CCSBT-ESC/0909/13

Commercial spotting in the Australian surface fishery, updated to include the 2008/9 fishing season

Marinelle Basson
Jessica Farely

Prepared for the CCSBT 14th Meeting of the Extended Scientific Committee 5-11 September 2009, Busan, Korea

Table of Contents

Abstract

Data on the sightings of SBT schools in the GAB were collected by experienced tuna spotters during commercial spotting operations between December 2008 and April 2009. Spotting data has now been collected over eight fishing seasons (2001-02 to 2008-09). 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). As seen in previous seasons, the estimated index is lowest in 2003 and 2004, and the estimate for 2009 is about average.

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 6 fishing seasons (2003-2008). 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 scientific survey with consistent design and protocols from year to year is highly preferable. In 2009, 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 8 seasons (2002-2009).

Field procedures

Data were collected on SBT patches (schools) sighted by spotters engaged between December 2008 and April 2009 (called the 2009 fishing season). This year, data were collected by four spotters, three of which had participated in previous seasons. The forth spotter has been trained by one of the experienced spotters for several years, and he flew independently from early-March to mid-April 2009. Of these four spotters, two contributed just over 80% of the total search effort recorded.

A fifth spotter also operated in 2009, but did not collect data because he was working for a new company (i.e. one that had not caught its own fish for many years) and was not able to collect data consistent with his last year of spotting in 2007. Although it is unknown if this spotter will operate in 2010, he has indicated his willingness to collect data in the future.

The spotting data collected in 2009 were collected following the protocols used in the previous seven fishing seasons (see Basson and Farley, 2008). 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 patches of SBT. During some flights, the pilot also searched for patches. 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 patches (or patches). The spotter estimated a range for the size of fish in the patches (in kg) and the biomass of each patch (in tonnes). It is important to note that many SBT patches are recorded as single patches (~35-60% by 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 (intensive 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 114 commercial spotting flights in the 2009 fishing season. Due to GPS problems, flight path data for 14 of these flights were not available and thus the proportion of search time and biomass sighted in the 'core' fishing are currently unknown - although the total search effort and biomass for the flights are known and are included in the standardisation analysis (below).

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 88 of the 114 commercial flights in 2009 (77.2%). Note, however, that the total biomass shown in Table 2 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).

In past fishing seasons, the location of SBT sightings varied little (Figure 1) with the area of highest SBT sighted per nautical mile searched occurring within the same 'core fishing area' (130.2-132.9°E and 32.7-34.0°S) and around the inshore lumps/reefs each season. In 2009, however, a significant amount of search effort occurred to the southeast of the core fishing area. This shift in effort occurred around mid-March as SBT as SBT became more difficult to find in the core area.

Figure 2 and Figure 3 show the size of SBT schools and fish recorded by spotter 1 between 2002 and 2009. 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. On average, it appears that the mean size of schools increased between 2004 and 2008, but decreased in 2009. The mean size of fish decreased between 2004 and 2006, then remained stable before increasing slightly in 2009.

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

Season	Spotter 1	Spotter 2	Spotter 3	Spotter 4	Spotter 5	Spotter 6	Spotter 7
2002	61.3	7.6	11.7	-	5.6	13.9	
2003	20.2	11.5	33.2	1.2	4.4	29.5	
2004	42.2	15.2	19.4	-	-	23.2	
2005	39.7	9.3	19.5	-	5.0	26.5	
2006	44.2	11.6	-	-	14.8	29.5	
2007	38.0	11.1	-	-	22.1	28.8	
2008	37.3	23.7	-	-	-	39.0	
2009	39.0	9.0	-	-	-	41.4	10.7

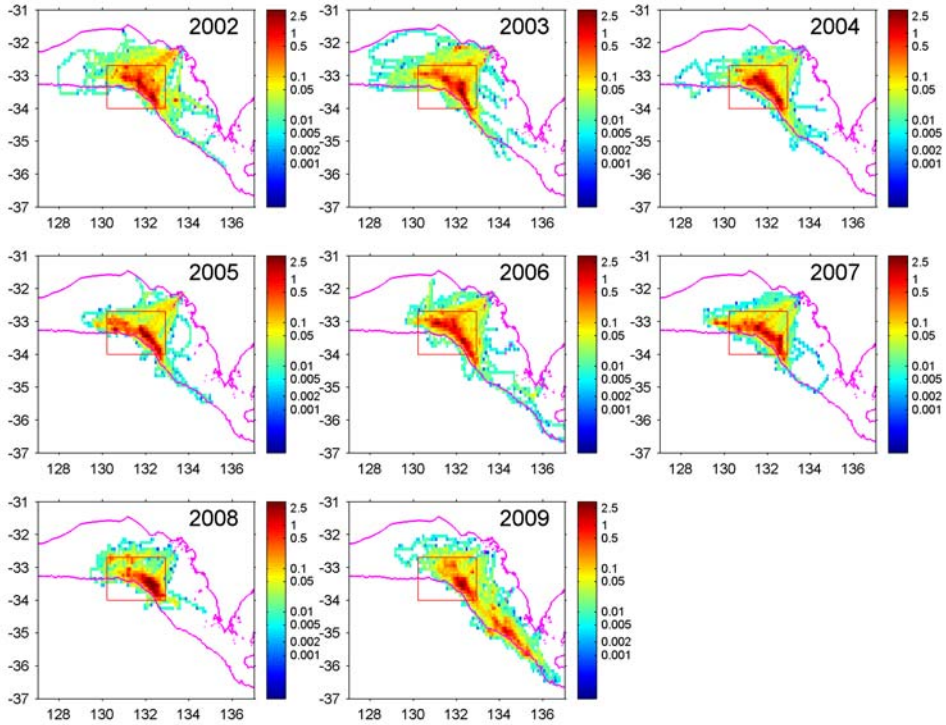
Table 2. Search effort and SBT sighted by commercial spotters in the 2002-2009 fishing seasons.

Fishing season	No. flights	Search effort (hrs)	% flights with SBT recorded	Total number of schools	Total biomass[1] recorded	% of effort in the core	% of biomass in the core[2]
2002	86	325	83.7	1182	44626	80.6	87.7
2003	102	425	82.4	1301	38559	78.9	76.5
2004	118	521	77.1	1133	33982	88.9	90.4
2005	116	551	94.0	2395	87447	88.5	83.2
2006	102	452	82.4	1554	50524	83.1	73.4
2007	120	600	91.7	2600	94018	86.5	80.0
2008	93	451	80.6	2529	100341	94.2	92.6
2009	114	527	77.2	1353	41514	54.2	67.7

[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] Does not include data for flights where flight path data was not obtained. i.e. 20 flights in 2005 (CCSBT-ESC/0509/23), 8 flights in 2008 (CCSBT-ESC/0809/25) and the 14 flights in 2009 (see above).

Figure 1. Search effort (a) and SAPUE (b) 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.

(a) Search effort (nm flown/0.1º square)



(b) SAPUE (tonnes/nm/0.1º square)

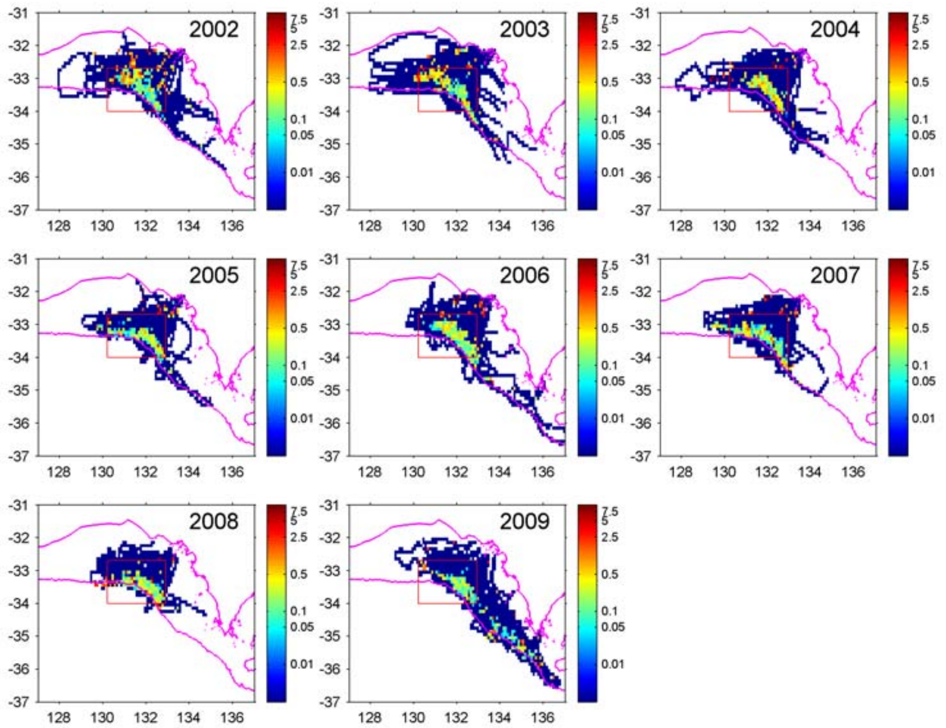


Figure 2. Proportion of SBT schools by size class (bars) and mean school size (line) recorded by one commercial spotter in the 2002-2009 fishing seasons. Total number of school size estimates = 6,075.

