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Aerial survey indices of abundance: comparison of estimates from line transect and "unit of spotting effort" survey approaches.

Jessica Farley

Sophie Bestley

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Executive summary

An aerial survey was conducted in the eastern Great Australian Bight (GAB) between November 2002 and March 2003 (referred to as the 2003 season). The survey was consistent with the 2001-2 survey (2002 season) (Farley and Bestley, 2002) and comprised two parts: a reduced line transect component based on the 2000 line transect aerial survey design (Cowling, 2000) and a commercial spotting component. The same six industry spotters participated in both the 2002 and 2003 surveys.

The line transect component of the 2003 survey did not meet all of its objectives primarily due to poor weather conditions on days when aircraft and spotters were available. Of the 12 lines intended to be surveyed, only six were attempted and two were completed. Only two SBT schools were recorded during this component of the survey. Constraints on the availability of planes during suitable weather will potentially make it difficult to use commercial spotters to conduct a consistent (spatially and temporally) reduced line-transect survey each year.

The commercial spotting component of the survey was successful and data from 106 flights were collected between November 2002 and March 2003. A total of 55477 nautical miles of commercial search effort was recorded over an area of 947 x 0.1° squares, slightly higher effort and spatial range than in 2002. Spotters recorded 735 SBT sightings (comprising 1301 individual schools) totalling 38559 tonnes. The total number of sightings and number of schools recorded in 2003 was higher than recorded in 2002, but the overall biomass recorded was lower. A significant difference was found in the distributions of school sizes between seasons with proportionally more small schools recorded in 2003 than 2002. It is unclear if this was due to better sighting conditions during the season allowing for more smaller schools to be detected. The size distribution of fish recorded was similar between seasons, and the mean fish size tended to increase with increasing school size.

The commercial spotting data showed an apparent decrease in SBT relative abundance between the 2002 and 2003 fishing seasons from 1.09 to 0.85 tonnes per nautical mile searched. However, this surface abundance per unit effort (SAPUE) has not been adjusted (standardized) so that comparable indices can be developed. For example, the relative contribution of each spotter to the total search effort varied quite significantly between seasons, which biased our overall results towards the spotter with the highest effort. When data from individual spotters were analysed, an increase in unweighted SAPUE between seasons was observed for two of the five spotters compared. The reasons for both increasing and decreasing SAPUE between seasons are unclear, but may be due in part to changes in the area searched or proportion of "intensive" verses "broad scale" searching conducted by each spotter.

The data also showed that the probability of sighting SBT decreased with an increase in wind speed, swell height, and cloud cover for both the 2002 and 2003 fishing seasons, and increased with increasing air temperature in 2003. Differences in environmental conditions between seasons will therefore affect estimates of SBT surface abundance.

In 2003, a time stamp was recorded with each sighting of SBT allowing us to identify flights that overlapped both spatially and temporally, and to examine the potential differences between spotters ability to both detect SBT schools and estimate school biomass. Comparison between spotters based on total number of schools and total

biomass within a 0.1º square generally showed low correlation suggesting that detection rates of schools between spotters is highly variable. However, initial results of automated and manual comparisons of school biomass (see section 4.2.6) estimates between spotters are promising, and consistent overall with those of Cowling et al. (In press), who found good correlation in school size estimates between spotters from explicit experiments conducted in 1998 and 1999. Comparisons of school biomass estimates by spotters with AFMA catch data are also encouraging, although problems with the accuracy of the school location reduce the number of direct comparisons possible.

1 Introduction

This paper presents the results of a continuing aerial survey to develop indices of juvenile southern bluefin tuna (SBT) abundance in the Great Australian Bight. An annual aerial survey based on line transects was conducted in the GAB between 1991 and 2000 but was suspended in 2000-1 to allow analysis of existing data, and review its effectiveness. In 2002, an alternate survey approach was conducted to examine the feasibility of using commercial tuna spotters to collect data on SBT sightings in the GAB. Industry spotters were required to locate, identify, estimate the biomass of, and direct their company's fishing vessels to SBT schools in the near vicinity. The new aerial survey consists of two parts: (1) a commercial spotting component based on SBT sighted per unit of searching effort (a SAPUE index), and (2) a reduced line transect component based on the 2000 scientific aerial survey design (Cowling, 2000). Both components rely on the voluntary participation of professional spotters and pilots during the fishing season.

The 2002 study (Farley and Bestley, 2002) confirmed that commercial tuna spotters can collect large quantities of inexpensive information about the relative abundance of SBT. The installation and operation of data acquisition systems onboard commercial aircraft was found to be both feasible and practical, and the use of logbooks to record sighting data was also effective. Consistent and reliable data on SBT sightings and environmental information was collected during both commercial flights and line-transect flights in the eastern GAB.

One uncertainty in the previous line transect aerial surveys was determining the reliability of the spotters' sightings. This includes their ability to locate SBT schools during a flight and estimate the school biomass. Data collected in the commercial component of the 2002 aerial survey suggested that commercial data may have the potential to help resolve this uncertainty. Sightings rates between spotters can be compared when they are searching close together in time and space. Initial analysis showed that the mean overlap of commercial flights in 2002 based on 0.1º squares was 34.8%. Unfortunately, this analysis could not take into account the time of day that the overlap took place, so the true proportion of overlap would be substantially lower.

The commercial aerial survey data also have to potential to assist in "ground truthing" a spotters' ability to estimate SBT biomass by comparing sightings data collected during the survey against Australian Fisheries Management Authority (AFMA) catch data of SBT purse seined during the fishing season.

This report summarises the data collected in the 2003 fishing season and makes comparisons of effort, SBT sightings, SAPUE, and environmental variables between the

2002 and 2003 fishing seasons. Difficulties in interpreting the SAPUE data are also discussed.

2 Objectives

- reinstall data acquisition system into each commercial spotter plane participating in the survey, and provide logbooks and data collection protocols before the 2002-02 fishing season starts,
- collect accurate, complete and consistent data on flight paths and school locations both on the fishing ground in the SE Great Australian Bight and in other known "hot spot" areas inshore of the current fishing grounds.
- conduct at least 2 replicates of the 6 line transects that lie closest to the commercial fishing area as defined in CSIRO's 2000 scientific aerial survey,
- collect data on environmental conditions during the flights,
- whenever possible, validate school and fish sizes estimated by the spotters using catch data from fishing vessels,
- deploy an observer onto at least two flights per plane during the season,
- undertake analysis of both commercial and line transect data.

3 Methods

The 2003 aerial survey was based on the 2002 survey of Farley and Bestley (2002). The survey consisted of two parts: a commercial spotting component and a reduced line transect component based on the 2000 line transect aerial survey design (Cowling, 2000) in the eastern GAB (Fig. 1). Six commercial aircraft participated in the survey (five Cessna 337's and a Rockwell Aerocommander 500S) each with an experienced tuna spotter and a pilot. The same six spotters participated voluntarily in both the 2002 and 2003 surveys, although one spotter recorded no search effort for the commercial survey in 2002.

The commercial spotting component of the survey required each spotter/pilot to record SBT schools sighted in the GAB whilst engaged in commercial fishing activities. These sightings were used to calculate unstandardised indices of juvenile SBT abundance based on search effort in a similar way to calculations of unstandardised CPUE. The line transect component of the survey required spotters to fly along lines that lay closest to the commercial fishing area during the commercial survey season (Fig. 1). The survey followed the protocols used in the 2000 survey regarding plane height and speed, environmental conditions, and time of day the survey was conducted. All schools within 7 nm from the transect line were recorded.

3.1 Data acquisition systems

The data acquisition systems (DAS) and basic data collection protocols used in the 2002 survey (Farley and Bestley, 2002) were used in the current survey. The DAS consisted of a GPS with track plotting and waypoint recording facilities and a laptop computer. A logbook, instructions and training were provided to each spotter/pilot team.

The DAS was run throughout each flight (both commercial and line transect) to record flight paths. Aircraft positions and altitude were logged every 15 seconds. For each flight, the start and end of each search period during the day and the location of all SBT sightings were recorded using the DAS. The waypoint number generated by the DAS was transferred to the logbook where the event details were recorded.

3.2 Data collected

An SBT sighting was defined as an individual or group of schools (patches). For each sighting, the time, number of schools, school biomass (tonnes), and size range of fish (kg) was recorded either in the logbook or entered directly into the GPS. Estimates were made by the spotter when flying directly over (circling) each sighting. Sightings data were recorded in one of three ways depending on the spotter: (1) the number of individual schools in the sighting and an estimate of the biomass of each school, (2) the total number and average biomass of each school in the sighting, or (3) the total number and biomass of schools in the sighting. Occasionally, a range was recorded for a school biomass (eg. 20-30 tonnes); in these cases the mean of the range was used as the biomass estimate. Spotters were also asked to record the biomass and size of fish estimated by a vessel if the school was caught immediately after it was recorded as a sighting. For each sighting, the time and search type (intensive or broad scale) was also recorded. All school and biomass estimates were made without reference to the other spotters.

Since SBT are highly mobile, it is possible for spotters to record the same school at different locations on a single day. However, spotters argued that this rarely occurred, and that they would identify all schools that were recorded twice in the logbooks.

Environmental variables were also recorded at the start of each search period, and when any variable substantially changed during the flight, regardless of whether SBT were sighted. The environmental variables included wind speed and direction, swell height and direction, visibility (distance searched from aircraft), air temperature, cloud cover (1-8), and spotting conditions (1-5). The duration of each variable state during the day and the mean for the flight was determined. When more than one spotter collected environmental data on a given day (n = 30 days) the mean value was used in analysis. Significant differences in environmental variables between the 2002 and 2003 seasons were tested using unpaired t-tests.

Additional data including remotely sensed NOAA-AVHRR 3-day sea surface temperature (SST) composites and SeaWIFS 9 km 8-day sea surface colour (SSC) (a proxy for chlorophyll) composites were also obtained.

3.3 Analysis of commercial spotting data

The daily flight paths (track logs) of each plane were exported from the GPS to a text file and analysed using MATLAB. The length and duration of "search" sectors during flights were calculated using the GPS logged position and time. Logbook data on SBT sightings were summarised to produce a daily total number of sightings, schools, and total biomass per plane. Total SBT biomass was estimated as the number of schools seen multiplied by the school biomass for each sighting.

Indices of juvenile SBT abundance were calculated for the survey area, based on biomass sighted (*B*) per unit effort (*D*) (Klaer et al., CSIRO unpublished report). The standard unweighted mean (μ^s) was calculated as:

$$\mu^s = \frac{\sum_{u=1}^{n}(B_u / D_u)}{n}$$

where u = a sampling unit: the flight and 0.1° squares

B_u = the biomass of SBT observed within a sampling unit

D_u = the effort in a sampling unit: distance (nm) and time flown (min)

n = the total number of sampling units.

The standard deviation of the standard unweighted mean σ^s was calculated as:

$$\sigma^s = \sqrt{\frac{\sum_{u=1}^{n}\left((B_u / D_u) - \mu^s\right)^2}{n}}$$

The weighted mean with the weight being the distance flown in a sampling unit was calculated as:

$$\mu^w = \frac{\sum_{u=1}^{n} B_u}{\sum_{u=1}^{n} D_u}$$

and the standard deviation as:

$$\sigma^w = \sqrt{\frac{\sum_{u=1}^{n} D_u\left((B_u / D_u) - \mu^w\right)^2}{\sum_{u=1}^{n} D_u}}$$

The 95% confidence intervals of the mean were calculated using the standard deviation as follows:

$$i^{95\%} = \pm\frac{1.96 * \sigma}{\sqrt{n}}$$

Six indices of abundance were calculated; four used the flight as the sampling unit and two used 0.1° squares as the sampling unit. Within each, indices were calculated using distance as a measure of effort. Indices were calculated for the whole survey area and for a core area of greater fishing activity based on effort. Only unweighted indices were calculated for indices using 0.1° squares.

3.4 Evaluation of spotter skill

In 2003, a time stamp was recorded with each sighting of SBT. This additional information allows us to more closely examine:

1) potential differences between spotters in ability to detect SBT schools
2) potential differences between spotters in biomass estimation
3) potential differences between spotters biomass estimation and AFMA catch data.

