CCSBT-ESC/0409/19

CSIRO
MARINE RESEARCH

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

Jessica Farley
Sophie Bestley
Robert Campbell
Klaas Hartman

Prepared for the CCSBT 5th Meeting of the Stock Assessment Group (SAG5) and the 9th Meeting of the Scientific Committee (SC9)
6-11 and 13-16 September 2004, Seogwipo KAL Hotel in Jeju, Korea

TABLE OF CONTENTS

FIGURES AND TABLES

1. Abstract

An aerial survey for juvenile southern bluefin tuna (SBT) in the Great Australian Bight (GAB) is one of the main projects in the Recruitment Monitoring Program. Between 1993 and 2000, a fishery-independent aerial survey was conducted based on line-transects using dedicated tuna spotters and aircraft, and the data formed the basis of a juvenile SBT index of abundance. This survey was suspended in 2000-1 to allow analysis of existing data, and review its effectiveness. Between 2002-2004, an alternate aerial survey approach was conducted to examine the feasibility of using experienced commercial spotters to collect data on SBT sightings in the GAB. This new aerial survey comprised two parts: (1) a 'commercial' spotting component based on SBT sighted per unit of searching effort (a SAPUE index), and (2) a reduced ad-hoc line-transect component based on the 2000 scientific aerial survey design (Cowling, 2000).

The commercial spotting component of the survey required industry aerial spotters to record SBT schools sighted whilst engaged in commercial fishing activities. A total of 1271 hours of search effort (166,315 nautical miles) was logged over the three survey seasons (2002-2004), and 2185 SBT sightings were recorded. The reduced transect survey relied on the volunteer participation of commercial spotters and planes when not required by their respective fishing companies. Unfortunately, constraints on the availability of these spotters during suitable weather made it difficult to conduct this component of the survey. Although 12 transect-lines were to be surveyed each season (6 lines twice), this was only achieved in the first season when 17.6 lines were completed. In 2003 and 2004, only 4.2 and 11.1 lines were surveyed respectively.

This report describes the methods used to estimate nominal and standardised estimates of surface abundance per unit effort (SAPUE) based on the commercial spotting data. We also present results of the reduced aerial survey analysis including the ability of a reduced transect design to give the same indices as the full transect design (1993-2000), and examine the relationship between the full aerial survey index and stock assessment indices.

2. Introduction

A fishery-independent annual aerial survey based on line-transects was conducted in the GAB between 1991 and 2000 (Cowling et al., 2002) 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 experienced commercial tuna spotters to collect data on SBT sightings in the GAB. Similar surveys have been conducted on other pelagic species such as northern anchovy (*Engraulis mordx*), Pacific sardine (*Sardinops sagax*), jack mackerel (*Trachurus symmetricus*), chub mackerel (*Scomber japonicus*) and bluefin tuna (*Thunnus thynnus*) using commercial spotting data (Lo et al., 1993; Squire, 1993). Klaer et al. (2002) calculated several annual indices of SBT abundance using historic spotting data collected intermittently in the GAB between 1982 and 2000. They found several technical difficulties in interpreting the data and concluded that historical data are not likely to produce useful indices of abundance.

The new SBT aerial survey consisted 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 line-transect component of the survey was conducted ad-hoc when the commercial fishery did not require aircraft and spotters, and the lines that lay closest to the fishing area were surveyed.

The 2002 survey (Farley and Bestley, 2002) confirmed that industry tuna spotters can collect large quantities of inexpensive information about the relative abundance of SBT. The installation and operation of data acquisition systems onboard 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 most flights. Problems identified in the 2002 were corrected in the following surveys.

This report summarises the data collected 2002-2004 fishing seasons, and provides comparisons of estimated indices of juvenile abundance (SAPUE) between seasons, including standardised SAPUE indices. Analysis of the line-transect component of the surveys is also given, including comparisons to SAPUE estimates.

3. Methods

3.1 Commercial spotting survey

The commercial spotting component of the survey required experienced aerial spotters to record SBT schools sighted in the eastern GAB whilst engaged in commercial fishing activities. These sightings were used to calculate indices of juvenile SBT abundance based on search effort. There were no restrictions on the environmental conditions that commercial spotting operations occurred in during the surveys, although spotting operations rarely occurred when wind speeds were >10-15 knots.

Data acquisition systems

A data acquisition system (DAS) was provided to each aircraft participating in the survey. The DAS consisted of a GPS with track plotting and waypoint recording facilities and a laptop computer. If the aircraft already had a suitable GPS or laptop, only the equipment required was provided. A logbook and a simple set of data collection protocols were developed and provided to each participating spotter/pilot team. Each team was trained in the use of the DAS and how to collect reliable data.

The spotter/pilot teams were instructed to run the DAS throughout each flight to record flight paths. Aircraft positions and altitude were logged every 15 seconds. For each flight, the spotter/pilot were asked to record the start and end of each search period during the day and the location of all SBT sightings using the DAS. The waypoint number generated by the DAS was transferred to the logbook where the event details were recorded.

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. Spotters were also asked to record the type of search effort (intensive, broad scale or assisting boats) undertaken during the flight, and to record any school that may have been previously recorded during the day (to eliminate double counting of schools). In the 2002 and 2003 seasons, spotters were asked to record the target species of each flight, since two fishing companies target skipjack as well as SBT.

Environmental variables were 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, the mean value was used in analysis.

Surface abundance per unit effort (SAPUE)

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.

Nominal indices of juvenile SBT abundance (surface abundance per unit effort – SAPUE) 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 (μ^W) 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 nominal SAPUE indices were calculated for each fishing season; 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 (nautical miles) and time (minutes) as a measure of effort. Only unweighted indices were calculated for indices using 0.1° squares. Indices were calculated for the whole survey area and for a core area of greater fishing activity based on effort (131-133ºE, 32.7-34ºS). Selecting a core area improves estimates of SAPUE by removing areas where skipjack are targeted (generally to the west of the core area) and areas of "broad search effort" surrounding the commercial fishing area.

SAPUE indices were compared to indices calculated by Klaer et al. (2002) based on historic spotting data collected between 1982 and 2000. This historic data consisted of hand drawn maps of flight paths (digitised and geo-referenced) and records of school sightings. The methods to estimate the indices in Klaer et al. (2002) are the same as those used in the current study. Indices compared were the biomass sighted per nautical mile flown (weighted and unweighted) for the whole area and a new core area used in Klaer et al (2002): 131-133ºE, 323-34ºS.

Standardisation of SAPUE

Preliminary methods to standardise the SAPUE data are given in Appendix A.

3.2 Reduced line-transect survey

The reduced line-transect survey required spotters as they became available during the season, to search along 6 transect-lines that lay closest to the fishing area at least twice during the fishing season. The area searched lies between 130 and 134ºE (lines 6-13), running out from the coast to just off the continental shelf (Fig. 1). The reduced line-transect component of the survey followed the protocols used in the 2000 survey regarding plane height (1200-1800 ft), plane speed (120 knots), environmental conditions (>5 nm visibility, <10 knots wind and <1/3 cloud), and time of day the survey was conducted (11am until dusk).

As described above, 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. All schools within 7 nm from the transect line are recorded, along with environmental variables. The same data acquisition systems and logbooks were used as described for the commercial spotting survey.

Analysis of data

The line-transect data obtained in the current survey covers a reduced region in both space and time compared to the original aerial survey (1993 - 2000) the line-transect data provided by the current survey covers a reduced region in both space and time. As SBT abundance varies spatially and temporally within the survey area, simply comparing the abundance index from the original survey with that obtained using the current data is inappropriate. Differences between the original index and a new index may be attributable to a bias in effort to high or low SBT abundance areas (in the current survey) and not to an actual shift in SBT abundance.