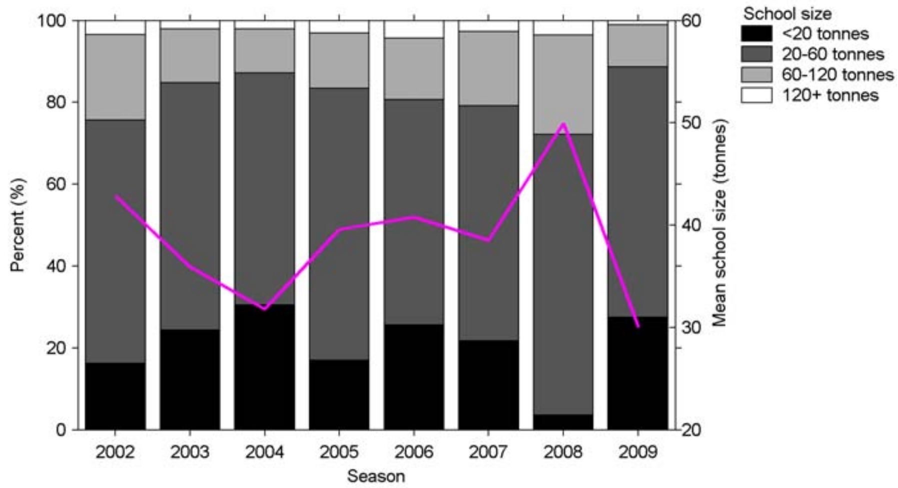
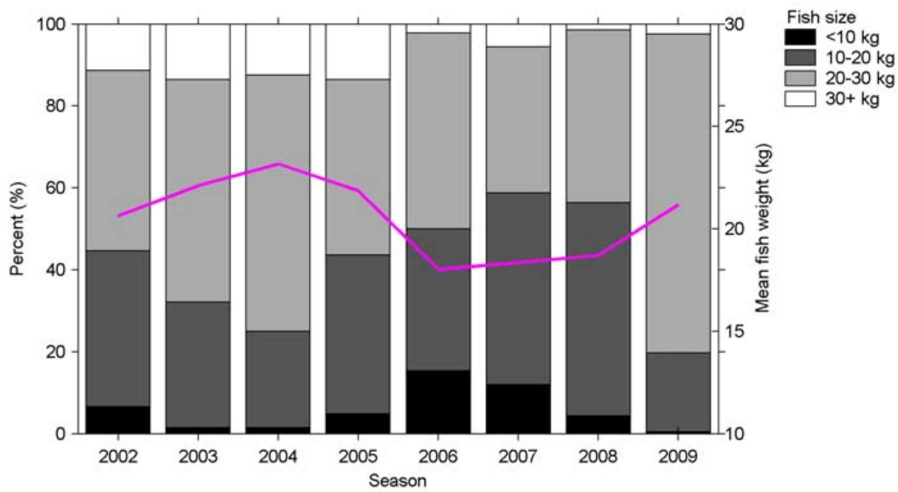


Figure 3. Proportion of SBT by fish size class (bars) and mean fish size (line) recorded by one commercial spotter in the 2002-2009 fishing seasons. Data are weighted by school size. Fish size data collected for 5,993 schools.



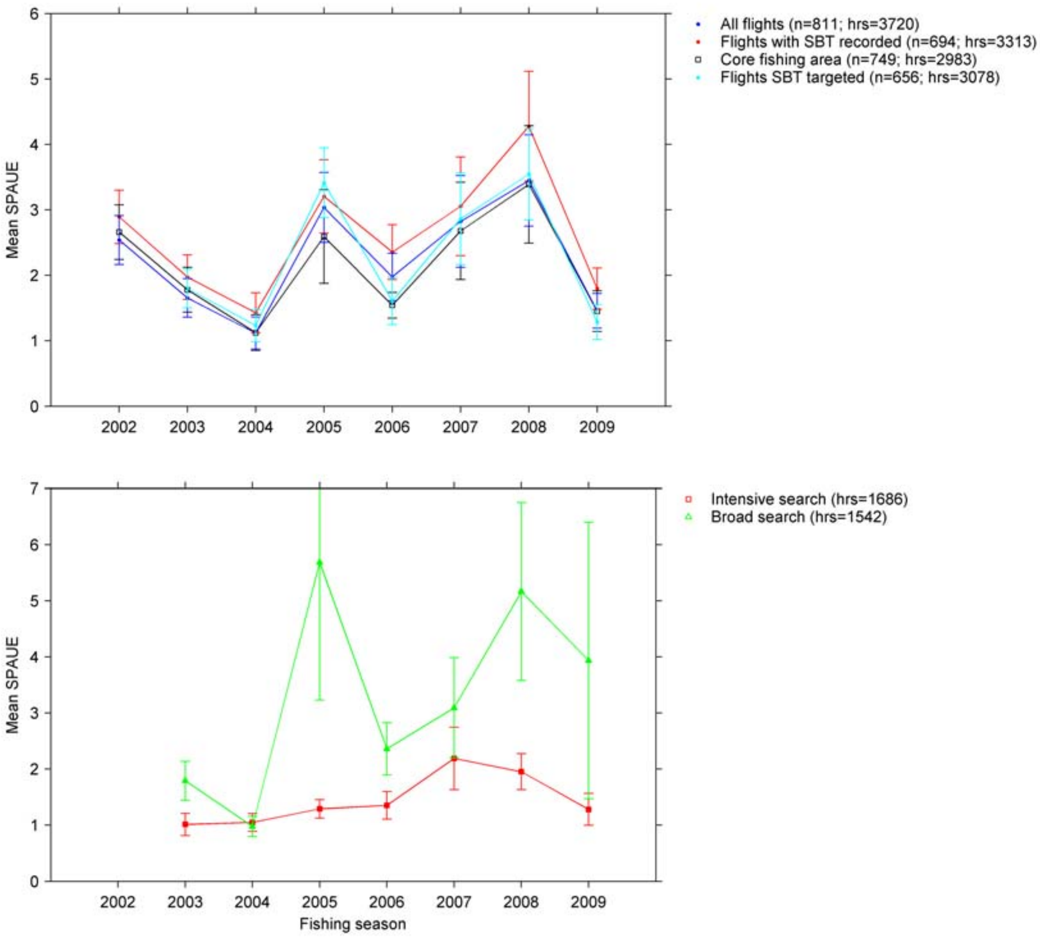
Nominal SAPUE

As for previous years, the duration of "search" sectors during flights were calculated using the GPS logged position and time. The logbook data on SBT sightings were summarised to give the total number of sightings, schools, and total biomass per plane per day. The data were extracted to ensure consistency between seasons. Flights were excluded if they were outside the main fishing seasons (December to March) and were less than 30 minutes duration 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 (tonnes) per unit of search effort (minutes). The SAPUE indices were calculated by geographic area (whole GAB and core fishing area), by search type (broad and intensive), and for flights where SBT was/was not targeted.

Four nominal SAPUE indices of juvenile abundance are shown in Figure 4a. All four indices fluctuate similarly between 2002 and 2009. The 2009 indices are the lowest since 2004. Not surprisingly, mean SAPUE was higher for flights that SBT were recoded, but as there were relatively few flights where SBT were not recorded (only 14.5% overall), it makes little difference to the overall SAPUE index obtained by season. The slightly lower mean SAPUE for the core fishing area in many seasons is also not surprising given that search effort is very high in this area. Figure 4b shows the comparison of mean SAPUE by search type. Since the type of search effort (broad/intensive) was not recorded in 2002, these indices can only be calculated for seven seasons. In 2009, the point estimate for the nominal SAPUE estimate (broad and intensive search) is lower than in 2008.

Figure 4. Nominal SAPUE indices (+/-se) (tonnes of SBT sighted per minute searching) for the 2002-2009 fishing seasons (a) for all flights, flights in the core area, or flights that SBT were recorded, and (b) by search effort type. Classifying search effort as either broad or intensive started in 2003 (i.e. the 2002/03 fishing season). Note that only flights in December to March were included, and when search effort was >30 minutes.



Standardised SAPUE

Commercial spotting data are available for eight seasons. These data can potentially be standardised to obtain an index of juvenile abundance (ages 2-4 primarily) in the GAB between December and March. Although there were six spotters in the second season, fewer spotters have been operating in recent years, and in 2009 only 3 spotters' data can be used in standardisation analyses (Table 3). In the past, we have explored the sensitivity of results to the inclusion/exclusion of data from different spotters and results showed that the index is not sensitive to this (see CCSBT-ESC/0809/25). The number of spotters required by industry has decreased, as there has been a tendency over time for fewer fishing companies to catch tuna for the other companies in the fishery. As in the past, we note that the commercial spotting data can 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 scientific 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).

Given the changes in spotting effort (Table 3), only data from spotters 1, 2, and 6 were in the updated modelling presented below. Data from four months (Dec, Jan, Feb and March) were included in the analyses, though sensitivity analyses were conducted on data from only January and February (see below).

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 5. Note that the scientific aerial survey transects are only flown during certain conditions, so that summaries of environmental conditions recorded during the scientific aerial survey and during commercial spotting operations would tend to differ. The data show that during the 2009 commercial spotting flights, the average wind speed was higher than previous seasons, while the other variables were not particularly unusual compared to previous seasons.

We have noted previously (e.g. CCSBT/ESC/0609/17) that although the mean air temperature can be quite similar between seasons, the monthly temperatures can be very different. Figure 6 shows the monthly mean air temperatures from the data over the past 8 seasons. In 2009, the average December and March temperatures were much lower than the January/February temperatures. The December average was second lowest recorded (the lowest was in December 2002) while the March average was the lowest March temperature.

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 again included in the standardisation analysis.

Table 3. Number of days flown by spotter, year and month (Dec-Mar) within a 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	spotter4	spotter5	spotter6	spotter7
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	2	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	
2007	Dec	5					11	
2008	Jan	11	11				9	
2008	Feb	11	6				12	
2008	Mar	8	5				4	
2008	Dec						9	
2009	Jan	11	4				13	
2009	Feb	9	7				11	
2009	Mar	15					9	7

Table 4. Average environmental conditions during search effort on commercial flights by season (all companies, Dec-Mar). 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	7.06	1.46	18.06	4.48	2.64	
2003	6.90	1.18	23.35	3.62	2.81	5.58
2004	7.92	1.65	19.75	3.95	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	6.98	1.87	21.10	3.60	2.78	7.92
2008	7.94	1.48	22.88	2.90	2.91	10.80
2009	8.47	1.53	20.33	3.42	2.72	5.81