Spatially gridded analysis

As for the 2002 analysis (Farley and Bestley, 2002) flight path data and SBT sightings data were gridded into 0.1º squares (approximately 6 nm x 6 nm). For dates where more than one flight occurred, we examined whether any two planes covered the same grid square; whether this dual coverage occurred within some minimum period of time; and whether any SBT sightings were made by either spotter during this period of dual coverage. If so, the total effort (nm), number of SBT schools and biomass were totalled for each grid square where overlap occurred per spotter.

Per sighting analysis

To calibrate spotters' school size estimates, the biomass of independently sighted schools were compared both manually and by an automated step-wise application of rules using the software package MATLAB. Individual schools were identified as likely to have been reported by two different spotters if the sightings were made within a specific period of time and distance apart. Since individual SBT can swim at least 2.5 nm/hr in the GAB (Davis & Stanley, 2001), we used one nautical mile and 30 minutes as the spatial and temporal criteria for comparison of schools sighted. For the manual comparison, schools up to 90 minutes and 2 nm apart were also compared. Note that since some spotters record schools in clusters (several schools together), we grouped schools together prior to the analysis if they were very close to each other both spatially and temporally. In the manual comparison, these groupings were judged for each specific comparison. If two spotters recorded multiple sightings within approximately one minute the biomass was aggregated. For the step-wise automated comparison schools sighted within 1 nm and 5 minutes were aggregated to a single sighting for the company.

Evaluating a spotters' ability to estimate biomass was also examined by comparing sightings data against Australian Fisheries Management Authority (AFMA) SBT logbook catch data for the purse seine fishery in South Australia. The biomass of SBT recorded in a purse seine catch from AFMA logbooks was compared to the biomass recorded for individual sightings for a spotter. As with the comparison between spotters (above), individual schools were identified as likely to have been recorded by a spotter before being caught by a vessel if the sighting was made within a certain radial distance and period of time prior to the catch location and time. We used three distances (one, two and three nautical miles) and three lengths of time (15, 30 and 60 minutes) as the spatial and temporal criteria for the comparison. Note that the data recorded in the AFMA logbooks is the time and position that the fish are transferred into the tow cage, not the time that the fish are caught in the purse seine net. The time difference between the two could hours, depending on the location of the cage that fish will be transferred into from the purse seine net.

Unfortunately, evaluating the spotters' ability to estimate fish size could not be examined by this method as fish size is not recorded in the AFMA logbooks.

4 Results and discussion

4.1 Line transect survey

The line transect component of the survey did not meet all of its objectives in 2003 primarily due to poor weather conditions. High winds and above average rainfall occurred in the Ceduna region in January and February 2003, which significantly reduced the number of suitable days for either commercial or line-transect flights. Aircraft are only available to participate in the line transect part of the survey when not required by the commercial fishery. This only occurs when tuna tow cages have been filled and new cages have not arrived on the fishing ground, or at the end of the fishing season. Several planes were available to fly transects in mid and late February, however, high winds, low cloud and rain made it impossible to meet the minimum environmental conditions required. When the weather finally became suitable and planes were available from mid-March, the JAMARC deadline for funding of 10 March had halted the survey.

Of the 12 lines expected to be surveyed, only six were attempted and two were completed. Of the incomplete lines, between a third and a half of the line was surveyed. Only two SBT schools were recorded during the survey. Analysis of the data was not undertaken due to its limited extent.

As reported last year, the use of commercial planes to fly transect lines similar to the former transect aerial survey is possible. However, constraints on the availability of aircraft during suitable weather will make it difficult to complete a consistent number of transect lines annually.

4.2 Commercial aerial survey

4.2.1 Spotting activities

Data from 106 commercial flights were collected between November 14, 2002 and March 12, 2003. A scientific observer was deployed on 8 of these flights to ensure that the data collected was consistent and reliable. The majority of technical and data collection problems encountered in the 2002 survey were not encountered during the current survey and data from 102 flights were suitable for analysis (compared to 86 of 124 flights in 2002). It is recommended, however, that an observer presence be continued on future commercial flights to ensure that consistent and reliable data is being collected.

As in the 2002 season, the majority of commercial flights originated from either Ceduna or Port Lincoln (Fig. 1). Searches usually started between 10:00 and 14:00 and finished between 15:00 and 18:00. Search time ranged from 17 minutes to nearly 7:40 hours per flight. Search altitude and flying speed were similar between seasons. Search altitude varied between 200 and 2500 ft although the most common heights were 900, 1000, 1200, 1500 or 2100ft. The average daily speed for the Aerocommander ranged between 137 and 154 knots (mean 145 knots), and the Cessna 337's ranged between 101 and 157 knots (mean 129 knots). In 2002, the mean speed of the Aerocommander was 145 knots, and the Cessna 337's was 123 knots. The distance from the aircraft that spotters were searching ranged from 1 to 16 nm (mean of 5.6 nm) depending on the spotting conditions.

4.2.2 Search effort

A total of 425 hours of commercial search effort (55477 nm) was recorded over an area of 947 x 0.1° squares during the survey. This is higher than in the 2002 season when 325 hours of search effort (44167 nm) covering 854 x 0.1° squares (Table 1) was recorded. Overall, data was collected from an area 11% larger in 2003 than in 2002. The greater spatial coverage in 2003 most likely reflects the greater number of flights that recorded data for the survey, rather than an increase in the spatial range of SBT in the GAB.

The majority of search effort occurred between December and March in both the 2002 and 2003 fishing seasons (Table 2). In 2003, the target species for all flights was SBT except for 14 flights when skipjack tuna were targeted (note that all SBT sighted during flights targeting skipjack were recorded). Five of the six spotters participating in the survey collected viable data in both the 2002 and 2003 seasons. However, the relative contribution by each spotter to the total effort varied between the two seasons (Table 3).

When the 2002 commercial spotting data was analysed (Farley and Besley, 2002), an area of core activity was selected between 130.9° to 132.6°E and 32.7° to 34.0°S, which contained 76% of total search effort. Although the distribution of effort changed slightly in 2003 (Fig. 2), the core area selected still contained 69% of total effort for the season. Very little effort was directed outside the core area (except en route to and from the Ceduna airport) especially in deeper water off the continental shelf. The flights between the Ceduna airport and the main fishing area often covered known "hot spot" areas such as the small inshore islands and reefs.

In 2003, two areas of concentrated search effort were observed surrounding the locations of fishing vessels, as compared to three areas in 2002. Figure 3 shows the proportion of effort by longitude for both seasons.

4.2.3 SBT sightings

Spotters recorded 735 SBT sightings (comprising 1301 individual schools) during the survey period (Table 1). The total biomass recorded in 2003 was 38559 tonnes, slightly lower than in 2002 (44626 t), however, it should be noted that the total biomass recorded does not represent the total biomass of SBT present in the survey area, as many schools were potentially recorded several times (either by different spotters on the same day or over several days) and standardisation between spotters has not been done. Overall, for the combined 2002 and 2003 seasons, 1405 sightings have been made by commercial spotters during commercial spotting operations, compared to 1731 over 10 years of the previous line transect survey (Cowling et al., In press).

All commercial sightings were made between 10 am and 6 pm, with most (72% of schools and 71% of biomass) recorded between 12 and 4 pm. SBT were recorded as individual schools (81% of sightings) or as "clusters" of up to 20 schools (3 sightings). Schools were recorded in only 151 (16%) of the 947x0.1° squares containing search effort, compared to 170 (20%) of the 854x0.1° squares in 2002 (Table 1). In short, SBT were sighted in fewer 0.1° squares in 2003 even though a larger area was searched than in 2002. Of the total biomass recorded in 2003, 62% was sighted in the core fishing area compared to 79% in the previous year indicating that the main fishing area (distribution of fish) can change between seasons.

A significant difference was found in the distributions of school sizes between seasons (Kolmogorov-Smirnov test = <0.0001), with proportionally more small schools recorded in 2003 than 2002 (Fig. 4). It is unclear if this was due to better sighting conditions during the season allowing for more smaller schools to be detected. The size distribution of fish recorded was similar between seasons (Fig. 5) with the mean fish size tending to increase with increasing school size in both seasons (Fig. 6). Whether this apparent relationship between fish and school size is a real phenomenon or is the result of spotters' bias in estimating fish/school size is unclear. Spotters record the mean size or range of sizes in a school but do not assign proportions to each size class if several exist in a school.

4.2.4 Indices of abundance

Mean daily surface abundance per unit effort (SAPUE) in 2003 ranged from 0 to 18.2 tonnes per nautical mile flown with an unweighted mean of 0.85. The flight with a SAPUE of 18.2 was considered unlikely to be a true search flight as only 16 minutes of flight time was recorded directly over four sightings. If this flight is excluded from the analysis, the mean unweighted SAPUE was 0.68 tonnes per nautical mile. Table 4 gives a summary of the nominal (unstandardised) SAPUE values calculated using distance flown as measures of effort for both the total and core fishing areas in 2002 and 2003. The results show an apparent decrease in abundance between seasons for all indices calculated.

As when using catch per unit effort (CPUE) from commercial fisheries as an index of stock abundance, the sightings rates from commercial tuna spotters must be adjusted (standardized) so that comparable annual indices of juvenile SBT abundance can be developed. The standardisation of the data removes factors, other than abundance, that influences SAPUE. For example, the relative contribution of each spotter to the total search effort varied quite significantly between seasons (Table 3), which biased our overall results towards the spotter with the highest effort. When data from individual spotters were analysed for the core fishing area during the peak of the fishing season (Dec-Mar), an increase in unweighted SAPUE between seasons was observed for two of the five compared (Table 5). The reasons for both increasing and decreasing SAPUE between seasons are unclear, but may be due in part to changes in area searched or the proportion of "intensive" verses "broad scale" searching conducted by each spotter. When a spotter is intensively searching around a vessel, effort generally increases in relation to the biomass of fish sighted, while during broad scale searches, effort decreases in relation to the biomass sighted. Unfortunately, search type was not recorded in 2002, so a comparison between seasons cannot be made at this stage.

Other factors that may influence SAPUE such as seasonal variations in environmental conditions (see section 4.2.4), area searched, time of day of searching, target species etc have not been accounted for in our analyses, although we have collected data that would allow for some confounding factors to be corrected for. This could be used to retrospectively improve the precision of the previous line transects surveys (1991-2000).

Despite problems of interpreting the SAPUE data, we found that SAPUE was highest within the core fishing area and around the nearshore lumps in both fishing seasons (Fig. 7). Within the core, SAPUE was higher in the north-west than the south-east. An examination of SAPUE by longitude (Fig. 8) confirms that peak SAPUE occurred between approximately 130 and 131.5ºE in both seasons, whereas effort peaked to the east of 131.5ºE. This pattern is consistent with higher effort (intense searching) associated with fishing vessels in the SE of the core area resulting in lower SAPUE, rather than real higher abundance of SBT in the NW.

4.2.5 Environmental conditions

As mentioned in section 4.2.4, variability in factors such as environmental conditions must be accounted for when analysing SAPUE data. Environmental variables are known to influence the detection of schools at the surface by changing the visibility during aerial spotting operations as well as influencing the surfacing rates of fish.

Unlike the line-transect component of the aerial survey, there were no restrictions on the conditions that commercial spotting operations occurred in. In both fishing seasons, however, the majority of commercial flights were made when the wind speed was less than 12 knots; just outside the 10-knot limit set for the line-transect surveys. The data collected from the spotters indicates that the probability of sighting SBT decreases with an increase in wind speed, swell height, and cloud cover for both fishing seasons, and increases with increasing air temperature in 2003 (Fig. 9). Predictably, SAPUE was higher when spotting conditions were good. Cowling et al. (In press) demonstrated that higher wind speeds and swell heights decreased the probability of detecting SBT at the shelf possibly as a result of surface disturbance reducing visibility into the water.

