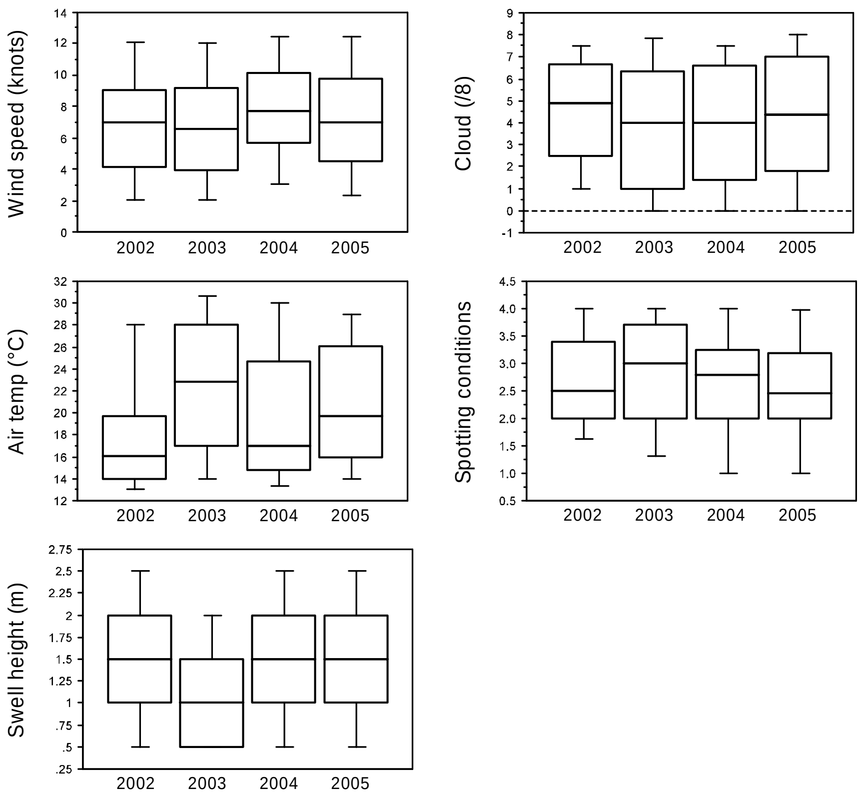

Figure 5. Box-plot of environmental variables recorded by the commercial spotters for flights during the 2002-2005 fishing seasons (Dec-Mar only). Centre line and outside edge of each box indicate the median and 25th/75th percentile around the median respectively.

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, while the total search time was (see results). 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 (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).

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 indices were calculated by geographic area (whole GAB and core fishing area) and by search type recorded by the spotters (broad and restricted). 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 (Figure 6). Approximately 84% of the total biomass and 85% of the total search effort was recorded in this core area.

Four nominal SAPUE indices of juvenile abundance are shown in Figure 7. These were calculated based on (1) all flights, (2) flights or portions of flights within the core fishing area, (3) flights or portions of flights recorded as ‘broad search’ effort, and (4) flights or portions of flights with restricted search effort around fishing vessels. Since type of search effort was not recorded in 2002, only two of the indices can be calculated for all four seasons. Three of the indices showed substantial declines prior to 2004, but all four increased between 2004 and 2005. Large variations were detected in SAPUE between the three spotters that contributed the most search effort, but most showed increases between the 2004 and 2005 seasons. 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.