To overcome this problem the original index must to be adjusted to what it would have been if the original survey had been conducted in the same area and time as the current survey. The simple approach taken in this report was to select the set of transect lines from each year of the original survey most similar to those flown in a current year of the survey. The index is then recalculated (see Bravington 2003) using just these lines and is comparable across the survey methods. Within the current survey, effort also varied from year to year, consequently the analysis needs to be performed on each year separately (as the individual years from the current survey are not directly comparable).

The major shortcoming of this method is that it reduces the historical data set significantly and therefore introduces greater uncertainty about the historical value of the index. A better method would use all the available data for each year to produce an index and then to adjust this to what it would have been in the area and at the time when the new aerial survey was conducted. This is beyond the scope of this report and it should also be noted that this would not improve the abundance index calculated from the current aerial survey.

An additional major problem with the current aerial survey is that there is only one spotter per plane and the original aerial survey used two spotters per plane. Without conducting some calibration experiments, it is not possible to determine the effect this had on sightings. Presumably a single spotter will be somewhere between 50% and 100% as efficient as two spotters will historically have been, the index for the current survey will therefore be this much lower relative to the original index. Only two of the spotters used in the current survey were used throughout the original survey so differences between spotters can also not be corrected for.

4. Results and discussion

4.1 Commercial aerial survey

Data were collected for 306 commercial spotting flights over the three survey seasons. Industry support for this component of the survey was good, although the number of planes that contributed decreased from 6 in 2002, to 5 in 2003 and only 4 in 2003. Fortunately, the four planes that participated in all three surveys were those that recorded the highest search effort in each season (>95%) (Table 1).

Environmental conditions

Data on environmental variables were collected for 296 commercial flights over the three seasons. The majority of these flights (78%) were conducted when the average wind speed for the flight was ≤ 10 knots - the limit set for the line-transect surveys.

Kruskal-Wallis tests showed significant differences in swell height and air temperature between seasons ($p<0.001$), and for wind speed at the 10% significance level ($p=0.063$). Overall, the 2003 season appeared more suitable for sighting SBT at the surface (lower swell height, wind speed and cloud cover, and higher air temperature and spotting conditions) than the other two seasons (Fig. 2). Note that data is only available for the days that flights occurred on; nothing is known about the conditions on the other days. The number of swell/wind free days in sequence may be an important factor.

Search effort

A total of 1271 search hours were logged (covering 166,315 nautical miles) during the three survey periods. Approximately 991 hours (88,245 nm) were flown in the core fishing area. Almost all search effort was recorded between December and March (97%; Table 2) and between about 128-135ºE (Fig. 3). The core area of high search intensity can also be seen clearly in Figure 3.

The number of flights, distance and area searched increased consecutively over these three seasons (Table 3). This increase in effort is predominantly due to better data collection in the latter seasons rather than a dramatic increase in the effort required to catch the SBT quota for the season. Unfortunately, there are some difficulties in interpreting the search data collected. Although spotters were required to record the type of search effort (intensive, broad scale or assisting boats) undertaken during each flight, analysis of the data shows that there are inconsistencies between spotters in categorising their search effort. Therefore, we assumed all search effort to be equivalent.

In the 2002 and 2003 seasons, the majority of flights were to search for SBT (n=165). However, 22 flights were to search for SBT and skipjack and another 30 flights to search for skipjack alone. SBT sighted during all flights were recorded. Examination of the 30 ‘skipjack flights’ revealed that if search effort occurred within the core fishing area, SBT was the predominant species sighted. In fact, only one skipjack school was recorded within the core area during ‘skipjack flights’, with the majority of schools being sighted to the west (n=41) or north (n=3) of the core. This suggests that by restricting the SAPUE analysis to the core area, we remove the majority of search effort targeting skipjack.

SBT sighted

SBT were sighted on 247 of the 306 flights logged over the three seasons. A total of 2185 sightings (3616 individual schools) were recorded with a total estimated biomass[1] of 117,167 tonnes. Figure 4 shows the locations of all SBT sightings made in the commercial surveys.

SBT were recorded as individual schools (83% of sightings) or as “clusters” of up to 30 schools (n=1). The relative proportion of small schools (<20 t) sighted increased consecutively over the three seasons, although the overall distributions of school size were similar between seasons (Fig. 5). Between 80 and 92% of schools sighted were ≤40 t in size in all three seasons. Mean school size was greatest in 2002 (Fig 5). The proportion of small fish (<15 kg) sighted decreased over the three seasons although the overall distributions of fish size were similar between seasons (Fig. 6). Between 63 and 78% of fish sighted were between 15-25 kg. Fish size tended to increase with school size in all three seasons (Fig. 7)

Although the total search effort increased consecutively over these three seasons, while the total biomass[1] of SBT sighted decreased. The percent of 0.1º squares searched with SBT sighted also decreased, while the proportion of flights with no SBT sighted increased (Table 3).

Nominal SAPUE

The six nominal SAPUE indices calculated by season for the total and core fishing areas are shown in Figure 8. Detailed results of all these indices including standard deviations and confidence intervals are given in Appendix B. The data shows a decreasing trend in nominal indices of abundance over the three survey seasons

Not surprisingly, the area of highest SAPUE was in the vicinity of the core fishing area (Fig. 9). We examined one of the SAPUE indices (biomass sighted per nautical mile flown) for the core area to determine if a similar pattern in SAPUE occurred for the four spotters that participated in all survey seasons. We limited the data to the main fishing season (December to March) and removed two flights with very high SAPUE (18.2 and 13.9). The results also show a decline in SAPUE for all spotters except one spotter who’s SAPUE increased between the 2002 and 2003 seasons (Fig. 10a). When the flights where no SBT were sighted were removed from the analysis, the same pattern in SAPUE exists (Fig. 10b).

There are many factors that can influence the sightings of SBT during the day, such as environmental variables. The commercial spotting data indicates that the probability of sighting SBT at the surface (nominal SAPUE) decreases with an increase in wind speed, swell height, and cloud cover, and increases with increasing air temperature and spotting conditions (Fig. 11). This is similar to the findings of Cowling et al. (2002).

Indices of juvenile abundance calculated in the current study are similar to estimates based on historical spotting data for 1999 and 2000 (Klaer et al., 2002), but are higher than for the previous years (Fig. 12). Klaer at al. (2002), however, identified a number of deficiencies and compounding factors in the analysis of the historical data that could not be resolved, making any comparison with the current study misleading. They found that the absolute estimates and trends were dependant on data treatment and the stratification scheme used, and that the indices were generally imprecise. The historic indices were based on distance flown from hand drawn maps of flight paths, which, in most cases, gave an underestimate of the distance flown based on the flight times provided. This underestimation of was probably due to the omission of most of the fine scale movements (concentrated circling around schools and fishing boats) by the spotter, which would lead to an overestimation of SAPUE. On the other hand, it is likely that the spotters only recorded SBT schools important to the fishing company, while all schools sighted are recorded in the current study. This would produce an underestimated SAPUE index.

SAPUE values may not provide good indices of juvenile abundance in the GAB because very little search effort occurs outside the core fishing area, and the survey is not systematic in its approach (random or uniform searches). It is also possible that the purse seine fleet may act like a large FAD (fish aggregating device). If this were the case, fishers (and spotters) may be able to maintain catch (and sightings) rates, even if substantial declines were occurring in other areas. Consideration could be given in the future to the use of spatially explicit models.

The measure of search effort used in the analysis may also be unreliable. Spotters work closely with the fishing fleet locating and often directing the setting of the purse seines. Although spotters are still looking for SBT schools during these times, they are generally restricted to the area around their vessels. The search effort logged during these times is not equivalent to broad scale search effort in the surrounding areas.

Standardised SAPUE

Preliminary results of SAPUE standardisation are given in Appendix A.