A comparison of environmental conditions as recorded by the spotters indicated that air temperature was the only variable significantly different between seasons, being higher on average in 2003 than 2002 (t-test, $P=0.022$). No significant differences were detected for the other variables compared (Table 6), although all were considered "better" on average for detecting SBT in 2003 than in 2002. For example, in 2003 the average wind speed, swell height and cloud cover were lower, while the average spotting conditions judged by the spotters was higher (~better) than in the previous season. Unfortunately, the environmental conditions for days when flights did not occur are unknown and will influence the overall surfacing behaviour of SBT for the season.

Satellite derived sea surface temperature (SST) and sea surface colour (SSC) for the core fishing area were consistently higher in 2003 than in 2002 up until March of both seasons (Fig. 10). SST and SSC for locations of SBT sightings show a similar variation, being significant higher on average in 2003 than in 2002 (Kolmogorov-Smirnov test =

<0.0001) (Fig. 11). For example, in 2002 only 0.8% of schools (1.5% of biomass) were sighted in surface waters ≥20 ºC while in 2003, 37% of schools (42% of biomass) were sighted in these water temperatures. The mean SST of SBT sightings increased during both seasons reflecting the increase in SST in the core fishing area (Fig. 12). Although it appears that SBT may surface in the warmest water in the core area (mean SST of sightings is consistently higher than the mean for the core; Fig. 12) this may not be the case as the relatively cool SSTs from off the continental shelf are included in the core area while search effort did not cover this region.

4.2.6 Evaluation of spotter skill

One of the main sources of uncertainty in analysing SAPUE (and line-transect) data is determining the reliability of the spotters' sightings including their ability to detect SBT schools and estimate biomass. Calibration of 'spotter skill' can be estimated from commercial spotting data when (i) spotters' are searching in the same area at approximately the same time, and (ii) when the same school of SBT is recorded by two or more spotters. Spotter skill can also be calibrated when a purse seine vessel catches a school of SBT (biomass is recorded in AFMA logbooks) after being recorded by the spotter.

In 2003, more than one flight occurred on 30 of the 50 days when commercial flights were made (n=82 flights), resulting in 85 potential instances of overlap in effort between two companies (Table 7). When examined at a grid scale of 0.1º square, 69 (81%) of these flight combinations showed some degree of spatial overlap, and when examined at a temporal scale of 30 minutes, 62 (73%) showed some degree of temporal overlap (Table 6). SBT sightings occurred in 46 (74%) of cases where two flights had periods of spatial and temporal overlap in effort.

A pair-wise least-squares regression analysis between spotters based on total number of schools within a 0.1º square (Fig. 13) or total biomass within a square (Fig. 14) generally showed low correlation ($r<0.4$), possibly due to the large number of zeros, which suggests that detection rates of schools between spotters is highly variable. This analysis, however, does not account for cases of variable effort by the two spotters, for example when effort by one spotter is extremely low in a square, thus reducing his chances of detecting schools. The analysis is also subject to errors where a school is recorded by two spotters at a distance apart and is subsequently analysed in adjacent 0.1º squares.

Comparing school biomass estimates between spotters was hard to evaluate because of the difficulty of identifying independent sightings of the same school/s. However this approach generally found much higher correlations than the spatially gridded approach ($r>0.9$ for some comparisons in both the automated and manual comparisons, Fig. 15 and 12). Although time-consuming, the manually filtered comparison of school size (Fig. 15) showed higher correlation than the step-wise analysis (Fig. 16) possibly because it allowed for more appropriate grouping of sightings when required. The automated method suffers from errors relating to requiring an "order of operations", for example edge effects where an edge school in a given cluster is first grouped with a middle school, subsequently leaving out another school at the other edge of the cluster. The results are also sensitive to low sample sizes - for example in Fig. 16, if the single outlier of 350t is removed from the comparison of companies 6 and 2, the r-value increases to 0.89. However, the initial results are promising, and consistent overall with those of Cowling et al. (In press), who found good correlation in school size estimates between spotters from explicit experiments conducted in 1998 and 1999.

The comparison of school biomass estimated by spotters with AFMA catch data for the purse seine fishery showed correlations coefficients between $r<0.01$ and $r=0.98$ (Table 8) depending on the company, and distance/time criteria used. A comparison of school biomass could not be made for two of the six companies, possibly because they recorded the lowest search effort in the survey (days and nautical miles) and subsequently had fewer possible sightings to use in the analysis. Using company 3 in Table 8 as an example, school biomass estimates showed highest correlation for comparisons using 15 minutes as the time-limit between the sighting and the catch record. (Fig. 17). Although more biomass estimates are included in the analyses using 30 and 60 minutes criteria, the correlation was much lower.

There are some problems associated with the pair-wise comparisons which limit the number of comparisons possible, the most important probably being the accuracy of the school location (for both the sightings and AFMA catch data). The inaccuracies are likely to be the result of:

1. sightings recorded by spotters not being directly over the schools;
2. schools moving after being recorded as a sighting;
3. the “chum” boat (a small boat that keeps the school at the surface before the purse seine vessel arrives) dragging a school several nautical miles, usually towards the approaching purse seine vessel, before being caught;
4. poor spatial resolution of the AFMA catch data as positions are reported in degrees and minutes, not decimal points of minutes.

The chum boat may also gather several schools together before they are caught, making a comparison of biomass inaccurate as it impossible to distinguish which schools sighted by the spotter were grouped. However, since the time taken between when a school is purse seined and when it is recorded in the AFMA logbook would be more than 15 minutes (and probably even more than 30 minutes), it is likely that the schools sighted by the spotter within these time limits were made when the fish were already in the purse seine net. These biomass comparisons are useful as problems associated with fish being lost or gained prior to being caught are reduced.

Although the data collected so far is limited, our attempt at quantifying the detection rates and biomass estimates of schools by spotters may be used to retrospectively improve the precision of the previous line transects surveys. Additional data collected in subsequent fishing seasons will help to improve these comparisons. In very few cases were one spotter’s estimates the same as another’s or the AFMA carch data, but in situations where correlation is high they can be adjusted to the same level.

5 Conclusions

1. Commercial tuna spotters can inexpensively collect large quantities of information about the sightings of SBT schools in the GAB.
2. Constraints on the availability of commercial planes during suitable weather make it difficult to conduct a reduce line-transect survey in the GAB. The number and location of transect lines completed annually will not be consistent between seasons, as the availability of planes and extent of suitable weather varies considerably between years. Unless this part of the survey is given higher priority by industry during the season, or dedicated aircrafts, spotters and pilots are contracted to conduct the survey, it is unlikely that a reduced line-transect survey will meet its objectives. At present, the availability of spotters participate in an independent survey is limited.
3. As with commercial CPUE data, there are substantial difficulties in analysing and interpreting the data collected in commercial spotting operations. The commercial spotting data showed an apparent decrease in SBT abundance between the 2002 and 2003 fishing seasons, with lower biomass recorded although overall search effort was apparently higher. However, when data from individual spotters were analysed for the core fishing area during the peak of the fishing season (Dec-Mar), an increase in SAPUE between seasons was observed for two of the five compared.
4. Additional research is required to standardize the commercial SAPUE data for the effects of spotter differences and environmental variation etc.
5. The commercial spotting data shows that the probability of sighting SBT decreased with an increase in wind speed, swell height, and cloud cover for both fishing seasons, and increased with increasing air temperature in 2003. This is similar to that found by Cowling et al. (In press).
6. Initial results of automated and manual comparisons of school biomass estimates between spotters are promising, and consistent overall with those of Cowling et al. (In press), who found good correlation in school size estimates between spotters from explicit experiments conducted in 1998 and 1999. Comparisons of school biomass estimates by spotters with AFMA catch data are also encouraging, although problems with the accuracy of the school location reduce the number of direct comparisons possible. However, since "calibration" is only possible if, by chance, there is overlap in the area and time searched by more than one plane, we may only be able to calibrate a subset of the spotters. Additional data collected in subsequent fishing seasons would help to improve these analyses.

6 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 spotters and pilots for their willingness to collect and record data over the summer field season including Micheal Bell, Ben Cool, David Franklin, Phillip Gibson, Derek Hayman, Lyell Jaensch, Andrew Jakob, Mile Mislov, Nat Nagy, Mark Nichols, Mozzie (Peter Stevens), Tony Warren and Kiwi

White. We also thank David Blacker, Joe Gobin, Justin Nelligan, David Puglisi, Marcus Stehr, Darren Tressider, Leith Whittaker, and Andrew Wilkinson for their support of the project. The assistance given to us by staff at Australian Fishing Enterprises, Ajka, Blaslov Fishing Company, DI Fishing Company, Emily Krstina, Stolts Sea Farm, and Australian Tuna Fisheries is also acknowledged. Finally thanks to Matt Sherlock at CSIRO for providing electronics assistance throughout the survey, and to Rosemary Bailey for data entry work. This study was funded by JAMARC, AFMA, and CSIRO Marine Research as part of the Japanese/Australia SBT Recruitment monitoring Program.

7 References

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Table 1. Comparison of search effort and SBT sightings between the 2002 and 2003 commercial aerial surveys.
A survey season is defined as November of the previous year to April of the given year.

Year	2002	2003
No. flights	86	102
Mean flight time/day (hrs)	3.8	4.0
Total distance flown (nm)	44167	55477
Total distance flown (nm) in core	32573	38056
Total time flown (hrs)	325	425
No. 0.1° squares searched	854	947
No. 0.1° squares with SBT	170	151
% 0.1° squares with SBT	20	16
No. sightings	670	735
No. schools	1182	1301
Mean school size (t)	37.8	29.4
Total biomass recorded	44626	38559

Table 2. Effort and SBT sightings data collected by month during the (a) 2002 and (b) 2003 commercial aerial survey seasons.

(a)

Month	Planes (n)	Flights (n)	Distance searched (nm)	Time searched (hrs)	0.1° squares searched	Sightings (n)	Schools (n)	Biomass* (t)
Dec 01	3	26	14391	102	569	298	613	21291
Jan 02	4	25	9726	75	347	154	295	10119
Feb 02	5	22	11350	87	453	150	199	9141
Mar 02	1	11	7744	55	379	68	76	4075
Apr 02	1	2	956	6	197	0	0	0
Total		86	44167	325	854	670	1183	44626

(b)

Month	Planes (n)	Flights (n)	Distance searched (nm)	Time searched (hrs)	0.1° squares searched	Sightings (n)	Schools (n)	Biomass* (t)
Nov 02	2	8	3812	26	522	6	11	125
Dec 02	2	20	11762	92	520	106	199	5171
Jan 03	5	40	21684	170	427	366	611	19550
Feb 03	6	19	8943	70	371	154	295	9714
Mar 03	3	15	9276	68	513	103	185	4000
Total		102	55477	425		735	1301	38559

* Biomass 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) and standardisation between spotters has not been done.

Table 3. Relative contribution (%) by spotter to total search effort (total nautical miles flown by all spotters) during the 2002 and 2003 commercial aerial surveys.
A survey season is defined as November of the previous year to April of the given year. Spotter 1 did not collect useable data in the 2002 season. The number identifying each spotter is not equivalent between tables and figures.

Spotter	2002	2003
1	0	1
2	5	4
3	6	10
5	11	35
4	13	28
6	65	22

Table 4. Comparison of surface abundance per unit effort (SAPUE) values for the total survey area and the core fishing area for the 2002 and 2003 commercial aerial surveys.
Indices were calculated using distance as the measure of effort, and for two sampling units (the flight and 0.1° squares). U = unweighted index, W = weighted index. A flight was excluded from the analysis (SAPUE of 18.2) because it was not considered a true search flight (see section 4.2.4).

Sampling unit	Area	Index	SAPUE	
			2002	2003
Per flight	Total	U	1.09	0.68
	"	W	1.01	0.68
	Core	U	1.26	0.78
	"	W	1.11	0.61
Per 0.1° square	Total	U	0.54	0.27
	Core	U	0.92	0.58

Table 5. Surface abundance per unit effort (SAPUE) values for the core fishing area by company for the 2002 and 2003 commercial aerial surveys.
SAPUE is unweighted using flight as the sampling unit. Flights were restricted to December of the previous year to March of the given year. A flight was excluded from the analysis (SAPUE of 18.2) because it was not considered a true search flight (see section 4.2.4). The number identifying each spotter is not equivalent between tables and figures. One company could not be compared as no search effort was recorded in 2002.