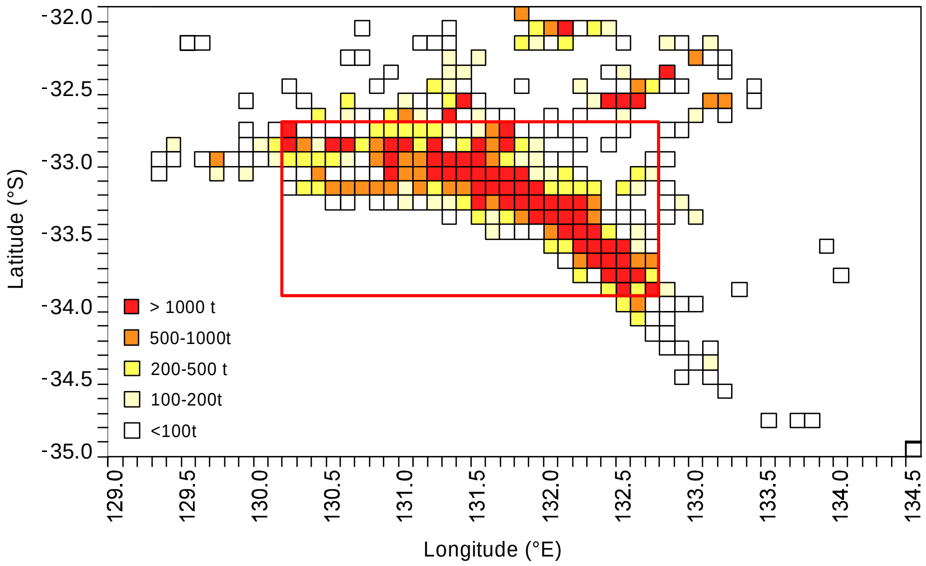

Figure 6. Combined total SBT biomass (tonnes) recorded by commercial spotters by 0.1° square during the 2002-2003 fishing seasons. The 'core fishing area' selected is shown by the square.

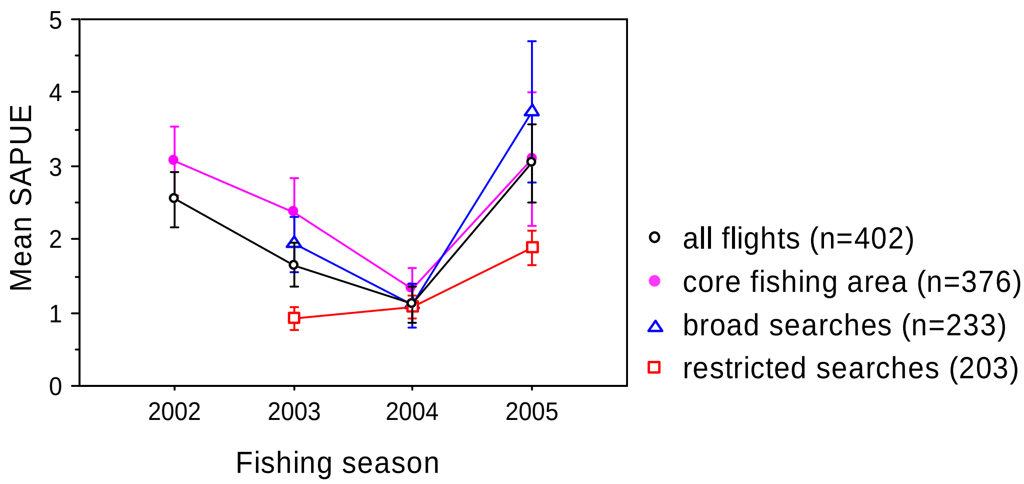

Figure 7. Nominal SAPUE indices (+/-se) for the 2002-2005 fishing seasons. Classifying search effort as either broad or restricted started in 2003 (i.e. the 2002/2003 fishing season).

Standardised SAPUE

There are now four 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 an important point 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 biasses 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 company, season and month within season

Company1	Dec	Jan	Feb	Mar	Company2	Dec	Jan	Feb	Mar
2002	14	7	7	11	2002		5	3	
2003		10	2	5	2003		6	3	
2004		9	15	16	2004		7	10	
2005		11	9	19	2005		7	2	
Company3	Dec	Jan	Feb	Mar	Company5	Dec	Jan	Feb	Mar
2002	8	5	3		2002			4	
2003	10	9	6	6	2003		5	1	
2004	11	5	9	2	2004				
2005	4	9	10	2	2005		1	6	
Company6	Dec	Jan	Feb	Mar					
2002	4	7	4						
2003	10	10	4	4					
2004	10	11	6	4					
2005	3	7	16	8					

Based on the information in Table 3, we have only included data from companies 1,3 and 6 in the standardisation analyses. Data from all months (Dec, Jan, Feb and March) were included in the analyses.

As noted in the past (e.g. CCSBT-ESC/0409/19) sighting conditions and surfacing behaviour are influenced by weather and environmental variables. Table 4 summarises the mean values of environmental variables recorded during spotting operations (visibility was not recorded in 2002). 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. Mean values of environmental variables (also see Figure 5)

Season	Wind	Spotting	Swell	Cloud	Temperature	Visibility
2002	7.05	2.64	1.44	4.48	17.91	-
2003	6.94	2.79	1.21	3.66	23.35	5.5
2004	7.91	2.64	1.65	3.94	19.73	7.8
2005	6.99	2.42	1.56	4.20	21.14	8.5

The sightings data

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 also as a set for just the core area. Most of the analyses were done on the 'whole area' dataset.