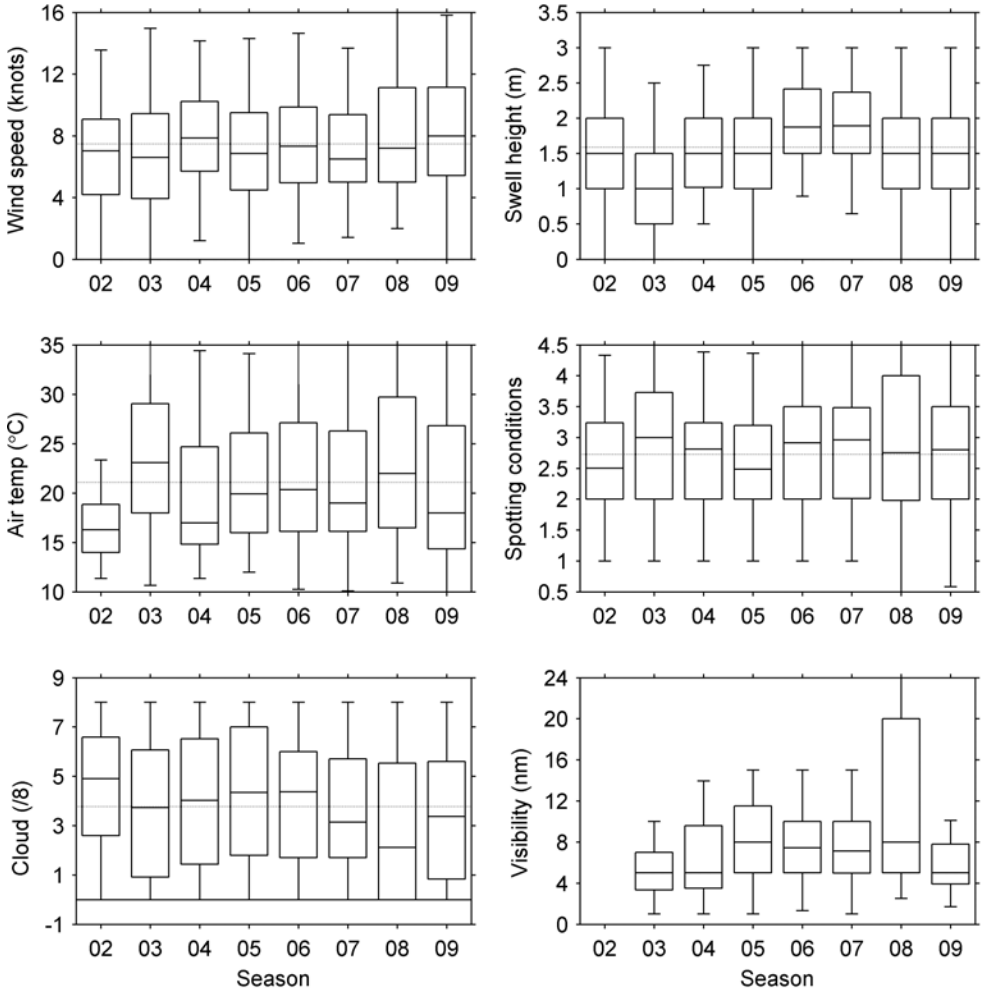


Figure 5. Boxplots summarizing the environmental conditions present during search effort on commercial flights by season (all companies, Dec-Mar). The horizontal band through a box indicates the median, the length of a box represents the inter-quartile range, and the vertical lines extend to the minimum 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.

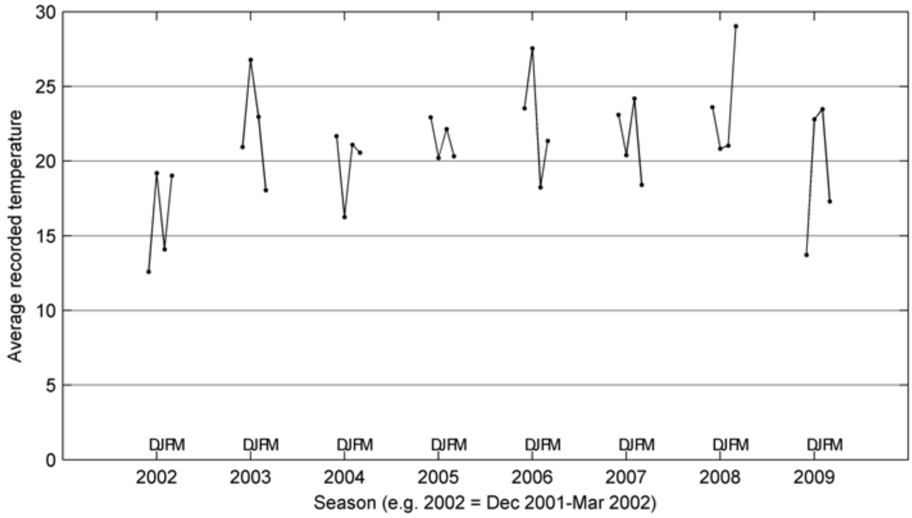


Figure 6. Average monthly air temperatures (all companies, Dec to Mar) from the spotting data for the past 8 seasons. DJFM = Dec, Jan, Feb, Mar.

The sightings data

The data are compiled as the biomass sighted and effort in hours flown on each day by each spotter. We have previously commented on alternative ways of compiling the data at finer spatial and temporal scales for analyses (CCSBT-ESC/0509/23). However, given the complexity of such a task and the availability of data from the aerial survey, we have followed the approach used in the past. 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 were below average in 2005 and 2007, and second highest in 2009.

Table 5. Number of days flown with no biomass sighted and days with some biomass sighted (all companies, Dec to Mar). 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
2008	18	75	93	19.4	16.3
2009	18	77	95	18.9	16.1

Modelling approach

We used the same modelling approach as in the past and updated those analyses with data from the 2009 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. As mentioned previously, only data for spotters 1, 2 and 6 were included in the analyses presented here. 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; 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. A value of $\Phi=1.5$ was found to be acceptable in the past, and was again used as the default in this working paper. Sensitivity trials with values of 1.2 and 1.7 supported the appropriateness of a value of 1.5.

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.

The first model that was fitted (model 1) is the same as that fitted in 2008:

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

Several sensitivity trials were also conducted:

1. Excluding non-SBT targeted effort
2. Excluding December and March data for all years
3. Including a month:season interaction
4. Including a spotter:season interaction
5. Using combined wind and direction covariates
6. Excluding swell and moon illumination covariates

Each sensitivity trial consists of a modification to model 1, either through a change in dataset (some runs of trials 1 and 2) and/or a change in covariates (some runs of trial 1, all runs under trials 3, 4, 5, and 6). Combinations of the above trials were not conducted. The rationale for the sensitivity trials are briefly outlined below.

<u>Target species</u>

In 2009, some commercial flights were conducted with the aim to spot mackerel ('Mack') and/or skipjack ('SKJ') rather than SBT. The information on target species has been recorded since the 2003 season, but has not been used previously, because SBT has usually been at least one of the (if not the only) target species. Given the observations of non-SBT targeted flights in 2009 (see Table 5), a sensitivity trial excluding these data was conducted.

The categories recorded in the data are: SBT, SBT/SKJ, SBT/Mack, SBT/SKJ/Mack, SKJ, Mack, SKJ/Mack. First, data with target recorded as 'SKJ', 'Mack' or 'SKJ/Mack' were excluded and model 1 was refitted. Second, model 1 with 'target' as an additional covariate was fitted, and third, model 1 with 'target' as an additional covariate was fitted to all the data (including target categories 'SKJ', 'Mack' or 'SKJ/Mack').

Months

In 2009, information from Industry indicated that the majority of SBT seemed to have left the GAB in around mid-March. As a result, spotting activities shifted to an area west and southwest of Port Lincoln (see Figure 1). If this departure was substantially earlier (or more complete by mid-March) than in past years, it could affect the standardised index. A sensitivity trial only based on data for January and February was therefore conducted.

Month:Season interaction

Differences in arrival and departure times of juvenile SBT may well differ between years and another way of potentially taking care of the concern raised above is to fit a model with an interaction between month and season (i.e. the coefficients for each month can vary from season to season).

Spotter:season interaction

Initially, when the time-series was relatively short and when all spotters were included in analyses, there appeared to be a strong interaction between spotter and season. This was difficult to include when the dataset became unbalanced due to incomplete coverage (i.e. not all spotters operating in all months and all seasons). Since we now only have data for spotters 1, 2, and 6 in recent years, and since these 3 spotters have operated in all seasons and most months, it was possible to again check for an interaction between these two covariates.

Combined wind & direction covariates

Experience in the field suggests that SBT are less likely to be at the surface, and less visible if they are at the surface, when the wind is from the south-east. Wind direction has been recorded and was summarised as the proportion of time ("day", i.e. during a flight on that day) that the wind was: Northerly (N), South easterly (SE), other (Oth) or calm. Given the significance of wind as a covariate, it seemed sensible to combine the strength of the wind and direction into new covariates. This was done by assigning a single direction for each day, depending on the maximum proportion. Three new variables, windN, windSE and windOth were constructed, setting the value equal to windspeed or equal to 0 depending on the single direction. The four example records below illustrate this:

wind	N	Oth	SE	Calm	(main direction)	windN	windSE	windOth
4.65	0.00	0.00	1.00	0	SE	0.00	4.65	0.00
6.83	0.00	0.26	0.74	0	SE	0.00	6.83	0.00
4.71	0.51	0.00	0.49	0	N	4.71	0.00	0.00
9.85	1.00	0.00	0.00	0	N	9.85	0.00	0.00

This does mean that if the wind was N for 51% of the time and SE for 49% of the time, the new variable implies it was N for the whole period. This could be dealt with by trying to split the day's data into a finer time-scale, but noting that most proportions are close to 0 or 1, we consider the approach taken here to be reasonable (Figure 7).