4.2 Reduced line-transect aerial survey

Constraints on the availability of commercial spotters and planes during suitable weather made it difficult to conduct the reduce line-transect component of the survey. Planes and spotters were only made available to the survey when not required by their respective fishing companies, which generally occurred in the latter part of the fishing season. The objective of the survey was to search 6 transect-lines twice (12 total) each season. However, this was only achieved in the first season when 17.6 lines were completed. In 2003 and 2004, only 4.2 and 11.1 lines were surveyed respectively (Table 4) (in some cases only part of a transect line was completed, hence the fractions in the number of lines completed). Almost no search effort (3%) was recorded in January in the current survey, while 30% was recorded in this month in the 1993-2000 surveys (Fig 13). The full historical time series of the SBT abundance index and those corresponding to the areas that were surveyed in 2002, 2003 and 2004 are shown in Figure 14. The difference between these indices show the level of uncertainty that is introduced by reducing the spatial and temporal coverage to that obtained in the current survey. The CVs were 49%, 152% and 78% for the time series corresponding to the areas surveyed in 2002, 2003 and 2004 (compared with an achievable CV of 30% for the full index). Additionally, the index for 2002 - 2004 may be underestimated by as much as 50% as only a single spotter was used in these years, and two spotters were used previous scientific aerial survey.

The high CV associated with the 2003 time series is a result of the limited data available for that year; less than 6 hours of transects were flown in 2003. Preliminary investigations indicate March to be the worst month for conducting an aerial survey due to a number of factors. This explains the high CV of 2004 in comparison to 2002 (similar effort was applied in both years) as 70% of the effort in 2004 occurred during March and only 40% in 2004.

Preliminary investigations indicate that the CV for the index corresponding to the 2002 spatial and temporal coverage (49%) is comparable to that achieved from the 1993-2000 survey for a single month (January or February). This is unsurprising as a similar number of lines were flown and these were spread throughout the whole season. This CV estimate however does not take into account the single spotter effect for the 2002 data, which will change things considerably.

5. Conclusions

1. Commercial tuna spotters can inexpensively collect large quantities of fishery-dependent data about the sightings of SBT schools in the GAB.
2. Nominal SAPUE indices show a decline in juvenile abundance over the three survey seasons. Caution must be adopted when interpreting trends in SAPUE because only a small area of the eastern GAB is searched and there is no systematic survey approach. No information is obtained on the abundance of SBT in the areas not searched by spotters.
3. The SAPUE indices calculated in the current study cannot be compared to the indices based on historic spotting data (Klaer et al., 2002) because of inconsistencies in the historic data (search effort and biomass sighted are most likely to have been underestimated).
4. Constraints on the availability of commercial spotters and planes during suitable weather make it difficult to conduct a reduce line-transect survey in the GAB. 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.
5. It is apparent that a reduced ad-hoc line-transect survey will not provide a reliable estimate of abundance, due in part to high variability in estimates resulting from reduced and variable effort (CV ~45-152%), and in part because of the most likely timing of transects .
6. The index for 2002-2004 based on the reduced line-transect survey may be underestimated by as much as 50% as only a single spotter was used in these years, and the original aerial survey used two spotters per plane. Without conducting some calibration experiments, it is not possible to determine the effect this had on sightings.

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 Michael Bell, Barry Brady, Ben Cool, David Franklin, Phillip Gibson, Derek Hayman, Brett Leech, Lyell Jaensch, Andrew Jakob, Mile Mislov, Mark Nichols, Peter (Mozzie) Stevens, Shane Thompson, Tony Warren and Kiwi White. We also thank David Blacker , Joe Gobin, Justin Nelligan, Robin Pike, David Puglisi, Joseph Puglisi, Marcus Stehr, Darren Tressider, and Leith Whittaker for their support of the project. The assistance given to us by staff at Australian Fishing Enterprises, Ajka, Blaslov

Fishing Company, DI Fishing, 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, Di Stanton and Katherine Tattersall for endless data entry work. We are also grateful for statistical help, manuscript reviews and advice by Mark Bravington, Marinelle Basson, John Gunn, Tom Polacheck and Alistair Hobday. This study was funded by JAMARC, AFMA, Australian Industry, and CSIRO Marine Research as part of the Japanese/Australia SBT Recruitment monitoring Program.

7. References

Bravington, M. 2003. Further considerations on the analysis and design of aerial surveys for juvenile SBT in the Great Australian Bight. RMWS/02/03.

Cowling, A. 2000. Data analysis of the aerial surveys (1993-2000) for juvenile southern bluefin tuna in the Great Australian Bight. RMWS/00/03.

Cowling A., Hobday, A. and Gunn, J. 2002. Development of a fishery independent index of abundance for juvenile southern bluefin tuna and improvment of the index through integration of environmental, archival tag and aerial survey data. FRDC Final Report 96/111 and 99/105.

Davis, T. L. O. and Stanley, C. A. 2002. Vertical and horizontal movments of southern bluefin tuna (*Thunnus maccoyii*) in the Great Australian Bight observed with ultrasonic telemetry. *Fishery Bulletin* 100, 448-465.

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

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

Lo, N.C., Jackson, L.D. and Squire, J.L. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat. Sci. 49:2515-2526.

Squire, J.L. (Jr.) 1993. Relative abundance of pelagic resources utilized by the California purse-seine fishery: Results of an airborne monitoring program, 1962-90. US Fish. Bull. 93:348-361.

Table 1. Relative contribution (%) of spotter to the total search effort (nautical miles) by commercial aerial survey season.

Spotter	Survey season 2002	2003	2004
1	0	1.1	0
2	5.2	4.3	0
3	6.1	9.9	13.0
5	10.9	34.7	19.3
4	12.8	27.7	22.7
6	65.0	22.3	45.0

Table 2. Search effort and SBT sightings data collected by month during the (a) 2002, (b) 2003 and (c) 2004 commercial aerial survey seasons.

(a)

Month	Planes (n)	Flights (n)	Distance searched (nm)	Time searched (hrs)	Sightings (n)	Schools (n)	Biomass[1] (t)
Dec 01	3	26	14391	102.3	298	613	21291
Jan 02	4	25	9726	74.7	154	295	10119
Feb 02	5	22	11350	87.2	150	199	9141
Mar 02	1	11	7744	54.8	68	76	4075
Apr 02	1	2	956	6.2	0	0	0
Total		86	44167	325.2	670	1183	44626

(b)

Month	Planes (n)	Flights (n)	Distance searched (nm)	Time searched (hrs)	Sightings (n)	Schools (n)	Biomass[1] (t)
Nov 02	2	8	3812	26.3	6	11	125
Dec 02	2	20	11762	91.9	106	199	5171
Jan 03	5	40	21684	169.7	366	611	19550
Feb 03	6	19	8943	69.6	154	295	9714
Mar 03	3	15	9276	67.8	103	185	4000
Total		102	55477	425.2	735	1301	38559

(c)

Month	Planes (n)	Flights (n)	Distance searched (nm)	Time searched (hrs)	Sightings (n)	Schools (n)	Biomass[1] (t)
Nov 03	2	3	988	7.1	1	1	11
Dec 03	2	21	9314	73.0	75	125	5108
Jan 04	4	32	17164	136.3	151	254	8281
Feb 04	4	40	24104	191.4	400	563	14219
Mar 04	3	22	15082	113.0	153	190	6363
Total		118	66651	520.8	780	1133	33982

[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).

Table 3. Search effort and SBT sighted during the commercial aerial surveys. SAPUE = surface abundance per unit effort. nm = nautical miles.