	SAPUE	
Spotter	2002	2003
1	2.28	0.72
2	1.26	0.99
3	0.53	1.02
4	0.51	0.94
5	0.46	0.34

Table 6. Ranges and means (+/- SD) of environmental data collected during the 2002 and 2003 commercial aerial surveys.
Environmental variables are mean daily environmental conditions estimated by spotters/pilots. *n* = 52 (2002) and 50 (2003). Significant differences between the means are marked: *** $p < 0.05$ (unpaired t-test).

		2002	2003
Wind speed (kt)	Range	0 - 15	1 - 15
	Mean	7.4 +/- 3.6	7.1 +/- 3.7
Air temperature (ºC)	Range	10 - 34	11 - 32
	Mean	18.2 +/-5.4***	21.0 +/- 6.6
Swell height (m)	Range	0.3 - 2.9	0.5 - 2.8
	Mean	1.5 +/- 0.7	1.3 +/- 0.6
Cloud cover (/8)	Range	0 - 8	0 - 8
	Mean	4.4 +/- 2.5	4.0 +/- 2.7
Spotting conditions (/5)	Range	1 - 5	1 - 5
	Mean	2.6 +/- 1.0	2.7 +/- 1.0

Table 7. Summary data for those dates of the SBT season 2002-2003 where more than one commercial flight occurred.

Date	# flights	Combinations of flights:			
		Total possible	Spatial overlap	Temporal overlap	Temporal overlap + SBT sightings
27-Nov-02	2	1	1	1	1
28-Nov-02	2	1	1	1	0
07-Dec-02	2	1	1	1	1
11-Dec-02	2	1	1	1	1
12-Dec-02	2	1	0	0	0
13-Dec-02	2	1	0	0	0
14-Dec-02	2	1	1	1	1
19-Dec-02	2	1	1	1	1
20-Dec-02	2	1	1	1	1
21-Dec-02	2	1	1	1	1
05-Jan-03	4	6	6	2	0
06-Jan-03	3	3	3	3	3
11-Jan-03	3	3	3	3	3
12-Jan-03	4	6	5	4	3
16-Jan-03	4	6	5	5	4
17-Jan-03	5	10	6	6	5
23-Jan-03	4	6	6	6	2
24-Jan-03	3	3	3	3	3
25-Jan-03	4	6	3	2	2
29-Jan-03	3	3	2	1	1
02-Feb-03	2	1	1	1	1
03-Feb-03	5	10	7	7	7
04-Feb-03	2	1	1	1	1
11-Feb-03	2	1	1	1	0
12-Feb-03	3	3	3	3	3
23-Feb-03	2	1	1	1	0
04-Mar-03	2	1	1	1	0
05-Mar-03	3	3	3	3	0
06-Mar-03	2	1	1	1	1
12-Mar-03	2	1	0	0	0
Total	82	85	69	62	46
% total			81	73	54
Progressive %			81	90	74

Table 8. Results of pair-wise least-squares regression analyses comparing the biomass (t) of individual commercial SBT sightings with biomass of individual catches from AFMA logbook records.
Sightings included occur within a set radius of 1, 2 or 3 nm of the reported catch location and within a time-limit of 15, 30, or 60 minutes prior to the reported time of the catch. R-value given only where n (shown in brackets) is > 2. Numbers in italics indicate a negative relationship. The number identifying each spotter is not equivalent between tables and figures.

		Company			
Distance (nm)	Time (min)	1	2	3	6
1	15			N/A (1)	
	30			N/A (1)	N/A (2)
	60	0.77 (4)		N/A (2)	*0.98 (3)*
2	15			0.48 (4)	N/A (1)
	30	N/A (1)	N/A (1)	0.26 (8)	0.24 (5)
	60	0.55 (7)	N/A (2)	0.23 (17)	0.05 (7)
3	15	N/A (2)		0.49 (5)	N/A (2)
	30	<0.01 (3)	N/A (2)	0.24 (11)	0.24 (7)
	60	<0.01 (11)	0.24 (5)	0.18 (21)	0.05 (9)

Figure 1. Location of the 2002 and 2003 commercial and line transect aerial surveys in the GAB.
The location of the shelf (200m isobath) is shown for geographical reference.

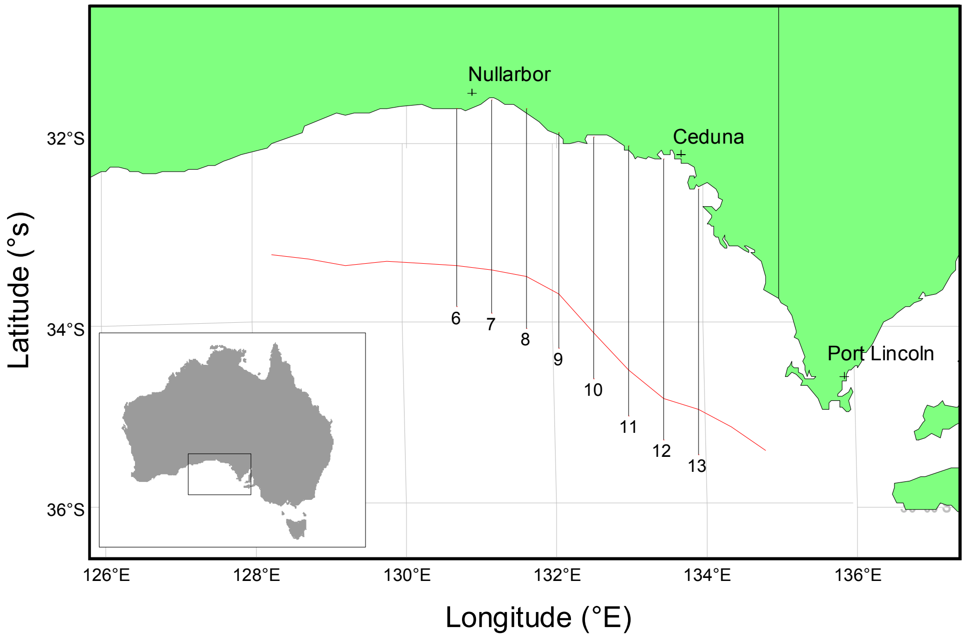
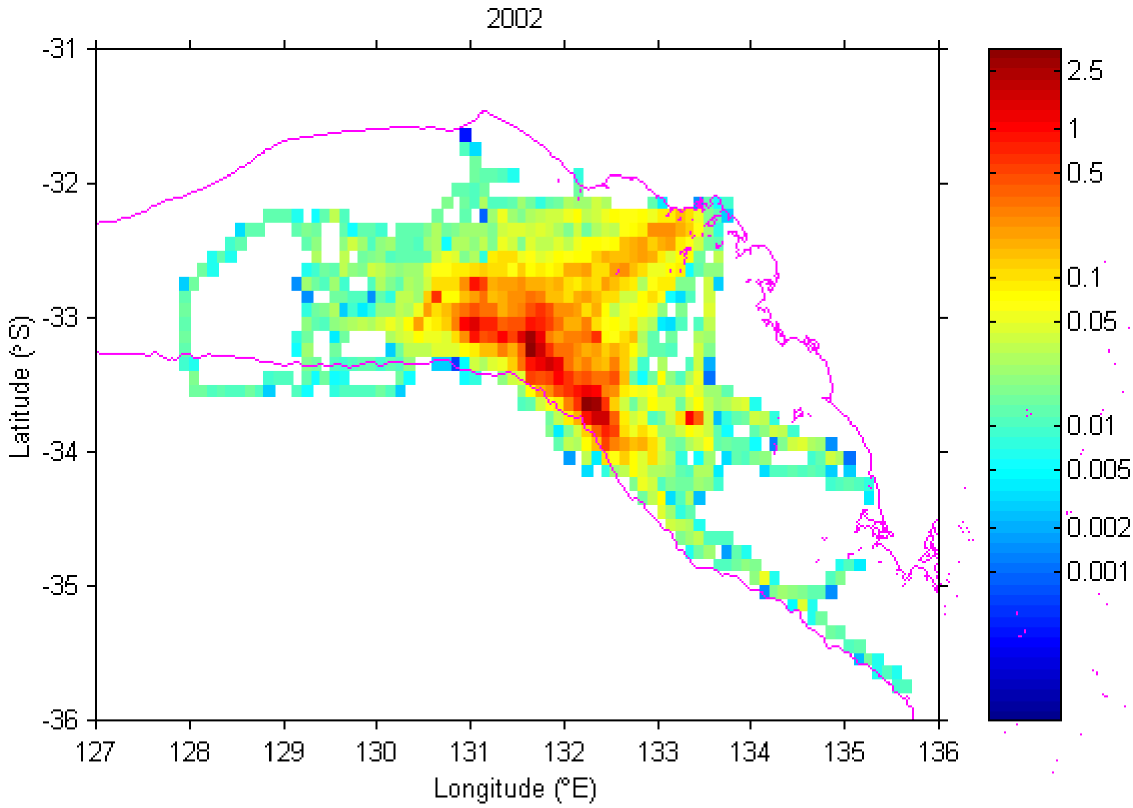


Figure 2. Commercial SBT search effort in the GAB during the 2002 and 2003 aerial surveys in distance flown (nm) per 0.1° square.
For direct comparison of location of effort, data is displayed as the percent (%) of total effort for the season. Coastline and shelf break (200m isobath) shown for geographical reference. Note the log scale for effort.



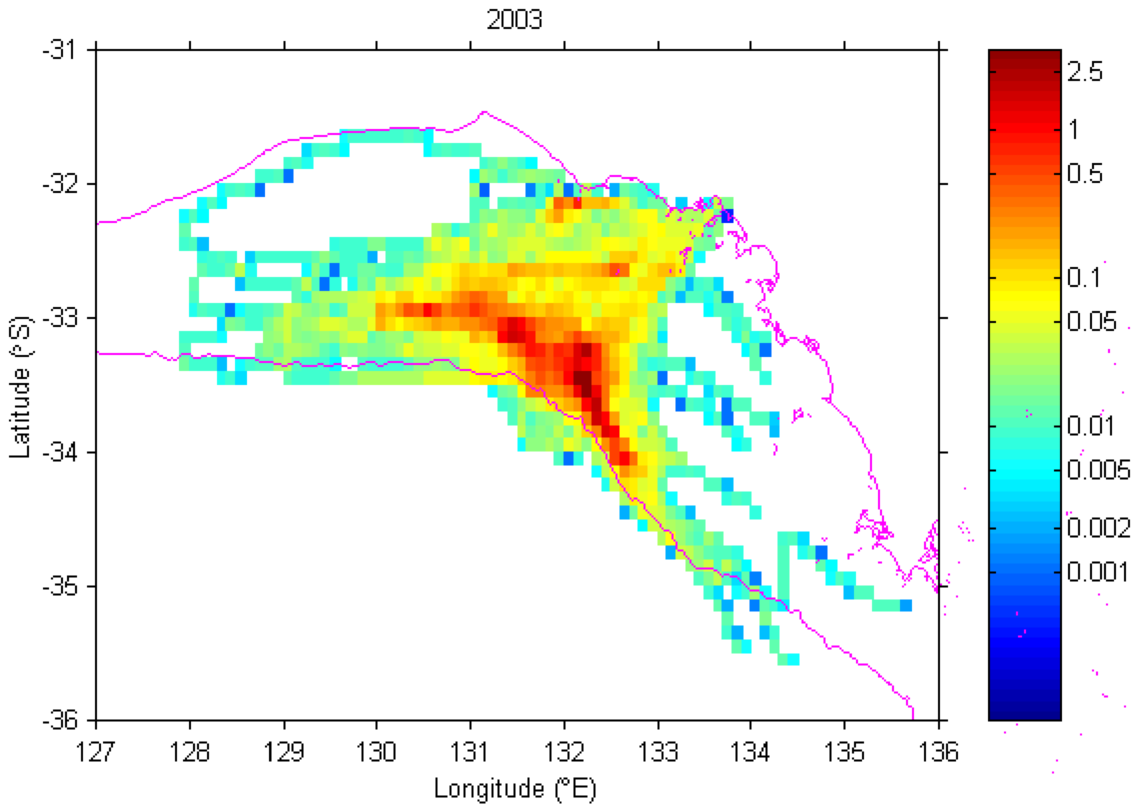


Figure 3. Proportion of search effort (nm) by longitude during the (a) 2002 and (b) 2003 commercial spotting seasons.