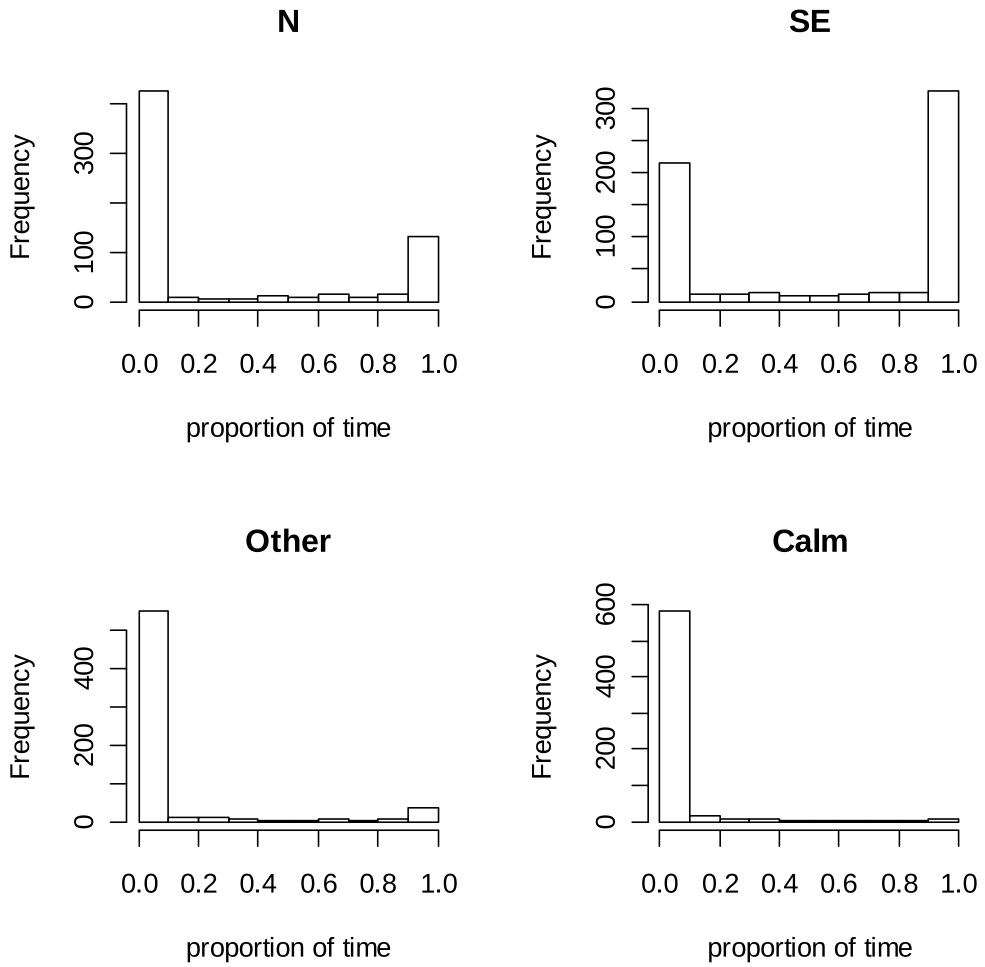


Figure 7. Histograms of the proportion of time (i.e. during a flight on a day) the wind direction was north (N), south-east (SE), other or calm, for the whole dataset (seasons 2002-2009). When Calm=1, the wind speed was always recorded as 0.

Swell and moon illumination

As will be seen in the results, swell and moon illumination were not significant in the basic model. Initially (i.e. when the time-series was relatively short), 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. Since last year's analyses, swell and moon illumination have however not been significant. Removing these two covariates provides a more parsimonious model.

Results

Diagnostics for Model 1 (Figure 8) shown that residuals are reasonably well-behaved, though the qq-plots are (as in the past) rather poor, and not linear as expected. 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.

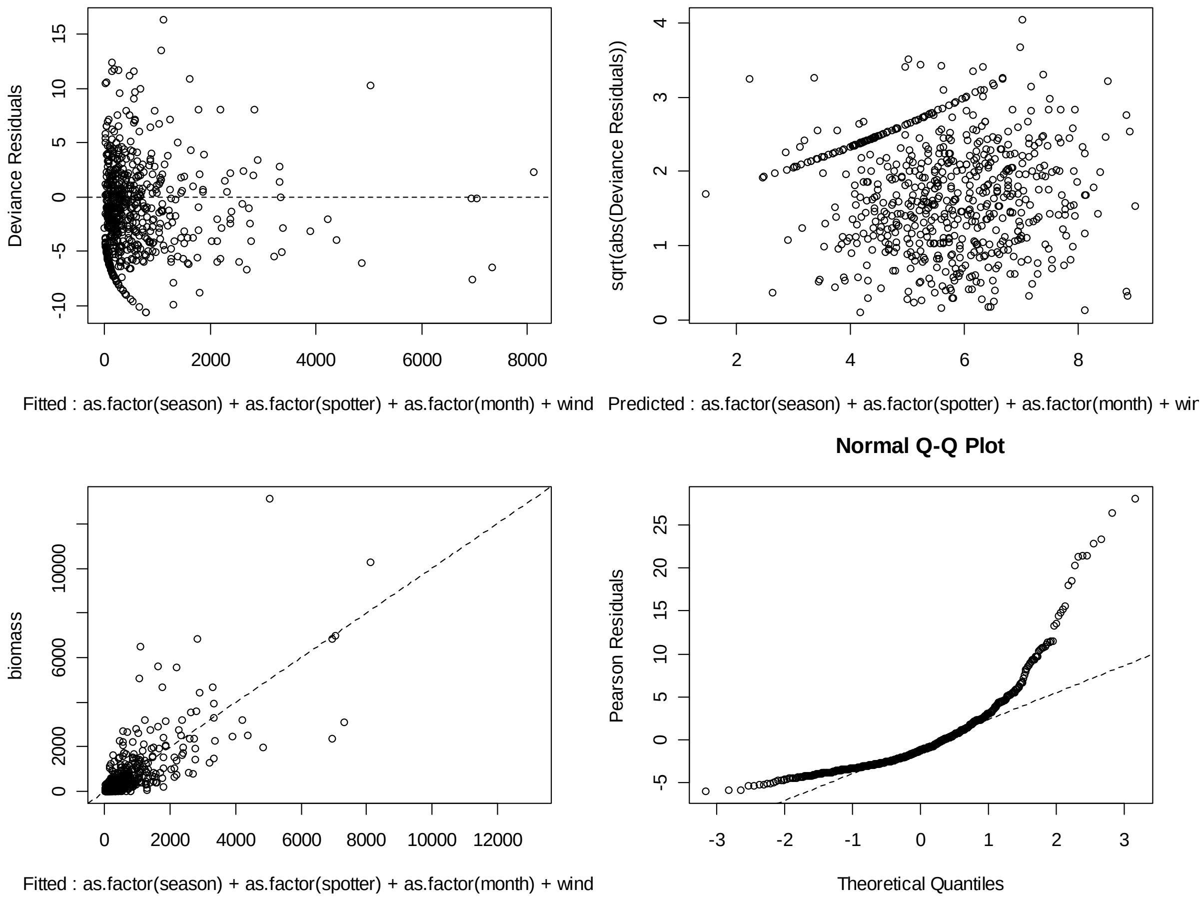


Figure 8. Diagnostics for Model 1 (see text) with spotters 1, 2, 6.

Estimated coefficients are given in Appendix A. Swell and moon illumination are not significant and dropping these two covariates is considered again below, but they are retained in the other sensitivity trials. The estimated annual index is shown in Figure 9.

1. Excluding non-SBT targeted effort

Diagnostics for a model which excludes non-SBT targeted effort are very similar to those for model 1, estimated coefficients are very similar and the resulting index is almost identical (Figure 9, symbols ‘o’ and ‘+’). Note that, since targeting information was not recorded in 2002, data for this season are excluded when fitting this model. Comparison between this model and model 1 have therefore been done by scaling the series to the mean over the period 2003 to 2009.

If “target” (which can be SBT, SBT/SKJ, SBT/Mack, or SBT/SKJ/Mack) is included as a covariate, and using the subset of data which excludes non-SBT targeted effort, only ‘SBT/Mack’ comes out as significant, but it does make a small difference to the standardised index (Figure 9, symbol ‘x’).

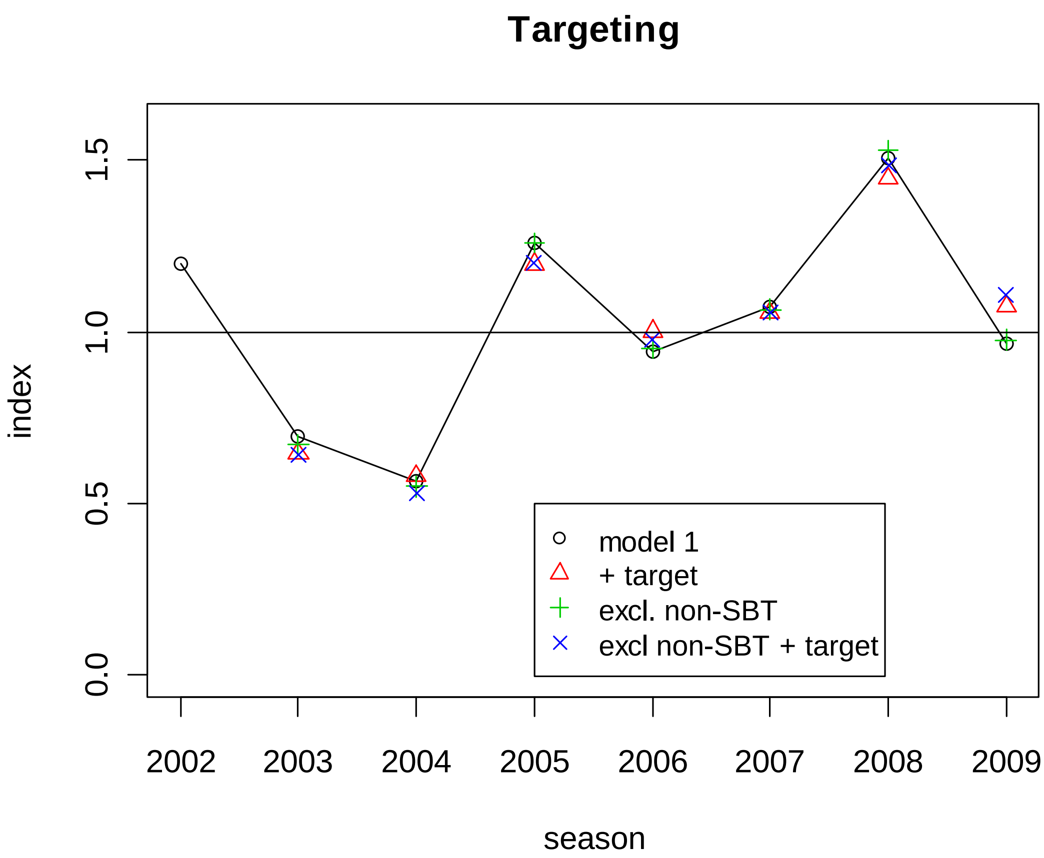


Figure 9. Standardised index for (a) model 1, (b) model 1 with targeting as a covariate on the full dataset, (c) model 1 with data excluding non-SBT targeting and (d) as in (c) but with target added as a covariate. The indices are standardised over the period 2003-2009.

Since SBT is also sometimes observed on flights targeted at skipjack or mackerel, it is possible to include all the data (i.e. including target recorded as 'SKJ', 'Mack' or 'SKJ/Mack'). In this case, none of the factor levels are significant, and there are only very minor differences between the index derived from this model, and that which excludes non-SBT targeted effort (Figure 9, symbols 'x' and triangle).

It is important to interpret the target information with some care. The main difference between flights targeted at non-SBT species versus those targeted at SBT, appears to be the locations or areas searched and, presumably, what the spotters are looking for. The raw data on sighting rate (SBT biomass / Search effort) by target category, relative to the target category 'SBT' shows very little pattern (Table 6). It is arguably not surprising that 'target' as a covariate is not highly significant.