Year	2002	2003	2004
No. flights	86	102	118
Total distance searched (nm)	44167	55477	66651
Total distance searched in core (nm)	32565	39052	55647
Total time searched (hrs)	325	425	521
No. 0.1° squares searched	854	947	775
No. 0.1° squares with SBT	170	151	109
% 0.1° squares with SBT	20	16	14
No. sightings	670	735	780
% flights with no SBT sighted	16	18	23
No. schools	1182	1301	1133
Mean school size (tonnes)	37.8	29.6	29.9
Total biomass[1] recorded	44626	38559	33982
Total biomass[1] recorded (core)	32112	22942	25414

Table 4. Search effort and SBT sightings in the line-transect survey for 2002-2004.

Survey season	2002	2003	2004
Number of lines searched	17.6	4.2	11.1
Distance searched (nm)	2769.6	647.9	1829.0
No. SBT sightings	37	2	7
No. schools	147	2	18
Biomass sighted	1961.7	80.0	207.5

Figure 1. Location of the commercial and line-transect aerial surveys in the GAB. Lines 6-13 (darker lines) were predominantly surveyed in 2002-2004. The location of the shelf (200m isobath) is shown for geographical reference.

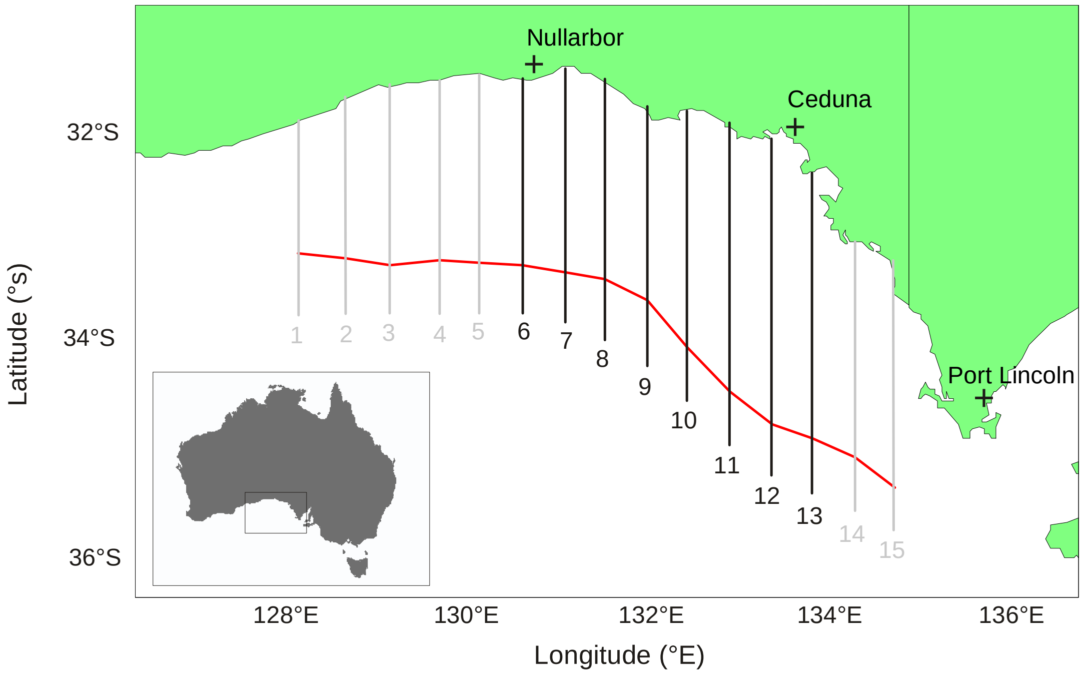


Figure 2. Box-plot of environmental variables recorded by the spotters over three survey seasons. Centre line and outside edge of each box indicate the median and 25th/75th percentile around the median respectively.

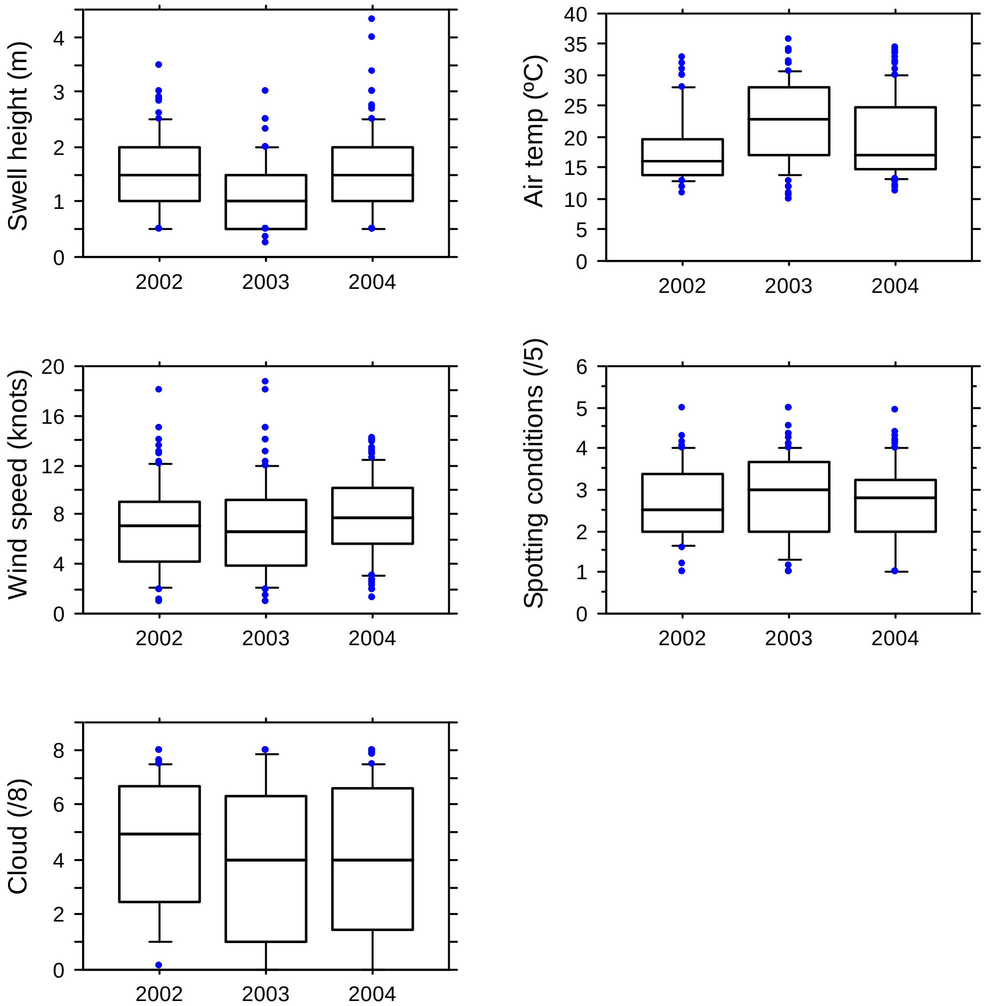


Figure 3. Commercial SBT search effort in the GAB in distance flown (nm) per 0.1° square by season. For direct comparison of location of effort, data are displayed as the percent (%) of total effort for the season. Note the log scale for effort.