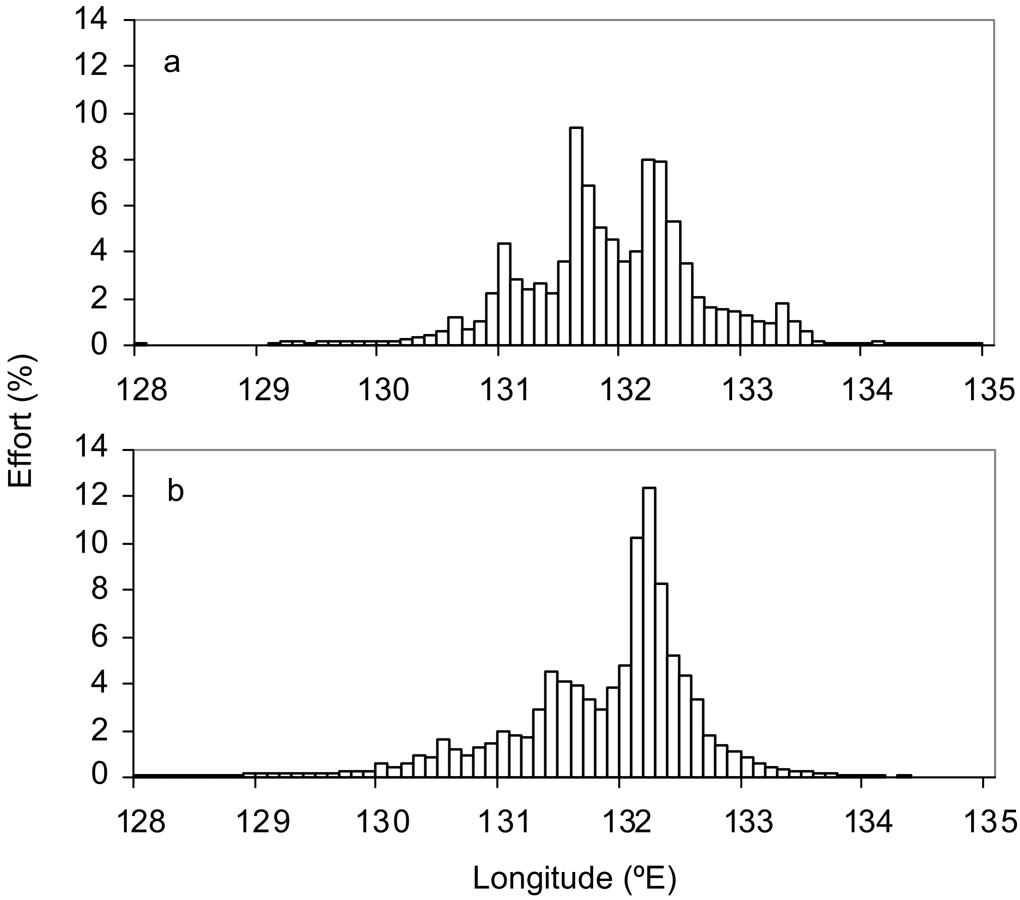


Figure 4. Size frequency of SBT schools sighted during the 2002 and 2003 commercial spotting seasons.
Data is weighted by number of schools per sighting.

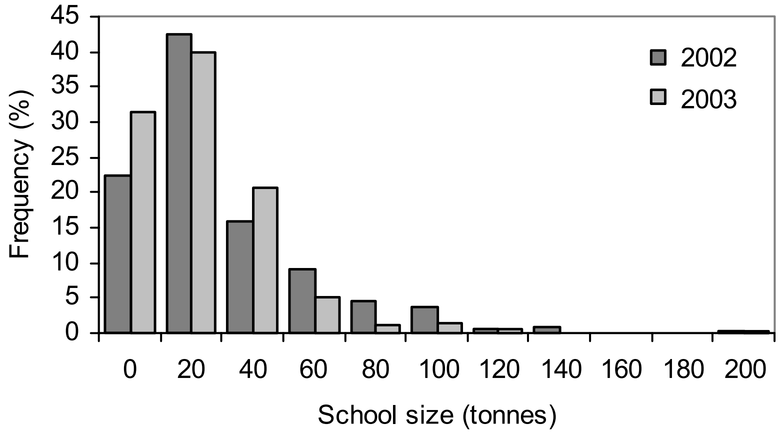


Figure 5. Size frequency of SBT sighted during the 2002 and 2003 commercial spotting seasons.
Data is weighted by school size.

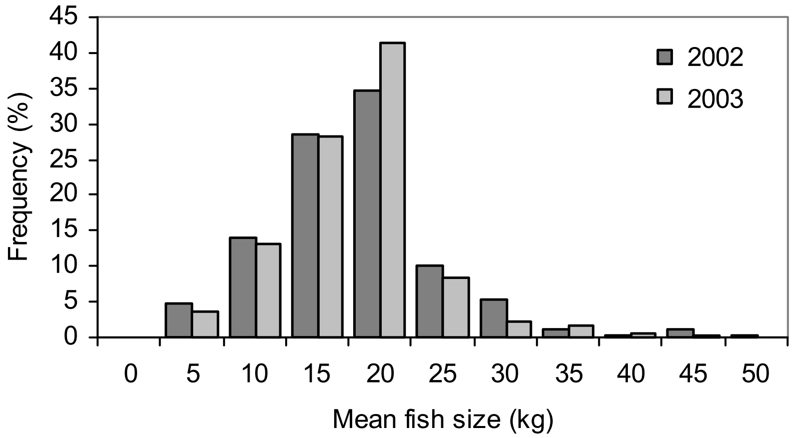


Figure 6. Box-plot of fish size in relationship to school size for the 2002 and 2003 commercial aerial survey seasons.
Centre line and outside edge of each box indicate the median and 25th/75th percentile around the median respectively.

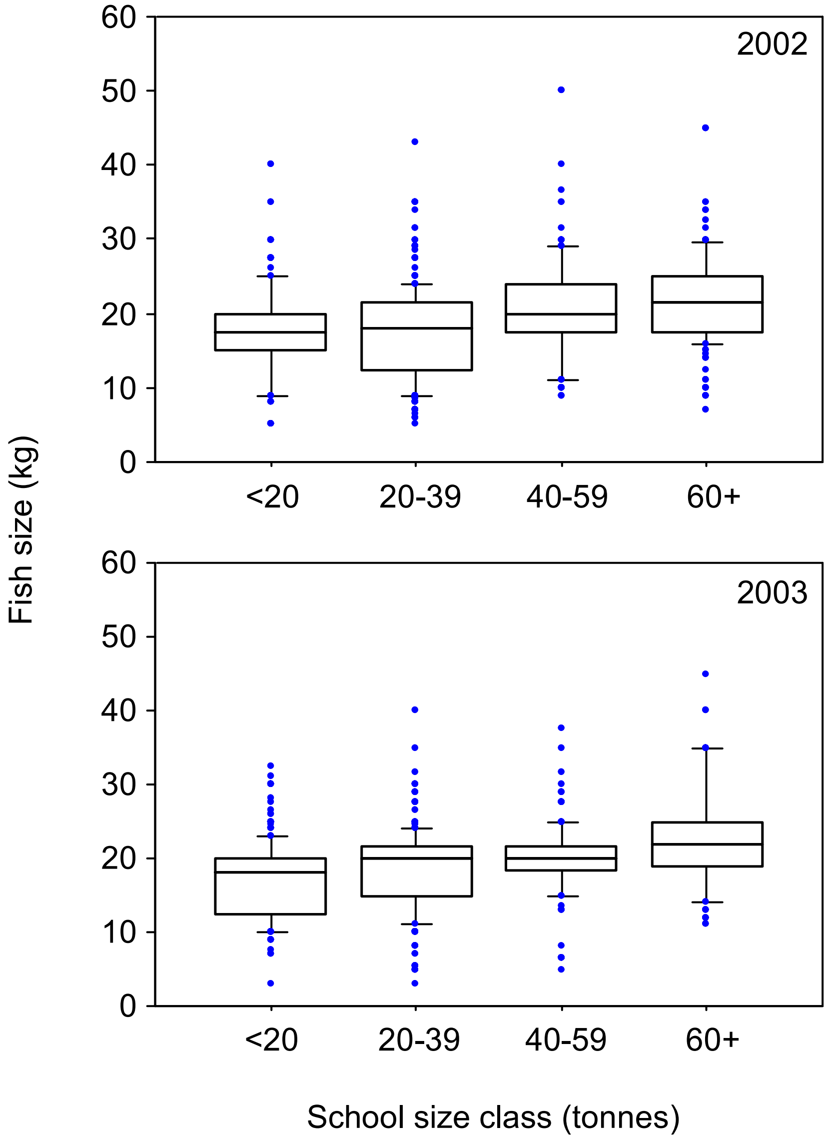


Figure 7. Surface abundance per unit effort (SAPUE) of commercial flights during the 2002 and 2003 aerial surveys in tonnes SBT per nautical mile per 0.1° square.
Areas of darkest blue indicate zero SAPUE. Coastline and 200m isobath shown for geographical reference. Note the log scale for SAPUE.

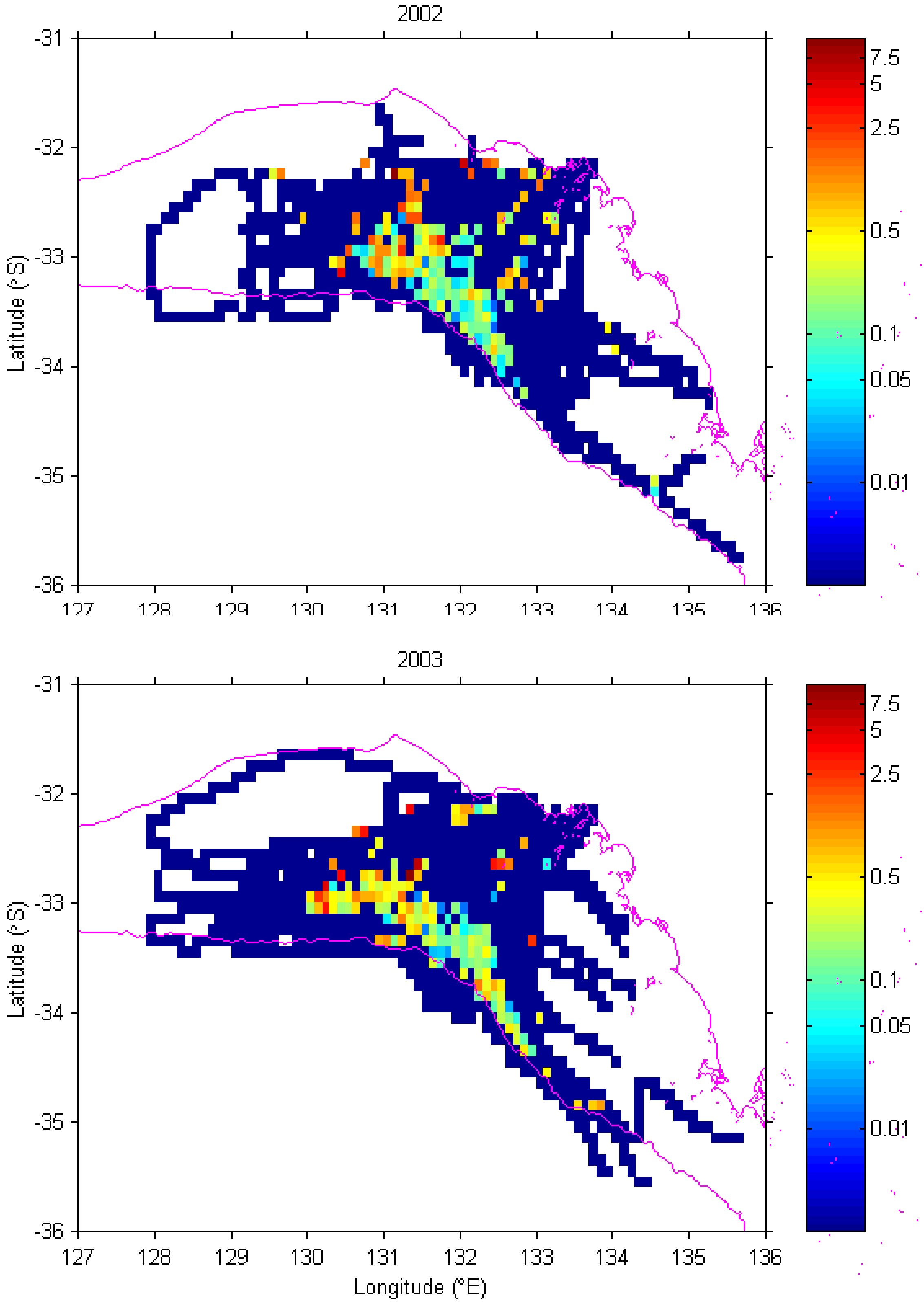


Figure 8. Comparison of total effort (nm) and surface abundance per unit effort (SAPUE) by longitude in the GAB for December 2001 to March 2002.
April is not included as only two flights were conducted.