Table 6. Unstandardised average sighting rate of SBT (total SBT biomass/total search effort) by target species relative to the unstandardised average sighting rate for target 'SBT', for seasons 2003-2009. The number of flights in each category is given in brackets.

Season	2003	2004	2005	2006	2007	2008	2009
SBT	1.00 (34)	1.00 (75)	1.00 (68)	1.00 (57)	1.00 (76)	1.00 (82)	1.00 (43)
SBT/SKJ	1.43 (19)	0.44 (2)	1.95 (7)	1.15 (4)	0.42 (2)	0.24 (1)	1.36 (11)
SBT/Mack				0.40 (8)	0.54 (6)	0.07 (1)	0.29 (16)
SBT/SKJ/Mack				0.10 (3)	0.13 (1)	0.05 (4)	2.71 (10)
SKJ	0.43 (1)	1.0 (11)	0.30 (7)	1.25 (5)	0.63 (3)	0 (5)	0.14 (3)
Mack				0.70 (3)	0 (1)		0.21 (5)
SKJ/Mack				0.35 (1)			

2. Excluding December and March data for all years

Most of the estimated coefficients are very similar between the two models. As expected, there are some differences between the season-effects. The biggest difference between the indices for this model and model 1 is in 2008 (Left panel, Figure 10 below), but the overall patterns over time are very similar. Since different datasets are used in the two models, goodness of fit comparisons (e.g. via AIC) are invalid.

3. Including a month:season interaction

When an interaction between month and season is included in model 1 (and the dataset includes all months), none of the interaction terms are highly significant; only two terms (out of 21) are significant at the 10% level (Appendix A). There is nothing noticeably different in the diagnostics. There is a modest reduction in the AIC: from 8026 for model 1 to 8023 for the model with month:season interaction. When there are interaction terms involving a time component, it is not straightforward to directly compare results with the 'no interaction' model. Instead of using a single month at which to predict the index, a value was predicted for each month. These predictions were summed by season and then scaled to 1(Right panel, Figure 10). Note that for model 1 (no interaction) this procedure leads to the same result as predicting the index at any single month.

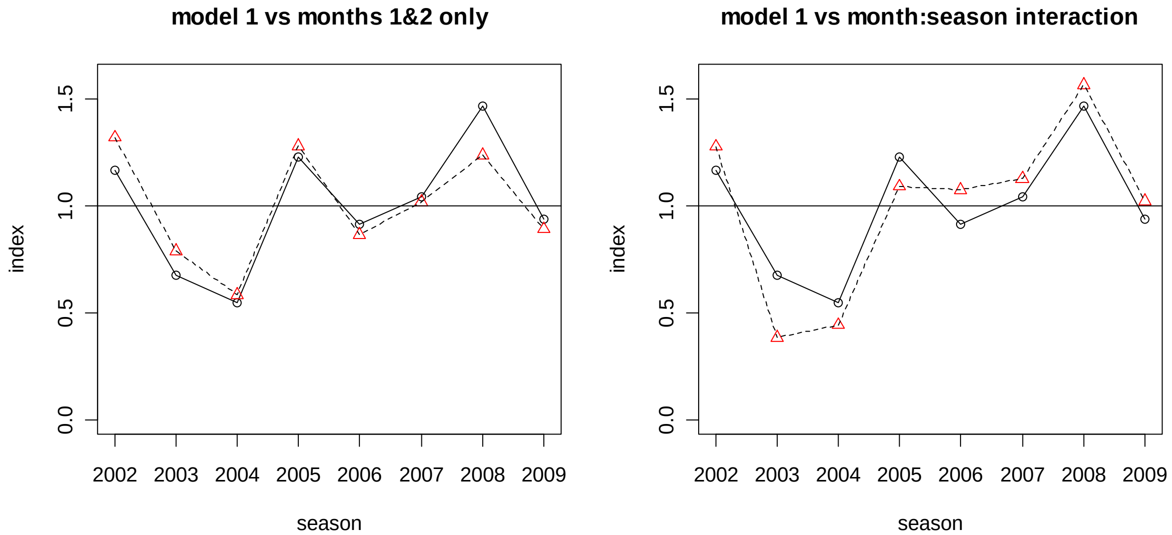


Figure 10. Left panel: comparison of the standardised scaled index for model 1 (open circles, solid line) and the same model, but using only data for months 1 and 2 (red triangles, dashed line). Right panel: comparison of the standardised scaled index for model 1 (open circles, solid line) and a model with interaction between month and season (derived by summing predicted values over all months, then scaling to the mean) (red triangles, dashed line).

4. Including a spotter:season interaction

When an interaction term between spotter and season is included, only a few interaction terms are significant: 2 at 10%, 1 at 5% out of a total of 14 terms (Appendix A). There is again nothing noticeably different in the diagnostics. There is a modest reduction in the AIC: from 8026 for model 1 to 8024 for the model with month:season interaction. The indices are almost identical; the biggest percentage difference is 2% for the 2002 season.

5. Using combined wind and direction covariates

Recall that for any record only one of the three covariates (windN, windSE and windOth) will be non-zero; the magnitude of the non-zero value will reflect the wind strength. The effect of including the three covariates is therefore similar to just including wind strength as a single covariate, but it allows for a different effect (or strength of effect) for wind in different directions. Given that 'wind' is significant in model 1, it is unsurprising that coefficients for all three covariates are significant in this model. Estimates for windN, windSE and windOth are also very similar to one another and to 'wind' in model 1:

```
                     Estimate  Std.Error  t.value Pr(>|t|)
windN                 -0.100   0.0203     -4.934    1.04e-06 ***
windSE                -0.104   0.0186     -5.569    3.84e-08 ***
windOth               -0.089   0.0246     -3.628    0.000310 ***
Model 1:
wind                  -0.116   0.0185     -6.299    5.69e-10 ***
```

There is an increase in AIC for the model with wind direction (8037, compared to 8026 for model 1); this and the similarity among coefficients suggest that 'wind' as a single covariate is preferable. The indices are also almost identical; the biggest percentage difference is 1.4% for the 2006 season.

6. Removing swell and moon illumination covariates

Swell and moon illumination are not significant in the fit of model 1 (Appendix A). When these covariates are left out, there is a slight decrease in the AIC, from 8026 (model 1) to 8022. Diagnostic plots are very similar (compare Fig 8 and Figure C1 in Appendix A) and estimates of coefficients for covariates in common to both models are also similar, as would be expected (Appendix A). The indices are essentially identical; the biggest difference is 1% for the 2003 season.

In the past we explored the effect of using a different assumption about the mean-variance relationship through different values of the Tweedie parameter, Φ. Those results suggested a value of 1.5 is appropriate. Here we checked whether this is still the case, using the more parsimonious model which excludes swell and moon illumination. Figure 11 shows the deviance residuals (square root of the absolute values) plotted against the fitted values for Φ=1.5. The smoother through the data shows that this value is still appropriate, since the smoother is relatively 'flat' (slope close to 0) for this assumption. A slightly lower value, Φ=1.4, was also tried with the model based on data from spotters 1 and 6 only. Although this leads to a slightly flatter relationship, the estimated index is essentially unaffected.

Comparisons between estimated standard errors from the GLM model and estimates from bootstrap analysis, as described in Basson and Farley (2005; CCSBT-ESC/0509/23), were made in the past. These comparisons showed that the model estimates of standard deviations were no smaller than the bootstrap estimates (from 500 replicates). We have not redone this analysis here under the continued assumption that the standard errors from the model can be used to indicate the uncertainty in the index. This assumption should be rechecked in future. As in the past, we note 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.

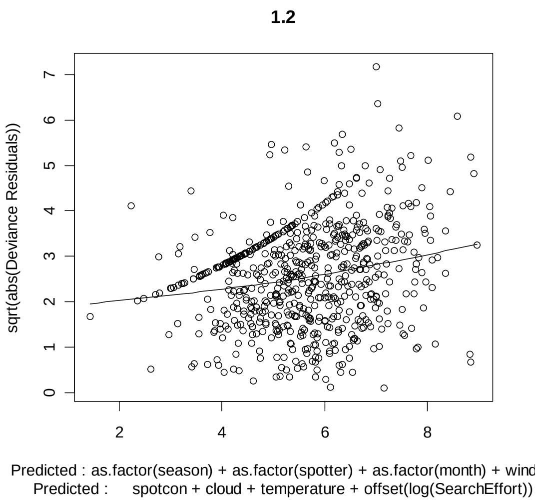
Figure 12 shows results of the standardised index for the parsimonious version of model 1, i.e. excluding swell and moon illumination (now referred to as Model 1b). For completeness, the model formula is repeated here:

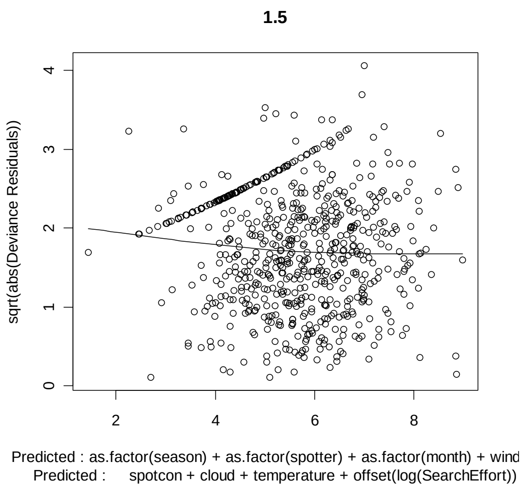
Model 1b:

```
glm(formula = biomass ~ as.factor(season) + as.factor(spotter) +
    as.factor(month) + wind + spotcon + cloud + temperature +
    offset(log(SearchEffort)), family = mvb.tweedie(1.5, 0),
    data = workdat09)
```

The ranges shown in Figure 12 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.

Results of the estimated index value and standard error are shown in tabular form in Table 7. Note that since the index is scaled to the series mean, values for earlier years will change as new seasons' data are added to the analysis, even if the model does not change. We suggest that the model using data for spotters 1, 2 and 6 (Model 1) be used in the next data exchange for this index.