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 the 3 companies combined. 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	Positive biomass	total days	% zero	%effort in hours
2002	6	57	63	10%	8%
2003	12	64	76	16%	12%
2004	19	79	98	19%	13%
2005	5	93	98	5%	4%

Modelling approach

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 (i.e differences between companies1) 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 values 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

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

[1] 'Company' can be equated with 'spotter' and the same spotter has flown for the given company over the time period considered here.

little effect on results or on the AIC statistic. An interaction between company and season appeared to be important and the following two models were compared in order to explore this further:

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))

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

For the no-interaction model (k=1.5), the AIC statistic was 4357.2, but for the model with interaction (also k=1.5) it was 4346.9 —a difference of nearly 10 units being a strong indication that the interaction model is better for prediction. Anova tests also indicated that the interaction term was significant.

Figure 8 shows the different time-trends estimated in the model with interaction, compared to the overall time-trend for the model without interaction. This overall time-trend is essentially identical to that of one of the companies in the interaction model (co1).

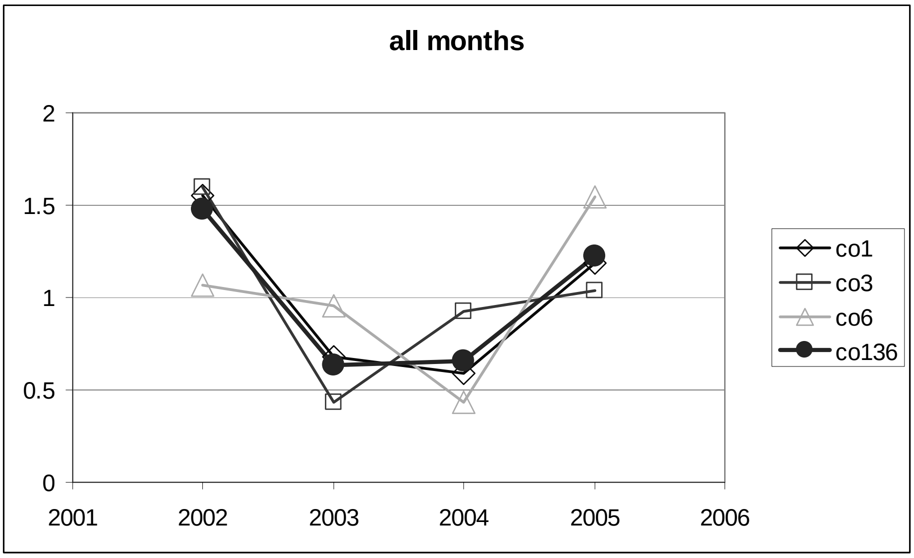

Figure 8. Time-trends of the standardised SAPUE index (surface abundance per unit effort) for companies 1, 3 and 6 from the interaction model (co1, co3, co6) and from the no-interaction model (co136). Seasonal sightings data from Dec, Jan, Feb and March only.

Various other interactions were considered (e.g. month:company) and effects of smaller time-units (e.g. week of the year instead of month), but these did not resolve the issue of a season:company interaction. Table A1 (Appendix 1) shows that swell is not significant in the model. Removing it does not, however, have a big effect on any of the quantities of

interest. The same is true for swell as a covariate in the no-interaction model (Table A2), and this term was left in the model.
Diagnostics show that residuals are reasonably well-behaved, but the qq-plots are 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 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 via the bootstrap.

Bootstrap trials

Bootstrap trials were conducted using "day" and "week" as resampling units and using the exponential distribution (with mean=1) to generate sets of weights with which to refit the original model. This technique, the "Bayesian bootstrap" (Rubin, 1981), avoids zero weightings which can lead to problems when the design becomes unbalanced with respect to factors in the model (e.g. missing company:month:season observations). The general aim of the bootstrap is to see whether there is model mis-specification that arises from substantial autocorrelation in the data that is not accounted for by the model (presumably due to omission of some important factor). This would be manifest as substantially higher variances than the nominal values directly from the GLM. A higher-than-nominal variance would also mean that model selection was prone to selecting too complex a model. If there is no indication of model mis-specification, the nominal variances are likely more precise than the bootstrap counterparts.