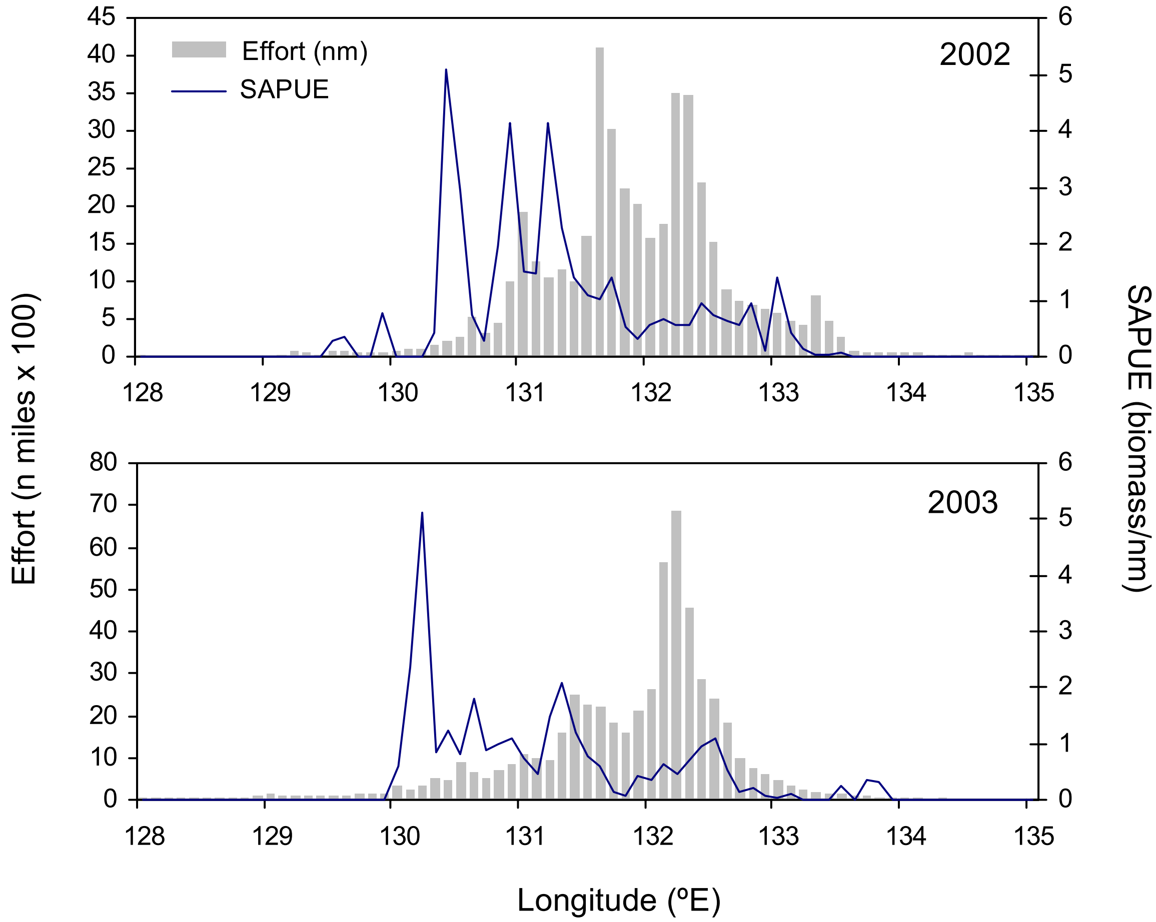


Figure 9. Box-plot of environmental variables recorded by the spotters in relation to SAPUE for the 2002 and 2003 commercial aerial survey seasons.
Centre line and outside edge of each box indicate the median and 25th/75th percentile around the median respectively. Wind speed was assigned a Beaufort (BF) sea state where 0 is no wind, 1 = 1-5 kts, 2 = 6-11 kts and 3 = 12-19 kts. Cloud cover was assigned 0-4 (no cloud to complete cloud cover based on the). Spotting conditions were assigned 0-5 (poor to good). SAPUE are the unweighted mean per flight.

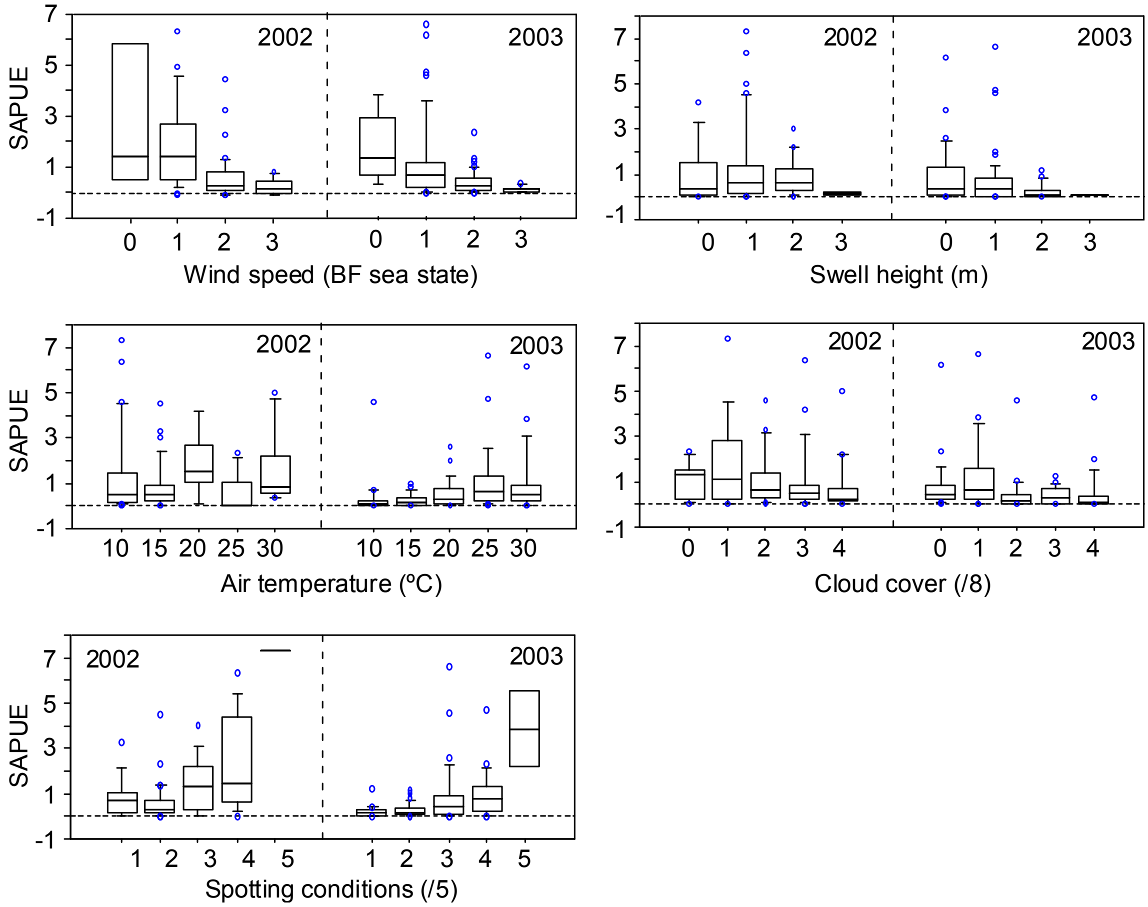
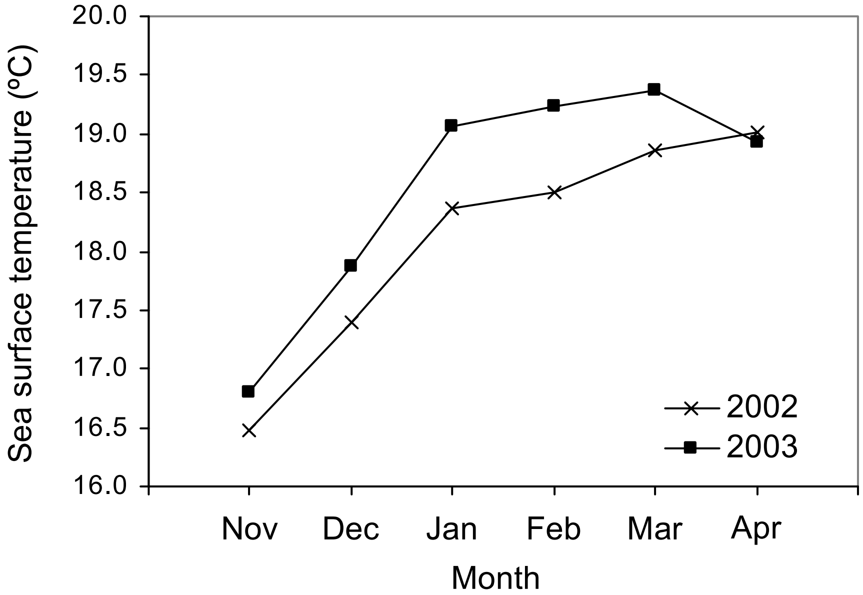


Figure 10. Monthly mean (+/-CV) sea surface temperature and sea surface colour (SSC) in the core region.
Data is based on NOAA-AVHRR 3-day sea surface temperature composites and SeaWIFS 9 km 8-day sea surface colour composites respectively.



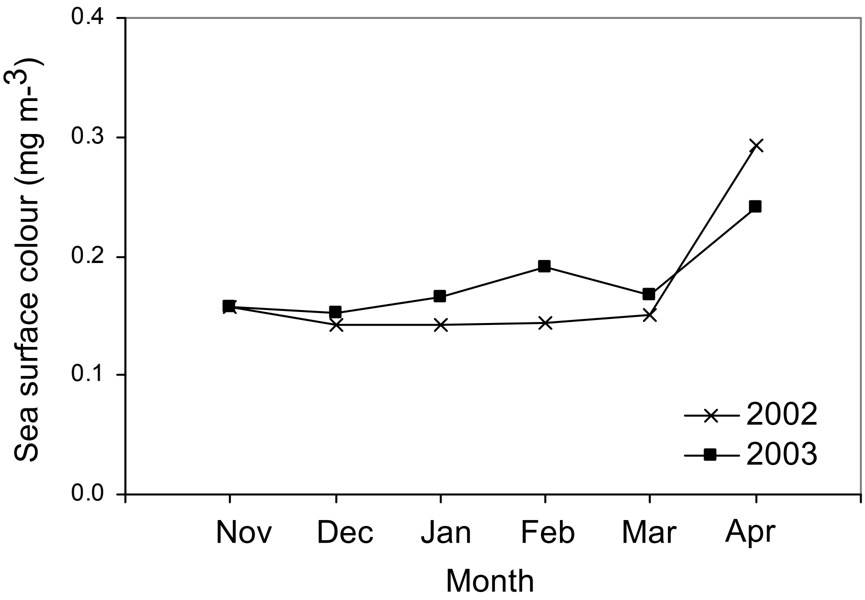


Figure 11. Percent of all SBT sightings and percent of total SBT biomass sighted by sea surface temperatures (SST) for the 2002 and 2003 commercial aerial survey based on 3-day composites.
Data was not available for some sightings data due to cloud cover.