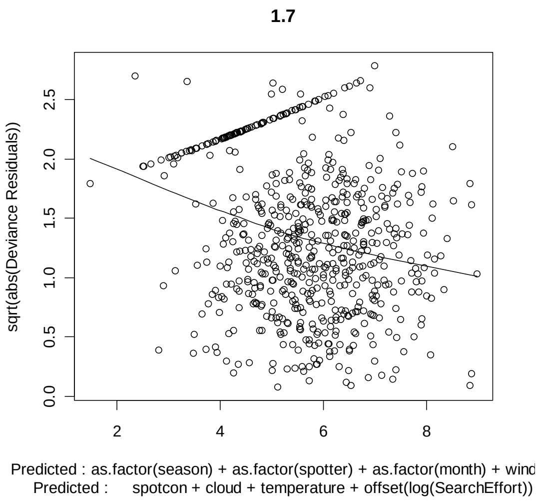


Figure 11. Square root of the absolute value of deviance residuals plotted against the predicted values for three values of the Tweedie parameter (1.2, 1.5 and 1.7). A 'flat' smooth through the points suggests that 1.5 is the preferred value.

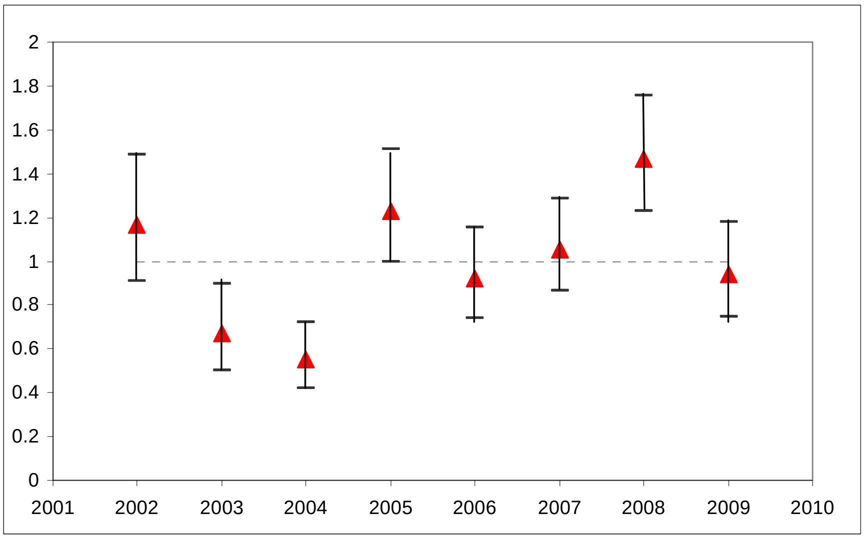


Figure 12. Estimates of standardised relative surface abundance, scaled to the mean over the period, for model 1b with spotters 1,2 and 6. Data for all months were included (December – March). The median and exp(predicted value + or – 2 standard errors) are shown. Values are scaled to the mean over the period, so the horizontal line at 1 indicates the mean. 'Season' is indicated by the second year in a split year so that, e.g. 2002 implies the 2001/2002 season.

Table 7. Standardised SAPUE index of juvenile SBT in the GAB for model 1b (see text). Season refers to the second year in a split year, i.e. 2002 = the 2001/2002 season. The estimated values are also illustrated in Figure 12 above.

Season	Model 1b: spotters 1,2,6	
	Estimate	SE
2002	1.16	0.143
2003	0.67	0.097
2004	0.55	0.073
2005	1.23	0.128
2006	0.92	0.103
2007	1.05	0.104
2008	1.47	0.132
2009	0.94	0.107

Summary

We present results of a standardised 'surface abundance per unit effort' (SAPUE) index, based on fitting a general linear model to the data. Due to the changes in spotter effort since 2006, it is currently most appropriate to only include data for spotters who have consistent and broad temporal coverage; these are spotter 1, 2 and 6. Extensive trials with different combinations of spotters included in analyses were conducted in the past (e.g. CCSBT-ESC/0809/25). We have not reconsidered the choice of spotter given the unbalanced nature of the dataset for combinations other than spotter 1, 2, and 6, and given that past work showed that the general temporal patterns, particularly in recent years, are not sensitive to the choice of spotters. We have, however, conducted 6 sets of sensitivity trials associated with changes in the dataset used and/or covariates included.

Most of the sensitivity trials made very little, if any, difference to the estimated index of abundance. Some trials did, however, make a small difference and these are worth noting here. Including target as a covariate did not have a substantial effect on results, and coefficients were mostly not significant. A summary of the frequency of different targeting categories by season (Table 6) shows that there were some changes in 2009; for example, a much larger number of flights targeting Mackerel (or Mackerel with skipjack / SBT) than in previous years. As noted in the past, such changes can complicate standardisation and even the recorded ‘target’ information may not fully capture changes in spotting activity between seasons. We suggest that this information continue to be recorded, so that the sensitivity of results to this covariate can continue to be considered.

An index based on a model with a month:season interaction is somewhat different from that based on a model with no such interaction. In broad terms, however, the overall temporal patterns are similar. The interaction does reduce the AIC somewhat, but there only very few of the individual coefficients are significant (and only at the 10% level). This is again an issue which should be regularly checked, but at this stage we consider that the more parsimonious model (with interaction term) is preferable.

The most recent analyses have confirmed that covariates ‘swell’ and ‘moon illumination’ are not essential in the model. The most important environmental variables for this dataset are: wind, spotting condition and temperature. Cloud is also relevant but appears to be ‘weaker’ than the other environmental covariates (significance at a lower level).

The estimated index is lowest in 2003 and 2004, as seen before, and the estimate for 2009 is about average (F). 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). We reiterate the caveat that it is well-known that not all juveniles spend their summers in the GAB. Unfortunately, there is no direct information about the proportion of the total juvenile population in the GAB each year. This is not a major problem if the proportion has remained approximately constant over time. If, however, there have been substantial changes in the proportion (e.g. through changes in movement dynamics) then it becomes more difficult to know how to interpret this index.

There are now five years of overlap between the SAPUE index and the scientific aerial survey index. It is encouraging that the overall patterns of the two indices are similar for the five years (2005-2009). 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 scientific survey. The changes in the number of spotters, their relative amount and timing of their effort, are making standardisation increasingly difficult. The changes in spatial coverage and ‘targeting’ in 2009 underline these concerns. We still consider the scientific aerial survey to be preferable as an approach to an index of juvenile abundance, compared to the commercial spotting.

References

Candy, S.G. 2004. Modelling catch and effort data using generalised linear models, the Tweedie distribution, random vessel effects and random stratum-by-year effects. CCAMLR Science, Vol 11:59-80.

Jørgensen, B. 1997. Theory of Dispersion Models. Chapman and Hall, London: Chapter 4.

Acknowledgements

We again especially thank the commercial spotters and pilots for their continued willingness to collect and record sightings data each fishing season. We also thank the tuna fishing companies in Port Lincoln for their continued support of the project. This study was funded by AFMA, DAFF, the Australian SBT Industry, and CSIRO's Wealth from Ocean Flagship.

Appendix A

Estimates of coefficients, standard errors and related 'significance' quantities for model 1 and sensitivity trials.

```
sapu> summary(tfit1)
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 = workdat09)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-10.590   -4.406   -1.302    1.231   16.396

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)            0.380305   0.409182   0.929  0.35303
as.factor(season)2003 -0.545861   0.208443  -2.619  0.00904 **
as.factor(season)2004 -0.755565   0.192075  -3.934 9.31e-05 ***
as.factor(season)2005  0.048645   0.178835   0.272  0.78571
as.factor(season)2006 -0.243252   0.183883  -1.323  0.18637
as.factor(season)2007 -0.112083   0.173279  -0.647  0.51798
as.factor(season)2008  0.227382   0.170036   1.337  0.18163
as.factor(season)2009 -0.217121   0.182844  -1.187  0.23550
as.factor(spotter)2   -1.654933   0.148449 -11.148  < 2e-16 ***
as.factor(spotter)6   -0.644669   0.098929  -6.516 1.49e-10 ***
as.factor(month)2     -0.217667   0.110329  -1.973  0.04895 *
as.factor(month)3     -0.770704   0.121153  -6.361 3.89e-10 ***
as.factor(month)12     0.284844   0.122263   2.330  0.02014 *
wind                  -0.116559   0.018505  -6.299 5.69e-10 ***
spotcon                0.347040   0.076928   4.511 7.72e-06 ***
swell                  0.023779   0.059699   0.398  0.69053
cloud                 -0.042592   0.018197  -2.341  0.01957 *
temperature            0.030087   0.007041   4.273 2.23e-05 ***
moonillum             -0.004893   0.119513  -0.041  0.96736
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for Tweedie family taken to be 21.76399)
    Null deviance: 28520  on 636  degrees of freedom
Residual deviance: 12050  on 618  degrees of freedom
AIC: 8025.7
Number of Fisher Scoring iterations: 6
```

Targeting : all data, including 'target' as a covariate

(Note: 2002 is excluded because target information was not recorded)

```
summary(tfit2.targall)
Call: glm(formula = biomass ~ as.factor(season) + as.factor(spotter) +
    as.factor(month) + wind + spotcon + swell + cloud + temperature +
    moonillum + as.factor(target) + offset(log(SearchEffort)),
    family = mvb.tweedie(1.5, 0), data = workdat09, subset = (season !=
        2002))

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-10.036   -4.411   -1.401    1.317   14.921

Coefficients:
                               Estimate Std. Error t value Pr(>|t|)
(Intercept)                   -0.573602   0.673208  -0.852  0.39456
as.factor(season)2004         -0.108399   0.213973  -0.507  0.61264
as.factor(season)2005          0.616165   0.197594   3.118  0.00191 **
as.factor(season)2006          0.437447   0.206537   2.118  0.03462 *
as.factor(season)2007          0.491463   0.200856   2.447  0.01472 *
as.factor(season)2008          0.806289   0.188414   4.279 2.21e-05 ***
as.factor(season)2009          0.508479   0.206642   2.461  0.01417 *
as.factor(spotter)2           -1.752245   0.154395 -11.349  < 2e-16 ***
as.factor(spotter)6           -0.586668   0.110107  -5.328 1.45e-07 ***
as.factor(month)2             -0.264744   0.116009  -2.282  0.02286 *
as.factor(month)3             -0.757184   0.125076  -6.054 2.62e-09 ***
as.factor(month)12             0.202907   0.133680   1.518  0.12962
wind                          -0.122649   0.019076  -6.429 2.78e-10 ***
spotcon                        0.346668   0.079034   4.386 1.38e-05 ***
swell                          0.012077   0.063456   0.190  0.84912
cloud                         -0.036965   0.018959  -1.950  0.05171 .
temperature                    0.032455   0.007205   4.504 8.14e-06 ***
moonillum                     -0.027980   0.125391  -0.223  0.82350
as.factor(target)SBT           0.407649   0.468512   0.870  0.38463
as.factor(target)SBT/Mack     -0.208874   0.511821  -0.408  0.68336
as.factor(target)SBT/SKJ       0.381596   0.492276   0.775  0.43857
as.factor(target)SBT/SKJ/Mack  0.026359   0.518496   0.051  0.95947
as.factor(target)SKJ          -0.058368   0.509639  -0.115  0.90886
as.factor(target)SKJ/Mack     -0.381854   1.553087  -0.246  0.80588
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for Tweedie family taken to be 20.78607)
    Null deviance: 26628  on 574  degrees of freedom
Residual deviance: 10606  on 551  degrees of freedom
AIC: 7193.1
Number of Fisher Scoring iterations: 6
```