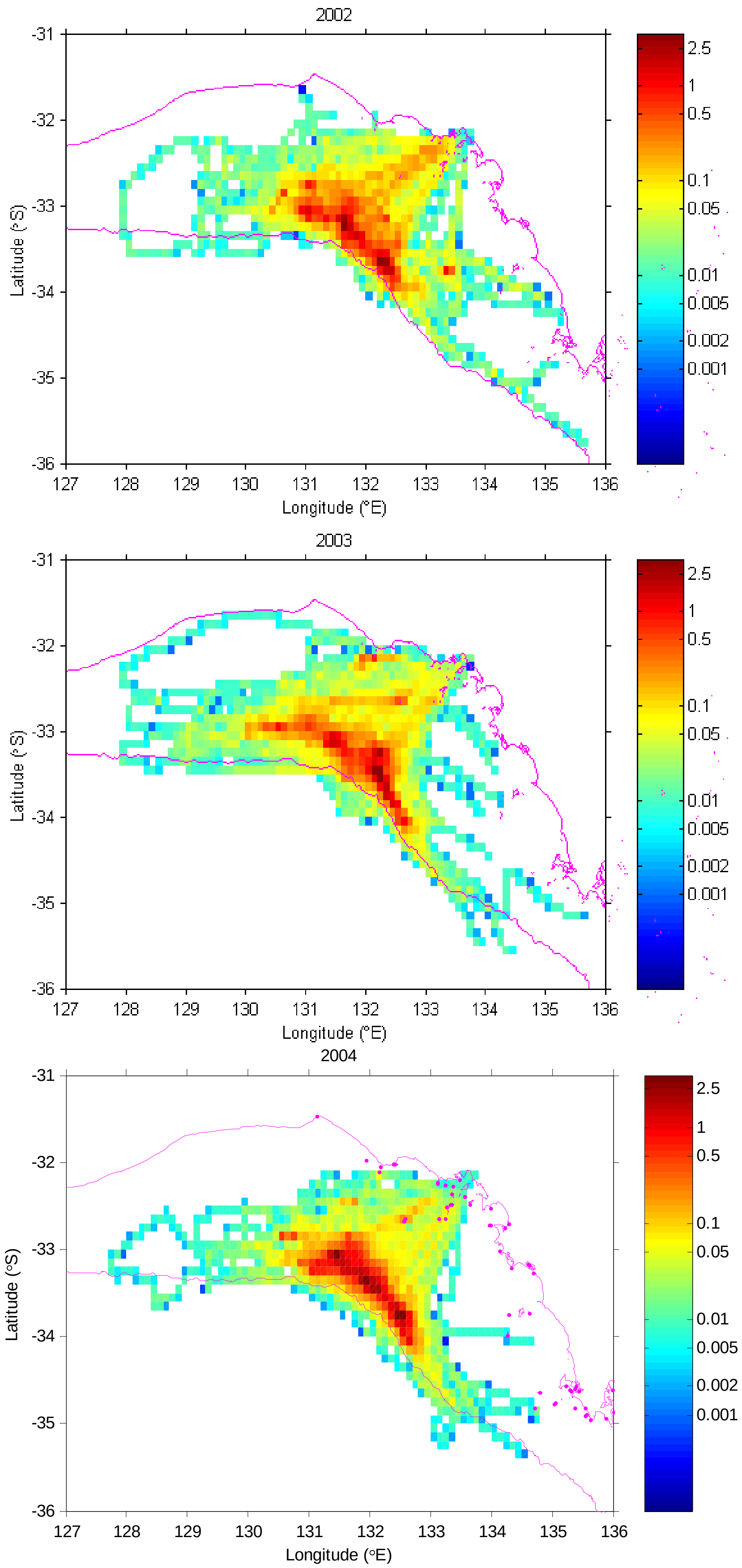


Figure 4. Location of all SBT sightings made during the 2002-2004 commercial aerial survey.

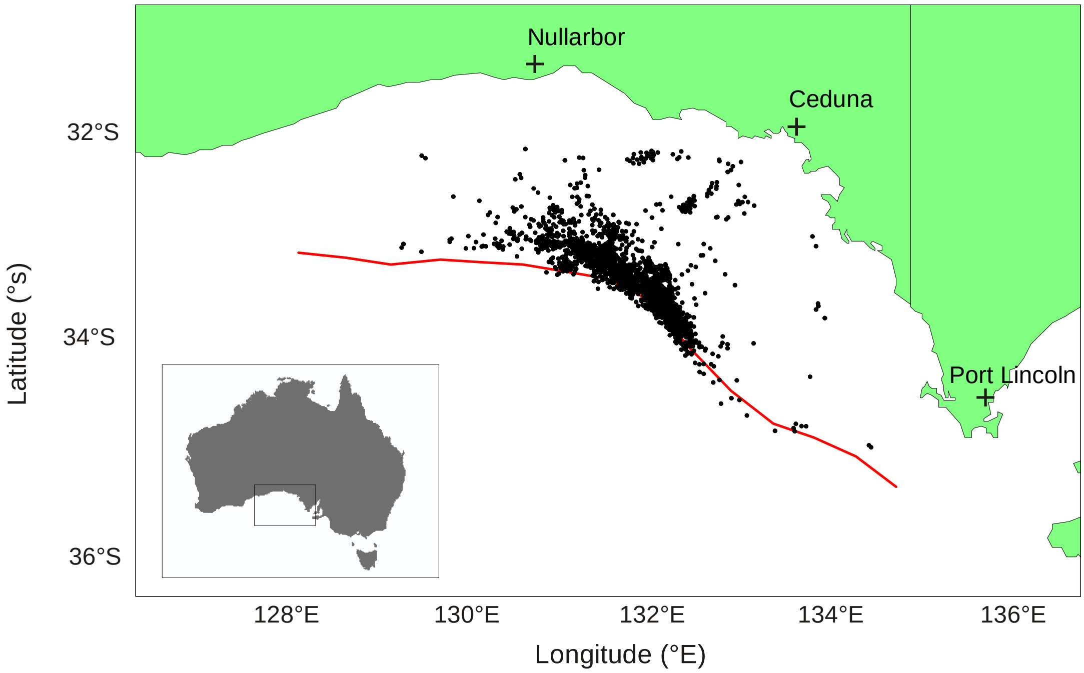


Figure 5. Size frequency of SBT schools sighted during the 2002 - 2004 commercial spotting seasons. Data are weighted by number of schools per sighting. Mean school size is given in brackets.

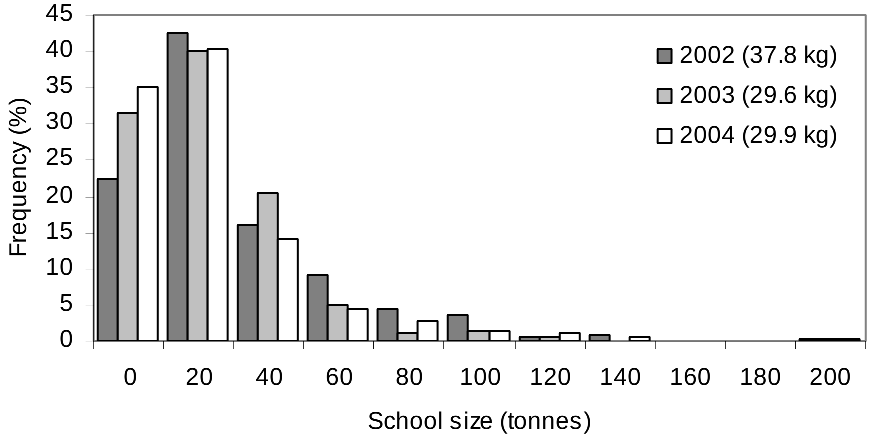


Figure 6. Size frequency of SBT sighted during the 2002 -2004 commercial spotting seasons. Data are weighted by school size.

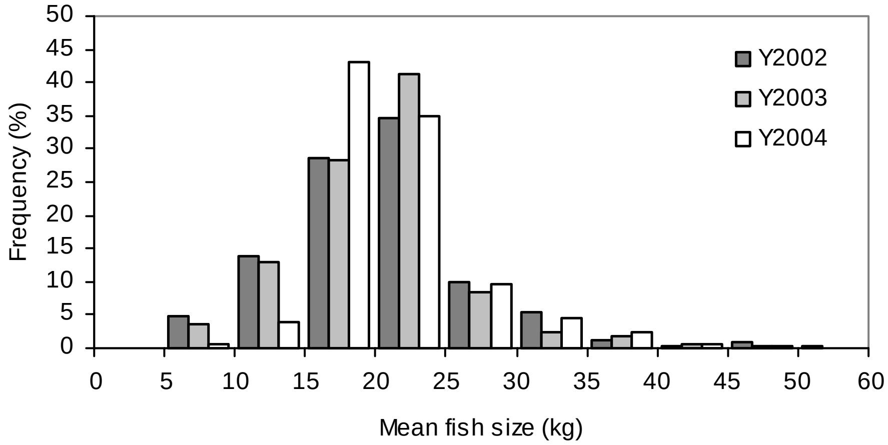


Figure 7. Box-plot of fish size in relationship to school size for the 2002 and 2003 commercial aerial survey seasons. Centre line and outside edge of each box indicate the median and 25th/75th percentile around the median respectively.