Results in Table 6 show that the bootstrap estimates are at least not larger than model estimates. It is a little surprising that the estimate from the bootstraps which use "week" as a resampling unit is so much smaller for the intercept. These results suggest that there is no obvious serious mis-specification, that the company/year interactions are important, and that standard errors from the model can be used to indicate the uncertainty in the indices for each company. Note, though, that the standard errors describe only the uncertainty about a particular company/year interaction 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.

It is interesting to consider the distributions of results (ie predicted levels of the index in each year) for the 3 companies combined. This is shown in Figure 9.

Figure 10 shows results for the three companies 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 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 (200 replicates)	
		day	week
Intercept	0.530	0.517	0.371
as.factor(season)2003	0.280	0.220	0.207
as.factor(season)2004	0.225	0.183	0.196
as.factor(season)2005	0.215	0.196	0.193

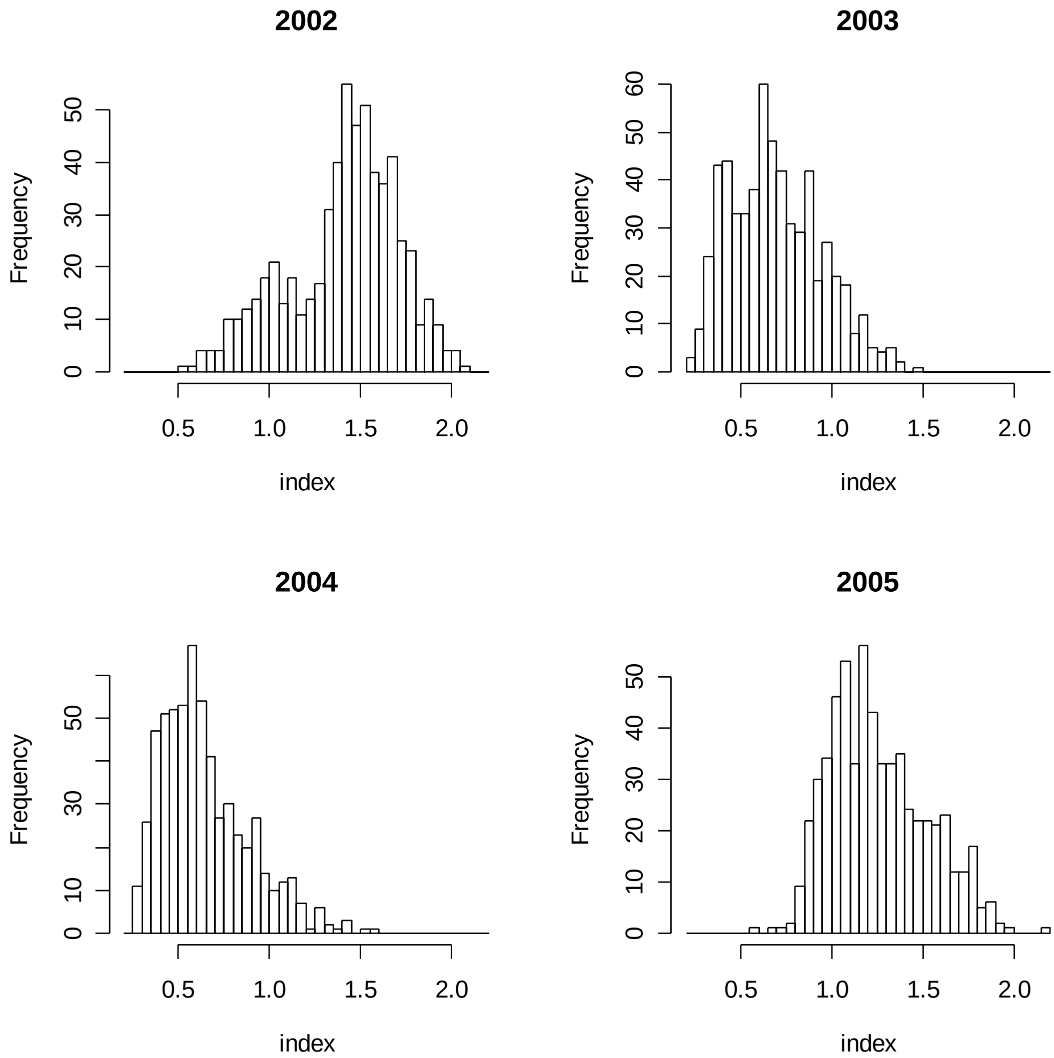

Figure 9. Bootstrap-based predicted results by season for the 3 companies combined after scaling to the mean of each company over the 4 seasons.