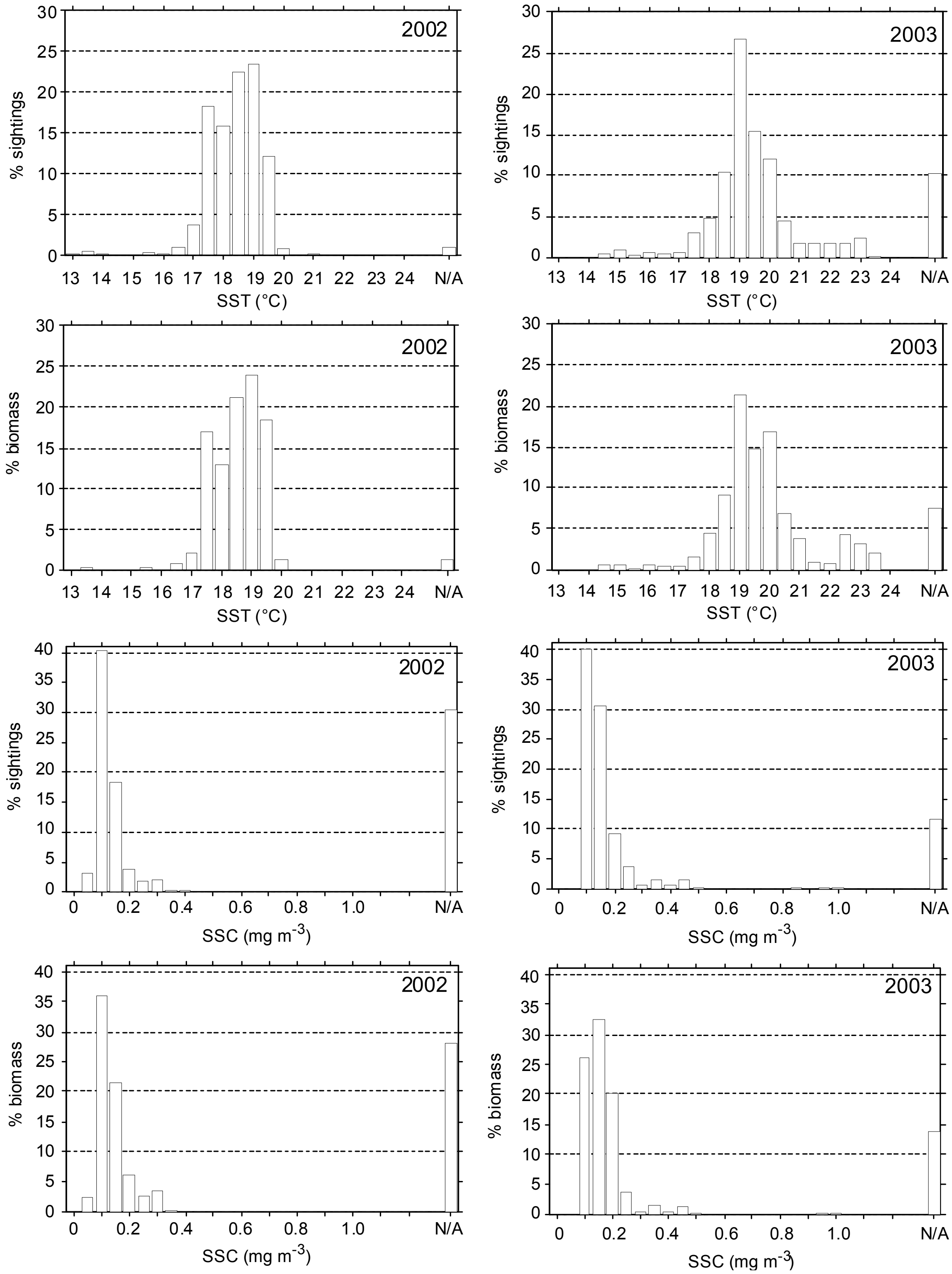


Figure 12. Monthly mean (+/-CV) sea surface temperature (SST) and sea surface colour (SSC) for SBT sightings and the core region.
Data is based on NOAA-AVHRR 3-day sea surface temperature composites and SeaWIFS 9 km 8-day sea surface colour composites respectively.

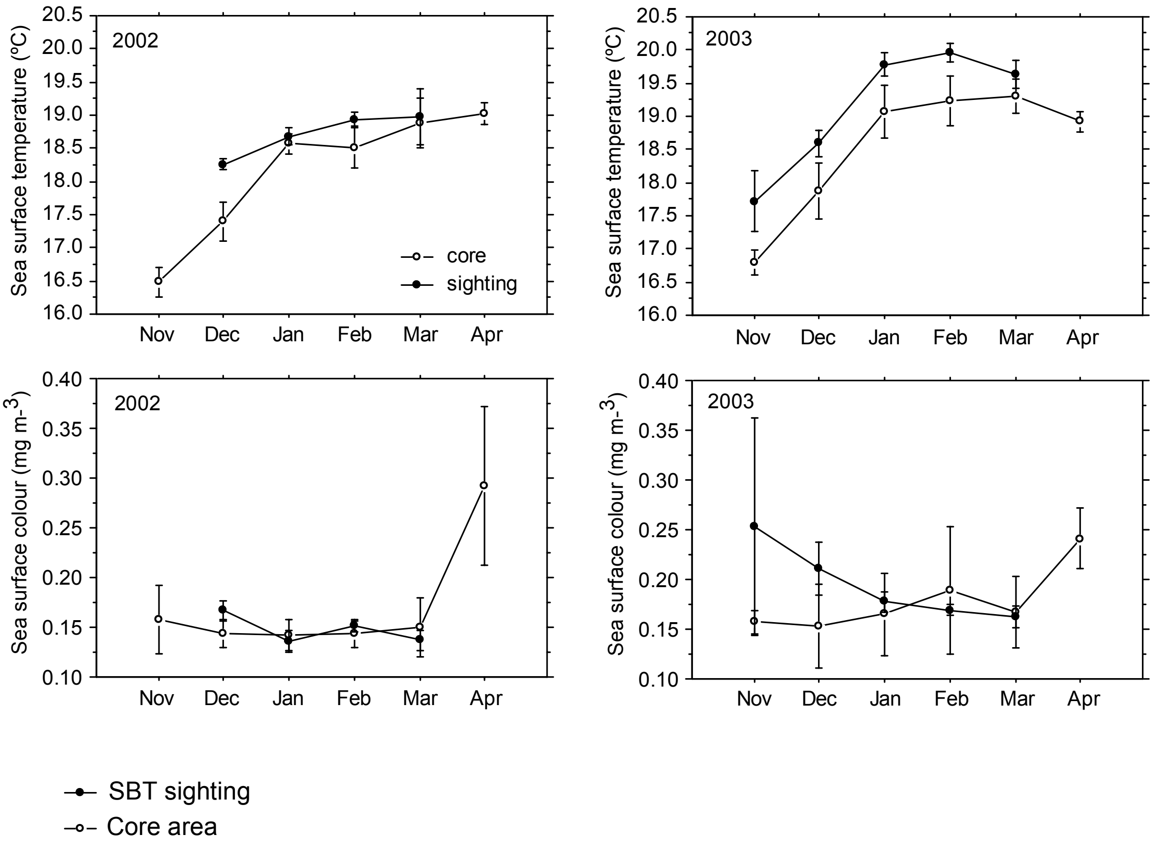


Figure 13. Pairwise analyses of number of SBT schools reported by two different companies within the same grid square within a specified time interval.
The grid resolution is 0.1 degrees per square (latitude x longitude) and the time interval is specified at 30 minutes. N = the number of squares, r=the correlation coefficient (least squares), m=the slope of the fit.

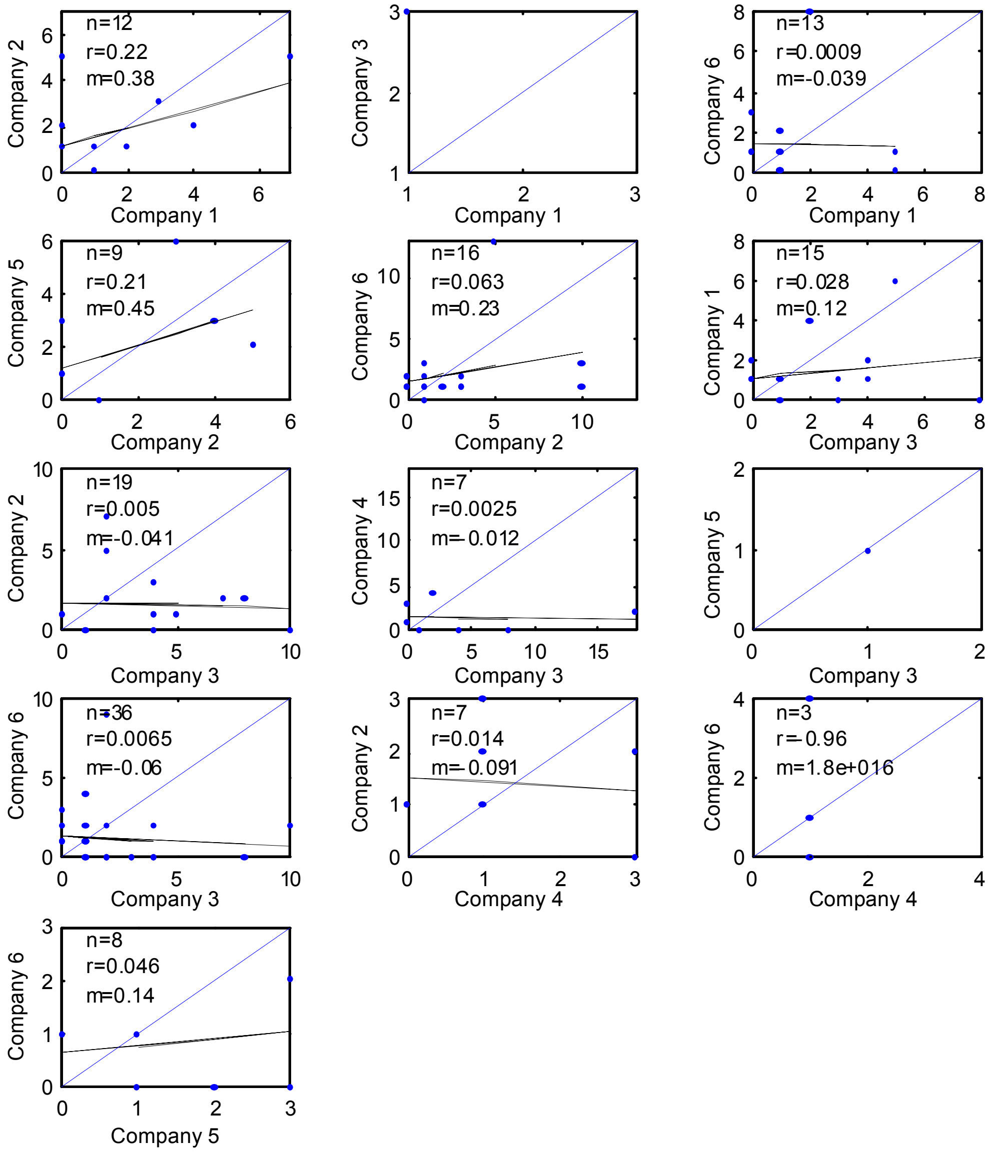


Figure 14. Pairwise analyses of total SBT biomass reported by two different companies within the same grid square within a specified time interval.
The grid resolution is 0.1 degrees per square (latitude x longitude) and the time interval is specified at 30 minutes. N = the number of squares, r=the correlation coefficient (least squares), m=the slope of the fit.