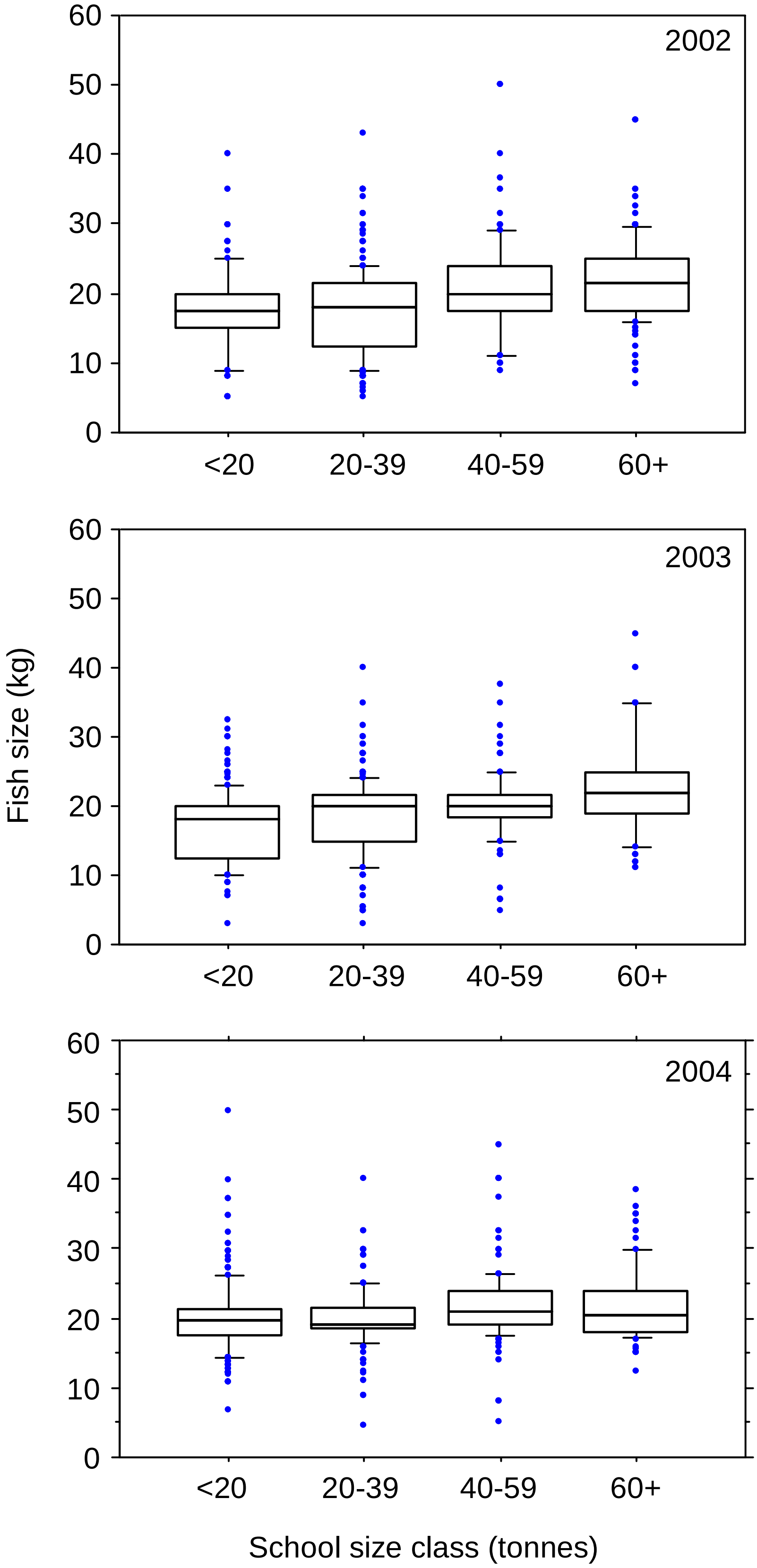


Figure 8. Nominal surface abundance per unit effort (SAPUE) by season. Indices were calculated for two measures of effort (nautical miles and minutes flown), two sampling units (the flight and 0.1° squares) and two regions (total and core area). U = unweighted index, W = weighted index.

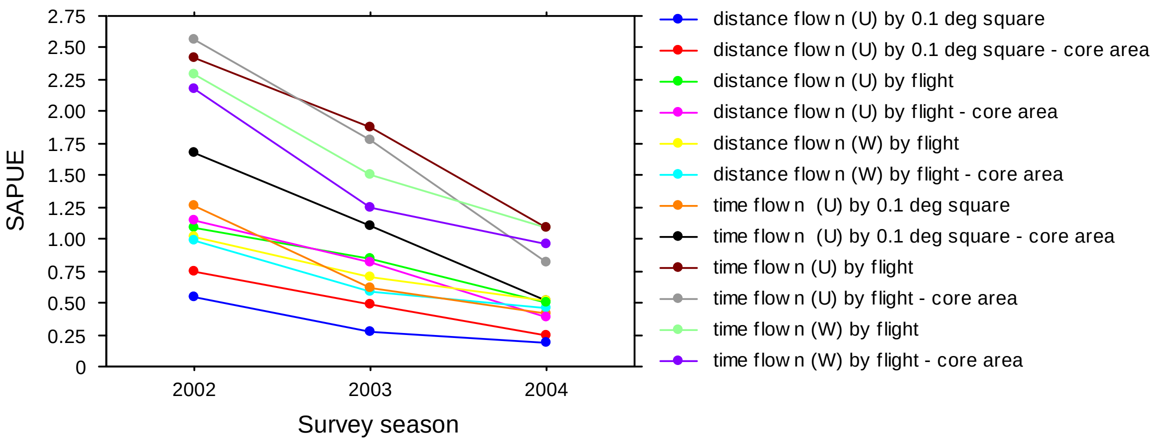


Figure 9. Surface abundance per unit effort (SAPUE) of commercial flights in tonnes SBT per nautical mile per 0.1° square by season. Areas of darkest blue indicate zero SAPUE. Coastline and 200m isobath shown for geographical reference. Note the log scale for SAPUE.