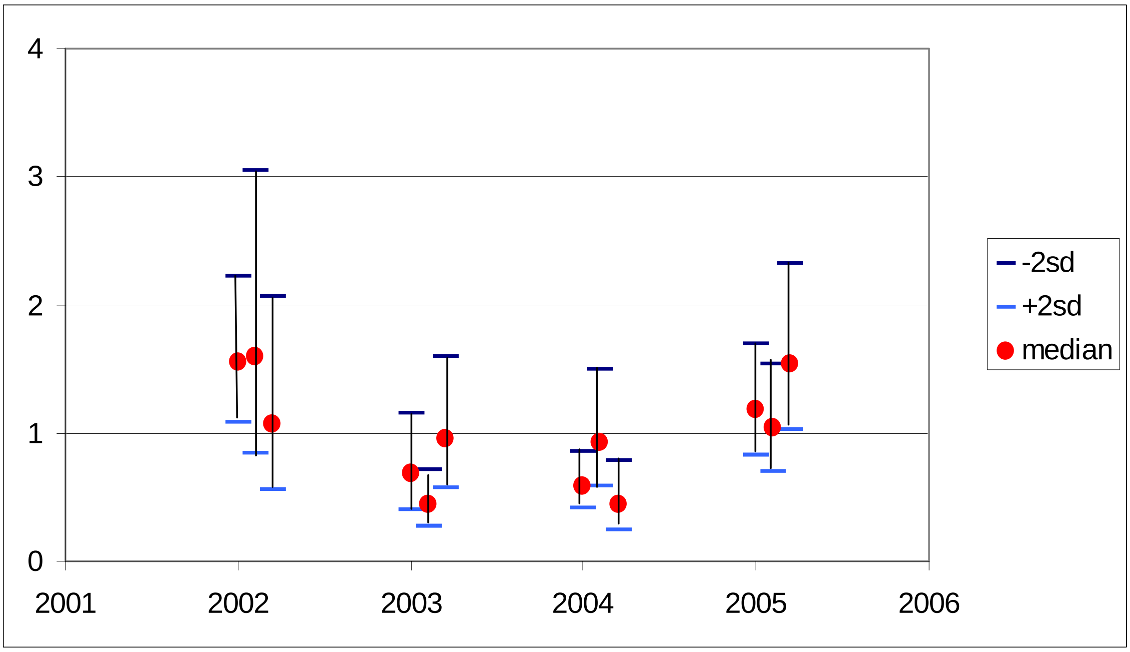

Figure 10. Estimates of SAPUE (surface abundance per unit effort) for companies 1,3, and 6 in each of the 4 past seasons. The median and exp(predicted value + or – 2 standard deviations) are shown.

Summary

The presence of the interaction, which the AIC shows should not be ignored, underlines the difficulty in interpreting the dataset and in deriving an annual abundance index from it. There are many possible reasons for seeing different time-trends for the different companies, either inherent in the raw data (e.g. because of operational factors and the nature of the commercial spotting activity), or in the analysis (eg some factors which have not and possibly cannot be taken into account, or the data being too aggregated in the first instance and correlations not properly being accounted for).

The estimated indices are all lowest in 2003 and 2004 (Figure 10). As was also evident in Figure 8, there are some indications that 2005 was higher than 2002 (e.g. company 6 in particular), but other indications that it was similar to, or below 2002.

It is worth recalling 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 does not suggest this).

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 fleets. However, the fishing and commercial operations occur in a relatively small area in the GAB. Also, a similar picture emerges (eg Fig. 8) when the analysis is done only on sightings made in the core area Although this does not indicate that location ('latitude-longitude') should not be a covariate in the model, it does suggest that the difference may be due to more complex processes that are not being captured.

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 as part of the Japanese/Australia SBT Recruitment monitoring Program.