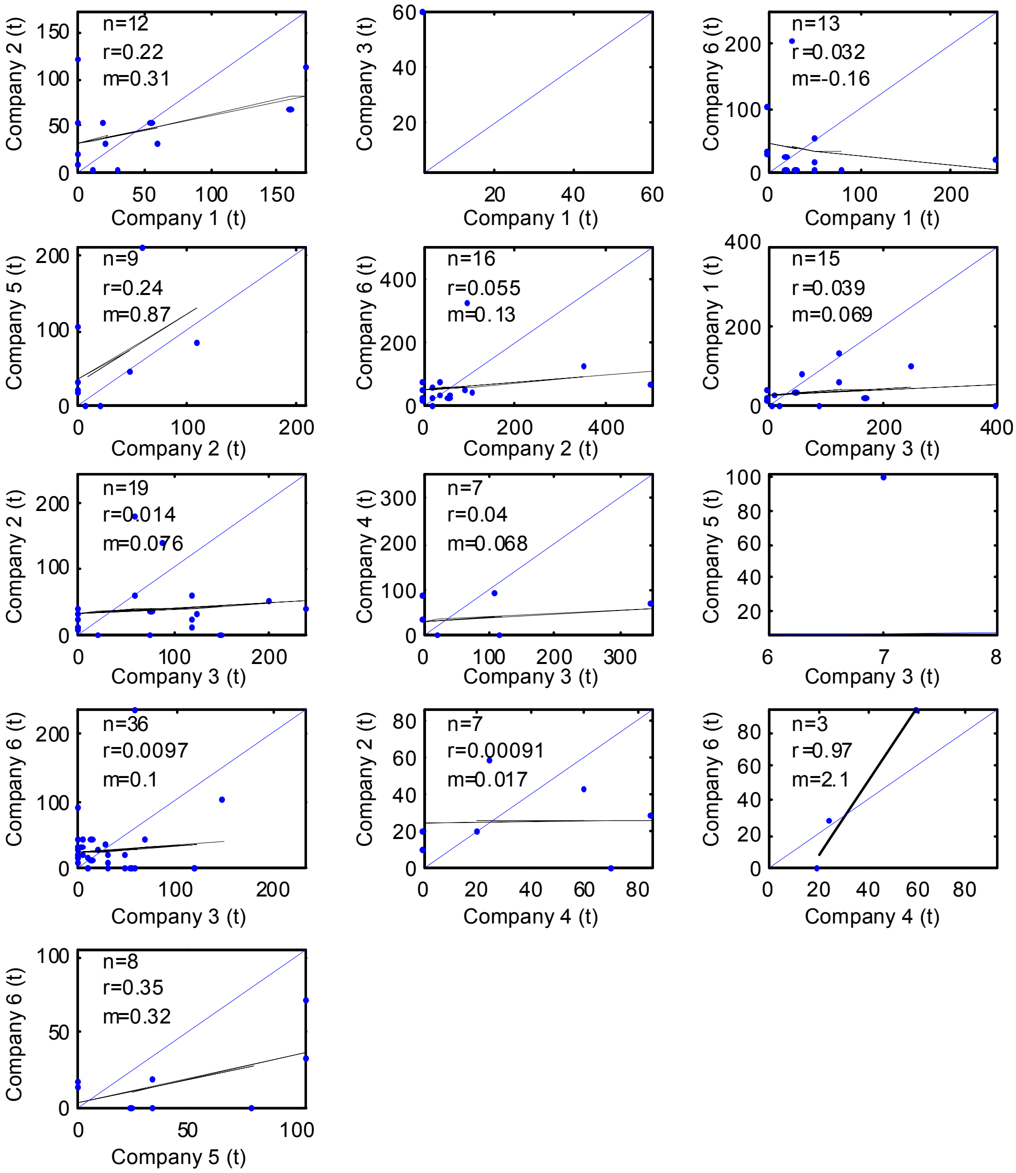


Figure 15. Comparison of SBT school biomass reported by two different companies. Schools were manually identified in the data. A minimum distance and time interval between sightings were selected for the comparison: (a) ≤1 nautical mile and ≤30 minutes, and (b) ≤2 nautical miles and ≤90 minutes. N = the number of comparisons, r=the correlation coefficient (least squares), m=the slope of the fit. Recall that schools identified by a company very close in space and time were aggregated into a single sighting prior to the analysis.

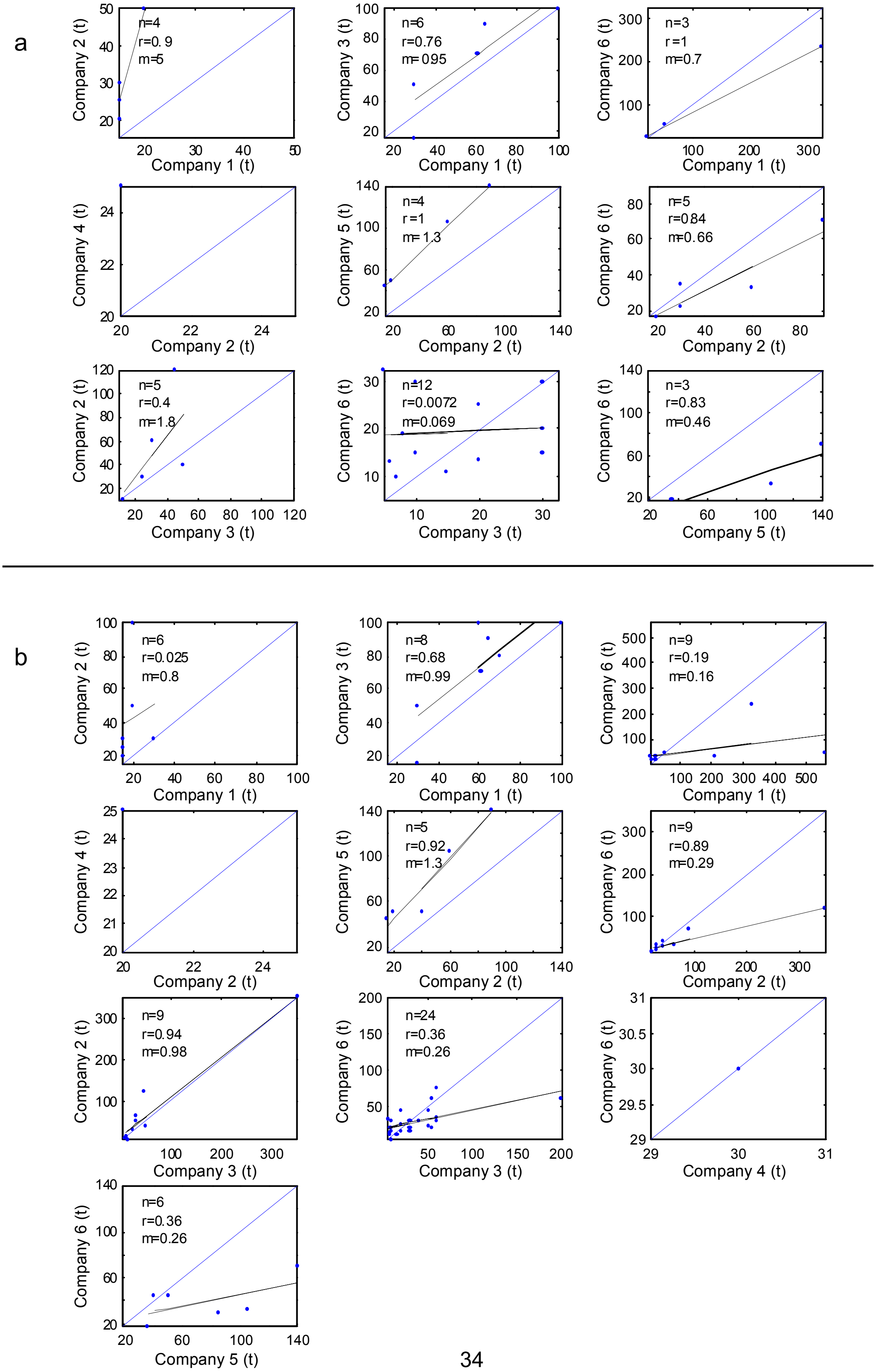


Figure 16. Pairwise analyses of total SBT biomass reported by two different companies within a set radius of 1nm and within a time-limit of 30 minutes.
The centre of the radius is each sighting by the company on the x-axis. Recall that schools identified by a company very close in space and time were aggregated into a single sighting prior to the analysis.

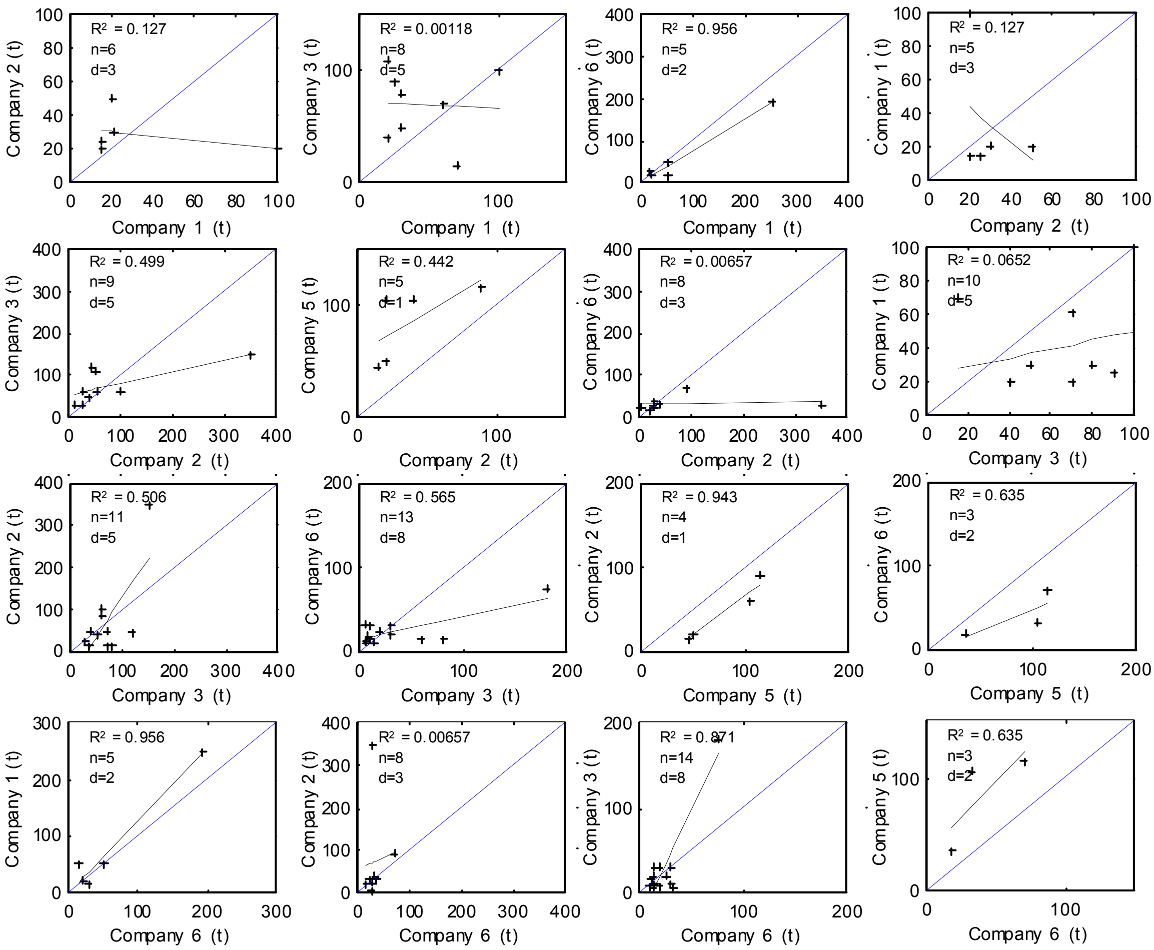


Figure 17. Pair-wise regression analyses comparing SBT biomass of individual SBT sightings reported by company 3 with AFMA ("company 7") log book records.
Sightings included occur within a set radius of 2 nm or 3 nm of the reported catch location and within a time-limit of 15, 30, or 60 minutes prior to the reported time of the catch. N = the number of comparisons, d=the number of dates, r=the correlation coefficient (least squares).