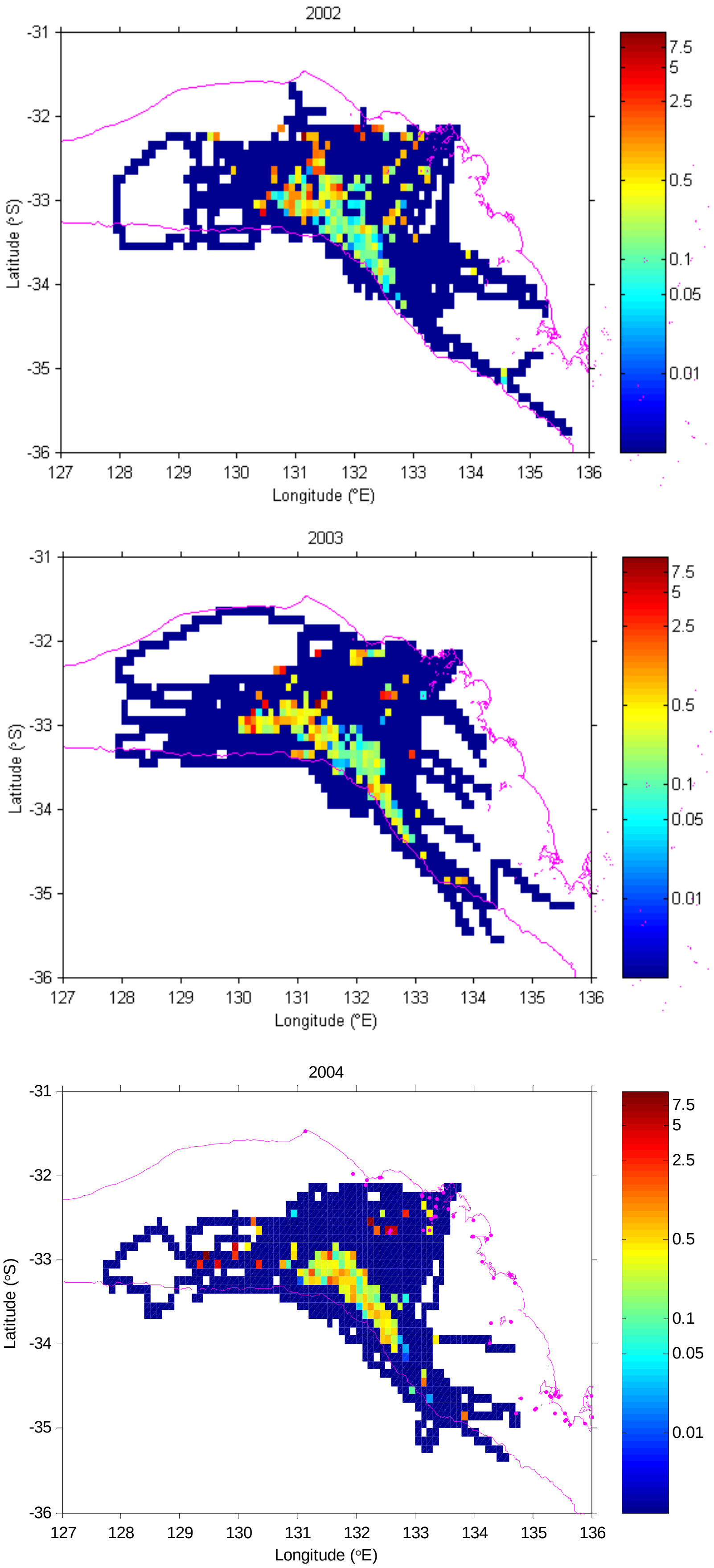


Figure 10. Mean nominal SAPUE in tonnes SBT per nautical mile flown by season and spotter for (a) all flights (n=277) and (b) flights that SBT were sighted on (n=206). Only data for the four spotters (different colours) that participated in all seasons were included. Data from November and April, and from two flights with very high SAPUE estimates were also removed. Standard errors are indicated.

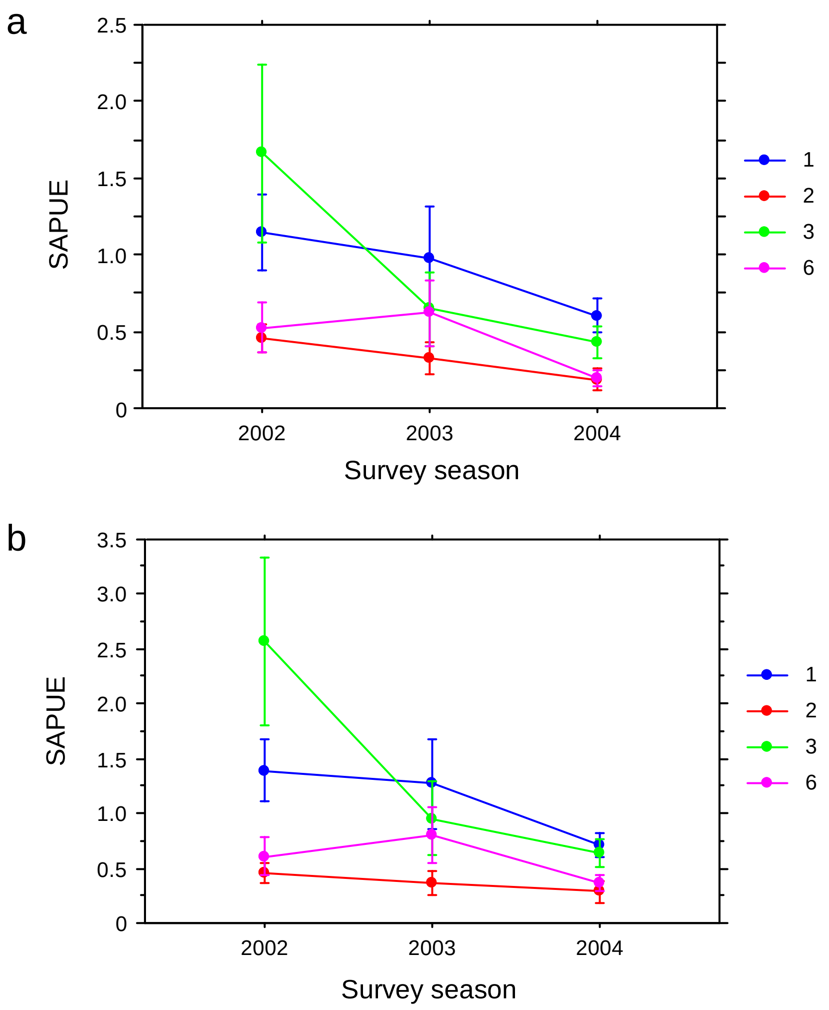


Figure 11. Mean (+/-se) of environmental variables recorded by the spotters in relation to nominal SAPUE (in tonnes SBT per nautical mile flown) for all seasons combined. Cloud cover was assigned 0-8 (no cloud to full cloud cover). Spotting conditions were assigned 0-5 (poor to good).