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Appendix 1

Table A1. Summary of results of model with season:company interaction

```
Summary(co3.twee0b)  Call:  glm(formula = 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)), family = mvb.tweedie(1.5, 0), data = sapu05sub.3co)
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-10.690   -3.853   -1.324    1.267   13.797
Coefficients:
                                          Estimate Std. Error t value Pr(>|t|)
(Intercept)                                1.20321    0.52953   2.272 0.023749 *
as.factor(season)2003                     -0.72517    0.27999  -2.590 0.010045 *
as.factor(season)2004                     -0.81975    0.22540  -3.637 0.000322 ***
as.factor(season)2005                     -0.11983    0.21548  -0.556 0.578544
as.factor(company)3                        0.24942    0.32700   0.763 0.446188
as.factor(company)6                       -1.24342    0.34904  -3.562 0.000425 ***
as.factor(month)2                         -0.12829    0.14394  -0.891 0.373464
as.factor(month)3                         -0.78359    0.17197  -4.557 7.45e-06 ***
as.factor(month)12                        -0.16235    0.16536  -0.982 0.326956
wind                                      -0.13492    0.02538  -5.315 2.02e-07 ***
spotcon                                    0.21788    0.09471   2.301 0.022075 *
swell                                      0.05586    0.08664   0.645 0.519604
cloud                                     -0.05750    0.02222  -2.588 0.010114 *
temperature                                0.03301    0.01062   3.109 0.002051 **
moonillum                                 -0.35099    0.15638  -2.244 0.025502 *
as.factor(season)2003:as.factor(company)3 -0.47150    0.46039  -1.024 0.306556
as.factor(season)2004:as.factor(company)3  0.42786    0.43271   0.989 0.323525
as.factor(season)2005:as.factor(company)3 -0.15995    0.39086  -0.409 0.682649
as.factor(season)2003:as.factor(company)6  0.71932    0.47109   1.527 0.127783
as.factor(season)2004:as.factor(company)6  0.07294    0.47792   0.153 0.878789
as.factor(season)2005:as.factor(company)6  0.64040    0.41826   1.531 0.126751
Signif. codes:  0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1
(Dispersion parameter for Tweedie family taken to be 20.141)
    Null deviance: 12986.2  on 334  degrees of freedom
Residual deviance:  5770.6  on 314  degrees of freedom
AIC: 4347.0       Number of Fisher Scoring iterations: 6
```

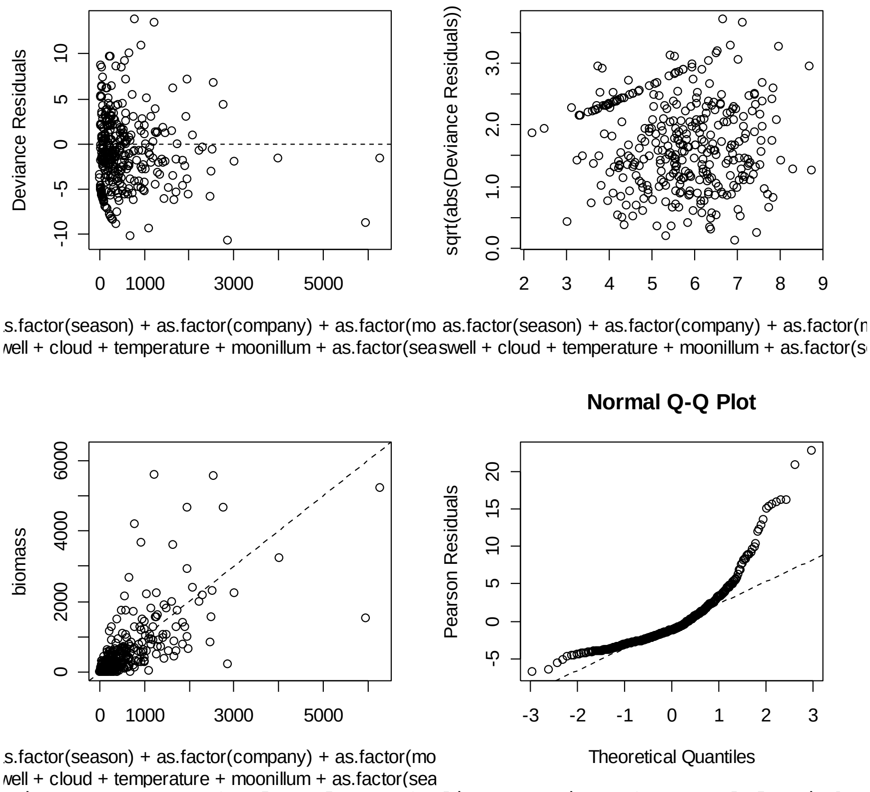

Figure A1. Default plot of diagnostics for model without interaction (x-label is the call as in the table above)