Targeting : Excluding non-SBT target data

```
sapu> summary(tfit2)
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 = wdat09.target)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-10.714   -4.330   -1.397    1.270   16.131

Coefficients:
```

```
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)           -0.076548   0.479844  -0.160  0.87332
as.factor(season)2004 -0.200654   0.214037  -0.937  0.34896
as.factor(season)2005  0.628724   0.195646   3.214  0.00139 **
as.factor(season)2006  0.349864   0.203130   1.722  0.08561 .
as.factor(season)2007  0.461313   0.191640   2.407  0.01643 *
as.factor(season)2008  0.823518   0.178977   4.601 5.30e-06 ***
as.factor(season)2009  0.374937   0.197314   1.900  0.05797 .
as.factor(spotter)2   -1.733687   0.155749 -11.131  < 2e-16 ***
as.factor(spotter)6   -0.636478   0.106586  -5.972 4.40e-09 ***
as.factor(month)2     -0.204468   0.119560  -1.710  0.08784 .
as.factor(month)3     -0.773063   0.132285  -5.844 9.08e-09 ***
as.factor(month)12     0.263835   0.134541   1.961  0.05042 .
wind                  -0.120871   0.019881  -6.080 2.35e-09 ***
spotcon                0.341395   0.083071   4.110 4.61e-05 ***
swell                  0.003053   0.066768   0.046  0.96355
cloud                 -0.043513   0.019729  -2.206  0.02786 *
temperature            0.030069   0.007430   4.047 5.99e-05 ***
moonillum             -0.035939   0.130416  -0.276  0.78299
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for Tweedie family taken to be 21.43103)

    Null deviance: 24560.9  on 529  degrees of freedom
Residual deviance:  9625.4  on 512  degrees of freedom
AIC: 6747.4

Number of Fisher Scoring iterations: 6
```

Targeting: Excluding non-SBT target data, adding ‘target’ as a covariate

```
sapu> summary(tfit2.targ)
Call: glm(formula = biomass ~ as.factor(season) + as.factor(spotter) +
    as.factor(month) + wind + spotcon + swell + cloud + temperature +
    moonillum + as.factor(target) + offset(log(SearchEffort)),
    family = mvb.tweedie(1.5, 0), data = wdat09.target)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-10.086   -4.189   -1.407    1.280   15.001

Coefficients:
                               Estimate Std. Error t value Pr(>|t|)
(Intercept)                   -0.116707   0.484296  -0.241  0.80966
as.factor(season)2004         -0.188068   0.221948  -0.847  0.39720
as.factor(season)2005          0.624967   0.200730   3.113  0.00195 **
as.factor(season)2006          0.419515   0.212291   1.976  0.04868 *
as.factor(season)2007          0.496629   0.203550   2.440  0.01503 *
as.factor(season)2008          0.839231   0.190071   4.415 1.23e-05 ***
as.factor(season)2009          0.544913   0.210010   2.595  0.00974 **
as.factor(spotter)2           -1.759018   0.154758 -11.366  < 2e-16 ***
as.factor(spotter)6           -0.582216   0.111578  -5.218 2.64e-07 ***
as.factor(month)2             -0.236015   0.118992  -1.983  0.04785 *
as.factor(month)3             -0.785754   0.132238  -5.942 5.23e-09 ***
as.factor(month)12             0.198764   0.135586   1.466  0.14328
wind                          -0.122062   0.019680  -6.202 1.15e-09 ***
spotcon                        0.337963   0.081876   4.128 4.28e-05 ***
swell                          0.012179   0.065965   0.185  0.85359
cloud                         -0.043132   0.019421  -2.221  0.02679 *
temperature                    0.032282   0.007408   4.358 1.59e-05 ***
```

```
moonillum                    -0.041090   0.128731  -0.319  0.74971
as.factor(target)SBT/Mack    -0.626791   0.250238  -2.505  0.01256 *
as.factor(target)SBT/SKJ     -0.027237   0.170348  -0.160  0.87303
as.factor(target)SBT/SKJ/Mack -0.420276   0.268222  -1.567  0.11776
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for Tweedie family taken to be 20.78439)

    Null deviance: 24561  on 529  degrees of freedom
Residual deviance:  9460  on 509  degrees of freedom
AIC: 6742.2

Number of Fisher Scoring iterations: 7
```

Using only months 1 and 2 (January & February)

```
sapu> summary(tfit1.m12)
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 = workdat09, subset = (workdat09$month == 1 | workdat09$month
== 2))

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-10.531   -4.372   -1.392    1.234   15.175

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)            0.139493   0.540747   0.258 0.796575
as.factor(season)2003 -0.514061   0.266677  -1.928 0.054644 .
as.factor(season)2004 -0.811090   0.248879  -3.259 0.001219 **
as.factor(season)2005 -0.029391   0.228875  -0.128 0.897890
as.factor(season)2006 -0.421995   0.251230  -1.680 0.093835 .
as.factor(season)2007 -0.258584   0.226980  -1.139 0.255321
as.factor(season)2008 -0.064123   0.236683  -0.271 0.786598
as.factor(season)2009 -0.390266   0.244216  -1.598 0.110866
as.factor(spotter)2   -1.633915   0.155359 -10.517  < 2e-16 ***
as.factor(spotter)6   -0.452445   0.124145  -3.644 0.000305 ***
as.factor(month)2     -0.205452   0.110110  -1.866 0.062830 .
wind                  -0.104423   0.022645  -4.611 5.47e-06 ***
spotcon                0.359604   0.097849   3.675 0.000272 ***
swell                  0.093939   0.078507   1.197 0.232220
cloud                 -0.058616   0.022931  -2.556 0.010971 *
temperature            0.036129   0.008908   4.056 6.06e-05 ***
moonillum             -0.045530   0.150780  -0.302 0.762844
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for Tweedie family taken to be 20.92120)
    Null deviance: 15603.6  on 396  degrees of freedom
Residual deviance:  7339.2  on 380  degrees of freedom
AIC: 4920.7
Number of Fisher Scoring iterations: 6
```

Interaction between month and season included

```
sapu> summary(tfit1.interm)
Call: glm(formula = biomass ~ as.factor(season) + as.factor(spotter) +
    as.factor(month) + wind + spotcon + swell + cloud + temperature +
    moonillum + as.factor(season):as.factor(month) + offset(log(SearchEffort)),
    family = mvb.tweedie(1.5, 0), data = workdat09)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-10.708   -4.445   -1.178    1.367   15.164

Coefficients:
                                          Estimate Std. Error t value Pr(>|t|)
(Intercept)                               0.283822   0.488895   0.581 0.561771
as.factor(season)2003                    -0.407279   0.315518  -1.291 0.197264
as.factor(season)2004                    -1.489099   0.380259  -3.916 0.000100 ***
as.factor(season)2005                     0.111365   0.302032   0.369 0.712468
as.factor(season)2006                    -0.396786   0.337036  -1.177 0.239553
as.factor(season)2007                    -0.022277   0.293485  -0.076 0.939519
as.factor(season)2008                     0.173349   0.302737   0.573 0.567127
as.factor(season)2009                    -0.188991   0.313177  -0.603 0.546430
as.factor(spotter)2                      -1.623251   0.143563 -11.307  < 2e-16 ***
as.factor(spotter)6                      -0.576534   0.099519  -5.793 1.12e-08 ***
as.factor(month)2                        -0.095681   0.368819  -0.259 0.795396
as.factor(month)3                        -0.891045   0.406967  -2.189 0.028949 *
as.factor(month)12                        0.218707   0.325073   0.673 0.501338
wind                                     -0.106016   0.018744  -5.656 2.40e-08 ***
spotcon                                   0.362351   0.077108   4.699 3.24e-06 ***
swell                                    -0.014947   0.059828  -0.250 0.802803
cloud                                    -0.031865   0.018294  -1.742 0.082057 .
temperature                               0.029375   0.007432   3.952 8.66e-05 ***
moonillum                                 0.029529   0.122946   0.240 0.810272
as.factor(season)2003:as.factor(month)2  -0.345337   0.544203  -0.635 0.525950
as.factor(season)2004:as.factor(month)2   0.978903   0.509260   1.922 0.055055 .
as.factor(season)2005:as.factor(month)2  -0.217834   0.458648  -0.475 0.634998
as.factor(season)2006:as.factor(month)2   0.020697   0.481648   0.043 0.965740
as.factor(season)2007:as.factor(month)2  -0.390450   0.454343  -0.859 0.390480
as.factor(season)2008:as.factor(month)2  -0.564026   0.477059  -1.182 0.237558
as.factor(season)2009:as.factor(month)2  -0.245435   0.476829  -0.515 0.606937
as.factor(season)2003:as.factor(month)3  -0.052217   0.581334  -0.090 0.928457
as.factor(season)2004:as.factor(month)3   1.061258   0.556127   1.908 0.056832 .
as.factor(season)2005:as.factor(month)3  -0.026436   0.504688  -0.052 0.958243
as.factor(season)2006:as.factor(month)3  -0.091361   0.532300  -0.172 0.863783
as.factor(season)2007:as.factor(month)3   0.032332   0.503594   0.064 0.948830
as.factor(season)2008:as.factor(month)3   0.319990   0.485818   0.659 0.510366
as.factor(season)2009:as.factor(month)3  -0.013590   0.512297  -0.027 0.978845
as.factor(season)2003:as.factor(month)12 -0.769337   0.537138  -1.432 0.152584
as.factor(season)2004:as.factor(month)12 -0.349201   0.655975  -0.532 0.594690
as.factor(season)2005:as.factor(month)12 -0.738254   0.689451  -1.071 0.284698
as.factor(season)2006:as.factor(month)12  0.550265   0.440678   1.249 0.212272
as.factor(season)2007:as.factor(month)12 -0.057218   0.429790  -0.133 0.894135
as.factor(season)2008:as.factor(month)12  0.242068   0.406659   0.595 0.551894
as.factor(season)2009:as.factor(month)12  0.067701   0.487690   0.139 0.889639
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for Tweedie family taken to be 19.75753)
    Null deviance: 28520  on 636  degrees of freedom
Residual deviance: 11379  on 597  degrees of freedom
AIC: 8023
Number of Fisher Scoring iterations: 6
```

Interaction between Spotter and Season included

```
sapu> summary(tfit1.inter)
Call: glm(formula = biomass ~ as.factor(season) + as.factor(spotter) +
```

```
    as.factor(month) + wind + spotcon + swell + cloud + temperature +
    moonillum + as.factor(season):as.factor(spotter) + offset(log(SearchEffort)),
    family = mvb.tweedie(1.5, 0), data = workdat09)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-10.456   -4.398   -1.314    1.289   14.122

Coefficients:
                                           Estimate Std. Error t value Pr(>|t|)
(Intercept)                                0.094814   0.418581   0.227  0.82088
as.factor(season)2003                     -0.641575   0.274875  -2.334  0.01992 *
as.factor(season)2004                     -0.609326   0.223902  -2.721  0.00669 **
as.factor(season)2005                     -0.013453   0.212419  -0.063  0.94952
as.factor(season)2006                     -0.168133   0.209356  -0.803  0.42223
as.factor(season)2007                     -0.282519   0.205073  -1.378  0.16882
as.factor(season)2008                      0.026824   0.204653   0.131  0.89576
as.factor(season)2009                     -0.310309   0.226109  -1.372  0.17045
as.factor(spotter)2                       -1.101179   0.474282  -2.322  0.02058 *
as.factor(spotter)6                       -1.112577   0.348194  -3.195  0.00147 **
as.factor(month)2                         -0.230924   0.109009  -2.118  0.03455 *
as.factor(month)3                         -0.785831   0.119034  -6.602 8.91e-11 ***
as.factor(month)12                         0.271063   0.122104   2.220  0.02679 *
wind                                      -0.105852   0.018774  -5.638 2.64e-08 ***
spotcon                                    0.428549   0.078997   5.425 8.40e-08 ***
swell                                      0.036941   0.059620   0.620  0.53575
cloud                                     -0.036936   0.017974  -2.055  0.04031 *
temperature                                0.028701   0.007014   4.092 4.86e-05 ***
moonillum                                  0.010613   0.117603   0.090  0.92812
as.factor(season)2003:as.factor(spotter)2 -0.402904   0.659028  -0.611  0.54119
as.factor(season)2004:as.factor(spotter)2 -0.617007   0.625091  -0.987  0.32400
as.factor(season)2005:as.factor(spotter)2 -1.287355   0.664448  -1.937  0.05315 .
as.factor(season)2006:as.factor(spotter)2 -0.723155   0.624159  -1.159  0.24707
as.factor(season)2007:as.factor(spotter)2 -0.505276   0.598961  -0.844  0.39923
as.factor(season)2008:as.factor(spotter)2 -0.375618   0.551833  -0.681  0.49634
as.factor(season)2009:as.factor(spotter)2 -0.767728   0.696454  -1.102  0.27075
as.factor(season)2003:as.factor(spotter)6  0.505789   0.469459   1.077  0.28174
as.factor(season)2004:as.factor(spotter)6 -0.354579   0.476417  -0.744  0.45701
as.factor(season)2005:as.factor(spotter)6  0.658619   0.418041   1.575  0.11567
as.factor(season)2006:as.factor(spotter)6  0.045731   0.432546   0.106  0.91584
as.factor(season)2007:as.factor(spotter)6  0.812699   0.409733   1.983  0.04777 *
as.factor(season)2008:as.factor(spotter)6  0.790797   0.405199   1.952  0.05144 .
as.factor(season)2009:as.factor(spotter)6  0.617317   0.426610   1.447  0.14841
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for Tweedie family taken to be 20.49872)
    Null deviance: 28520  on 636  degrees of freedom
Residual deviance: 11601  on 604  degrees of freedom
AIC: 8024
Number of Fisher Scoring iterations: 6
```

Wind strength and direction included

```
sapu> summary(tfit1.winddir)
Call: glm(formula = biomass ~ as.factor(season) + as.factor(spotter) +
    as.factor(month) + spotcon + swell + cloud + temperature +
    moonillum + windN + windSE + windOth + offset(log(SearchEffort)),
    family = mvb.tweedie(1.5, 0), data = workdat09)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-10.633   -4.447   -1.357    1.324   16.646

Coefficients:
                      Estimate Std. Error t value Pr(>|t|)
(Intercept)           0.196001   0.411254   0.477 0.633821
```

```
as.factor(season)2003 -0.555319   0.210539  -2.638 0.008560 **
as.factor(season)2004 -0.770732   0.193601  -3.981 7.68e-05 ***
as.factor(season)2005  0.053437   0.180028   0.297 0.766701
as.factor(season)2006 -0.236649   0.184870  -1.280 0.200998
as.factor(season)2007 -0.125809   0.174341  -0.722 0.470797
as.factor(season)2008  0.210478   0.172120   1.223 0.221853
as.factor(season)2009 -0.233825   0.184418  -1.268 0.205310
as.factor(spotter)2   -1.617478   0.148986 -10.857  < 2e-16 ***
as.factor(spotter)6   -0.642223   0.101577  -6.323 4.94e-10 ***
as.factor(month)2     -0.227838   0.111233  -2.048 0.040955 *
as.factor(month)3     -0.781457   0.123052  -6.351 4.17e-10 ***
as.factor(month)12     0.263923   0.123226   2.142 0.032603 *
spotcon                0.384708   0.076536   5.026 6.56e-07 ***
swell                  0.024051   0.060214   0.399 0.689725
cloud                 -0.040623   0.018333  -2.216 0.027069 *
temperature            0.029024   0.007504   3.868 0.000122 ***
moonillum             -0.019506   0.120272  -0.162 0.871215
windN                 -0.100200   0.020308  -4.934 1.04e-06 ***
windSE                -0.103500   0.018586  -5.569 3.84e-08 ***
windOth               -0.089076   0.024555  -3.628 0.000310 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for Tweedie family taken to be 22.02499)
    Null deviance: 28520  on 636  degrees of freedom
Residual deviance: 12155  on 616  degrees of freedom
AIC: 8036.6
Number of Fisher Scoring iterations: 6
```

Swell and moon illumination excluded (Model 1b)

```
sapu> summary(tfit1.slim)
Call: glm(formula = biomass ~ as.factor(season) + as.factor(spotter) +
    as.factor(month) + wind + spotcon + cloud + temperature +
    offset(log(SearchEffort)), family = mvb.tweedie(1.5, 0),
    data = workdat09)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-10.628   -4.385   -1.343    1.255   16.501

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)            0.443537   0.368572   1.203  0.22928
as.factor(season)2003 -0.551707   0.207631  -2.657  0.00808 **
as.factor(season)2004 -0.748942   0.190907  -3.923 9.72e-05 ***
as.factor(season)2005  0.052931   0.176155   0.300  0.76391
as.factor(season)2006 -0.231630   0.178813  -1.295  0.19567
as.factor(season)2007 -0.100002   0.169239  -0.591  0.55481
as.factor(season)2008  0.230693   0.169243   1.363  0.17335
as.factor(season)2009 -0.215274   0.182311  -1.181  0.23813
as.factor(spotter)2   -1.651105   0.147909 -11.163  < 2e-16 ***
as.factor(spotter)6   -0.649999   0.097876  -6.641 6.82e-11 ***
as.factor(month)2     -0.224004   0.109335  -2.049  0.04090 *
as.factor(month)3     -0.779696   0.119569  -6.521 1.45e-10 ***
as.factor(month)12     0.285178   0.121854   2.340  0.01958 *
wind                  -0.116504   0.018466  -6.309 5.34e-10 ***
spotcon                0.341825   0.075714   4.515 7.59e-06 ***
cloud                 -0.043158   0.018094  -2.385  0.01737 *
temperature            0.029583   0.006877   4.301 1.97e-05 ***
---
```

```
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for Tweedie family taken to be 21.70781)
    Null deviance: 28520  on 636  degrees of freedom
Residual deviance: 12053  on 620  degrees of freedom
AIC: 8022
Number of Fisher Scoring iterations: 5
```

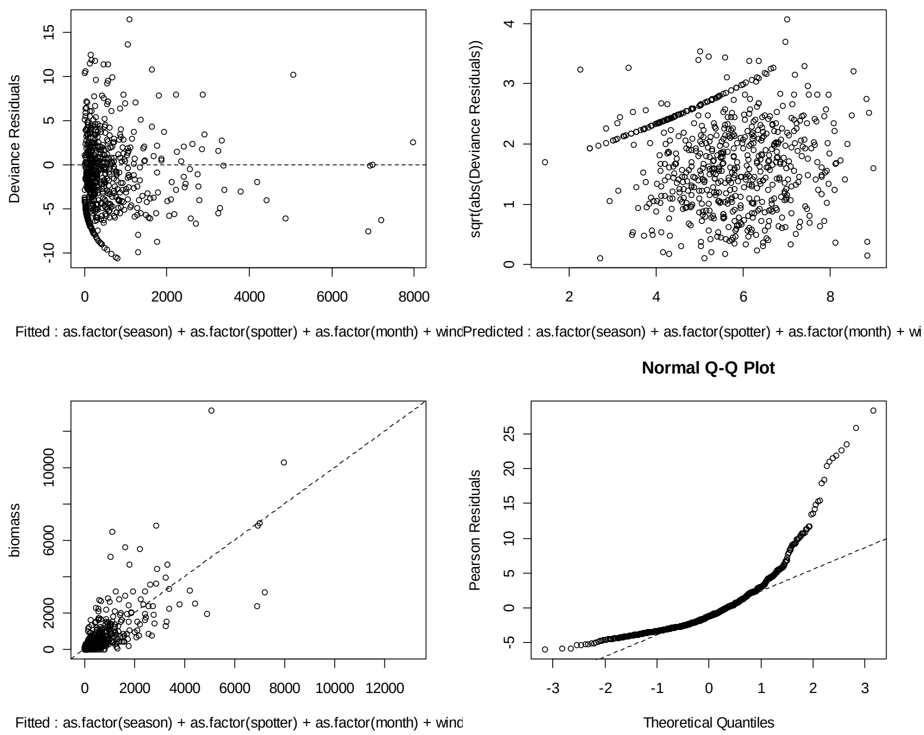


Figure A1. Diagnostics for model 1b.