Table A2. Summary of results of model with season:company interaction

```
summary(co3.twee1b)  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 = apu05sub.3co)
Deviance Residuals:
    Min       1Q    Median       3Q       Max
-10.945   -3.843   -1.258    1.317   17.427
Coefficients:
                      Estimate Std. Error t value Pr(>|t|)
(Intercept)            1.25160    0.53862   2.324 0.020766 *
as.factor(season)2003 -0.74315    0.19379  -3.835 0.000151 ***
as.factor(season)2004 -0.65917    0.17915  -3.679 0.000274 ***
as.factor(season)2005 -0.04093    0.17397  -0.235 0.814147
as.factor(company)3    0.14837    0.16495   0.899 0.369068
as.factor(company)6   -0.77358    0.15329  -5.046 7.56e-07 ***
as.factor(month)2     -0.17408    0.14772  -1.178 0.239496
as.factor(month)3     -0.82037    0.17761  -4.619 5.60e-06 ***
as.factor(month)12    -0.15032    0.16780  -0.896 0.370994
wind                  -0.13343    0.02570  -5.192 3.71e-07 ***
spotcon                0.19457    0.09337   2.084 0.037955 *
swell                  0.03259    0.08845   0.368 0.712805
cloud                 -0.06062    0.02289  -2.649 0.008481 **
temperature            0.03414    0.01098   3.110 0.002036 **
moonillum             -0.35761    0.15963  -2.240 0.025755 *
Signif. codes:  0 `***' 0.001 `**' 0.01 `*' 0.05 `.' 0.1 ` ' 1
(Dispersion parameter for Tweedie family taken to be 22.01888)
    Null deviance: 12986.2  on 334  degrees of freedom
Residual deviance:  6092.5  on 320  degrees of freedom
AIC: 4357.2   Number of Fisher Scoring iterations: 6
```

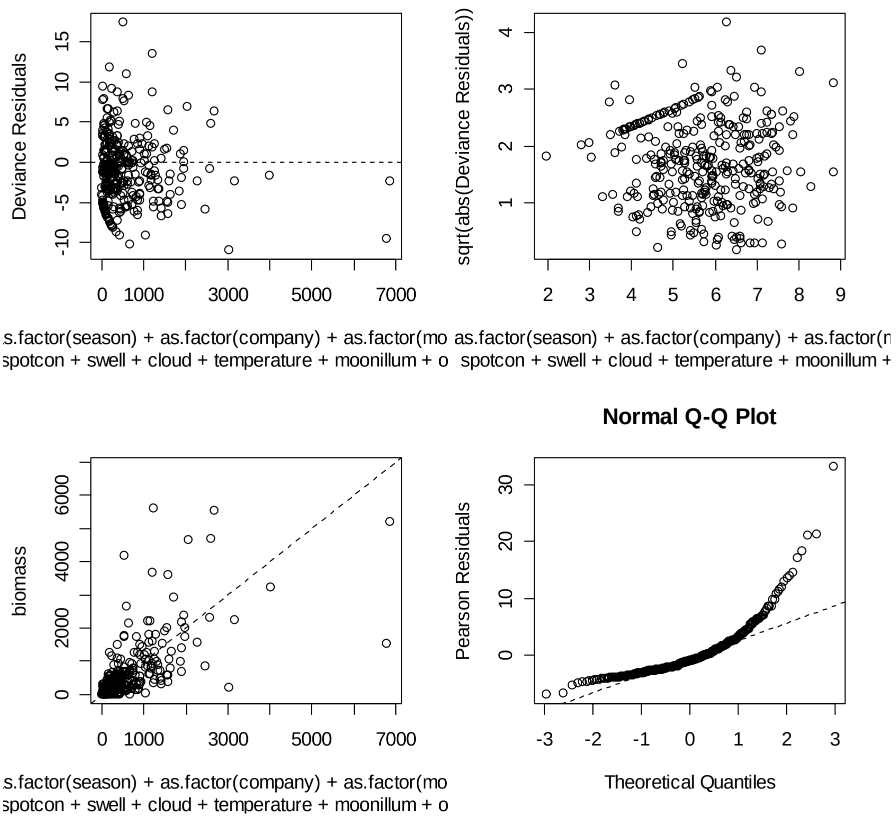

Figure A2. Default plot of diagnostics for model without interaction (x-label is the call as in the table above)