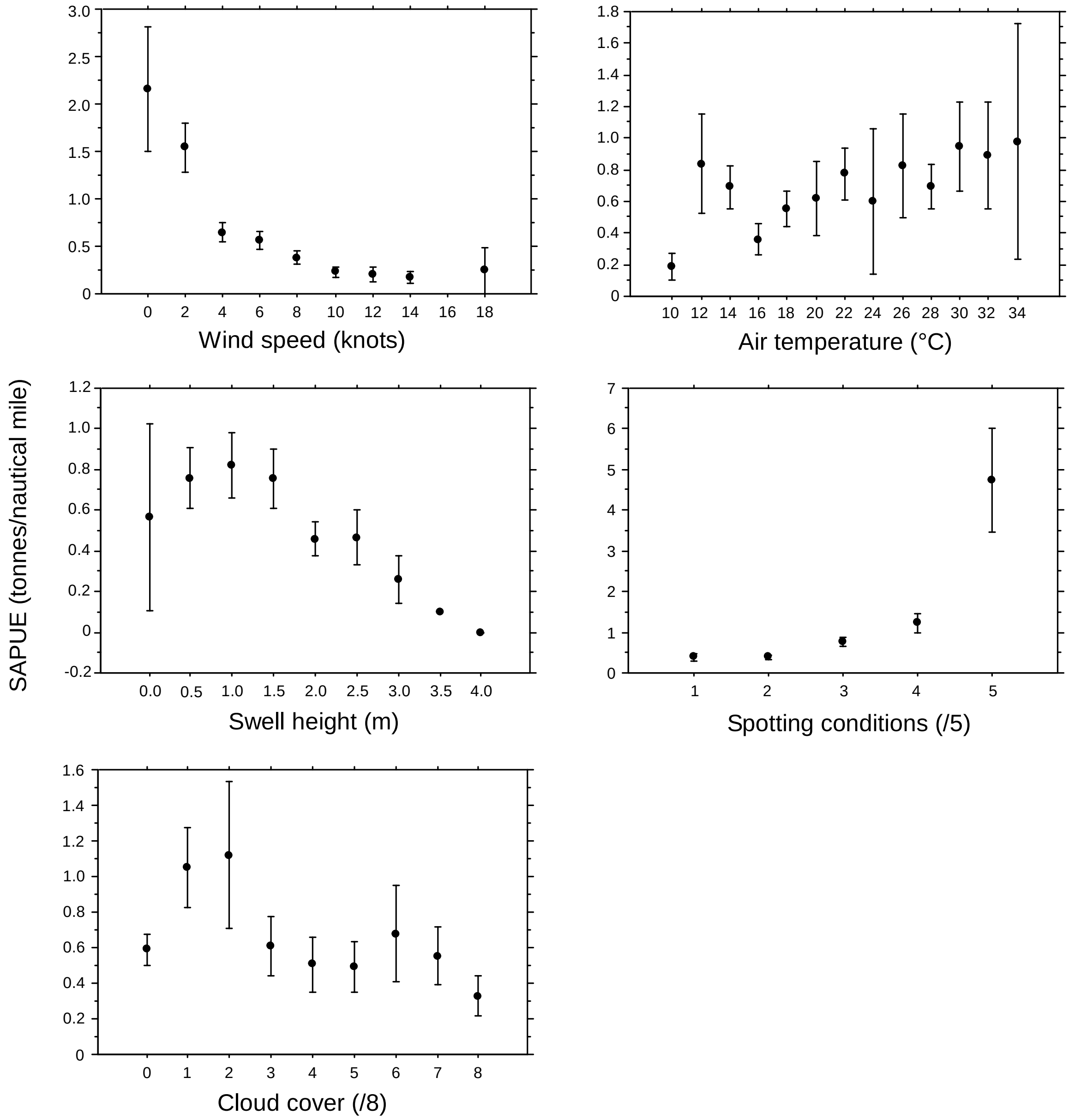


Figure 12. Nominal surface abundance per unit effort (SAPUE) in tonnes SBT per nautical mile flown by season and area. Diamonds are results from Klaer et al. (2002) based on historic spotting data, and squares are results from the current study. U = unweighted index, W = weighted index. 95% confidence intervals are indicated.

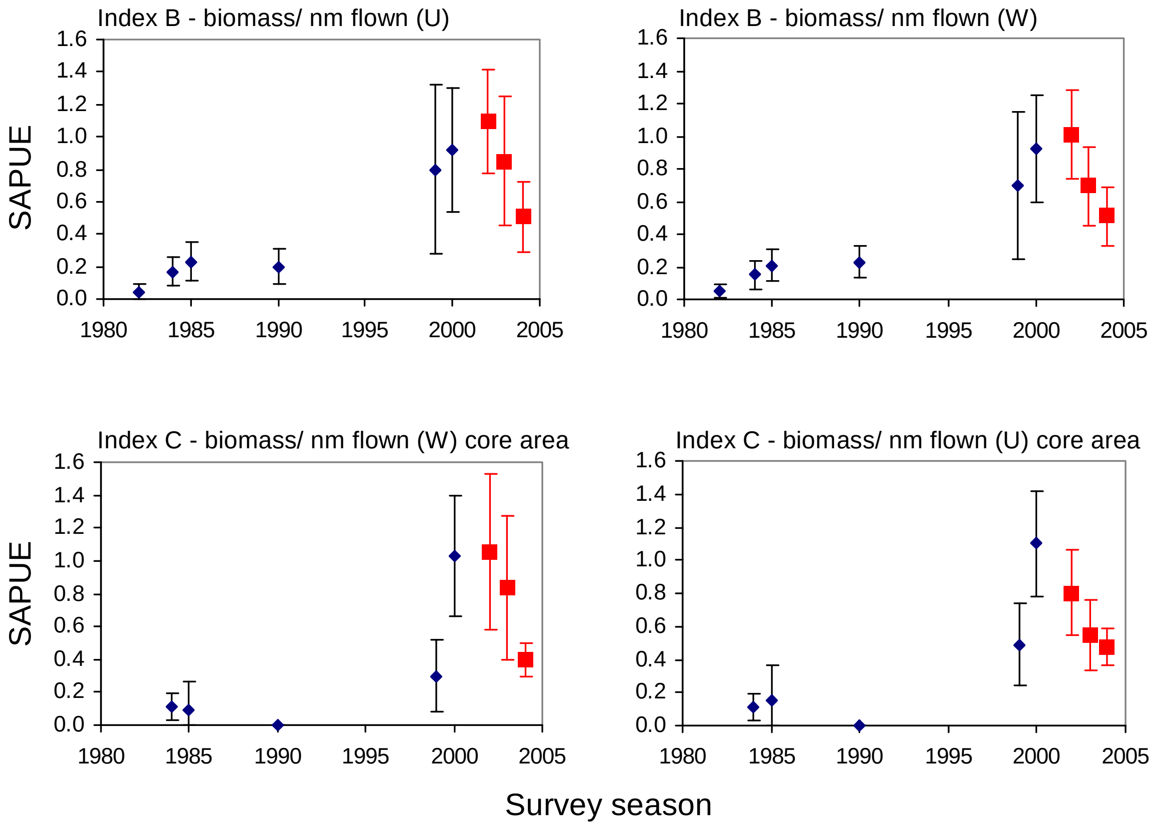


Figure 13. Proportion of total search effort on line-transects by month for the 1993-2000 dedicated aerial survey and the current 2002-2004 reduced aerial survey. A survey was not conducted in 2001.

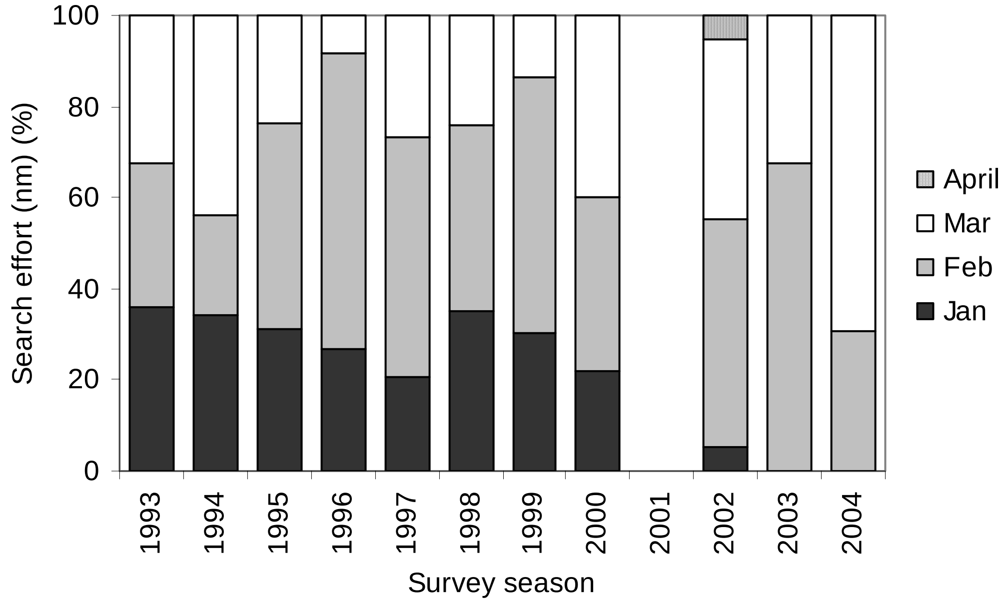
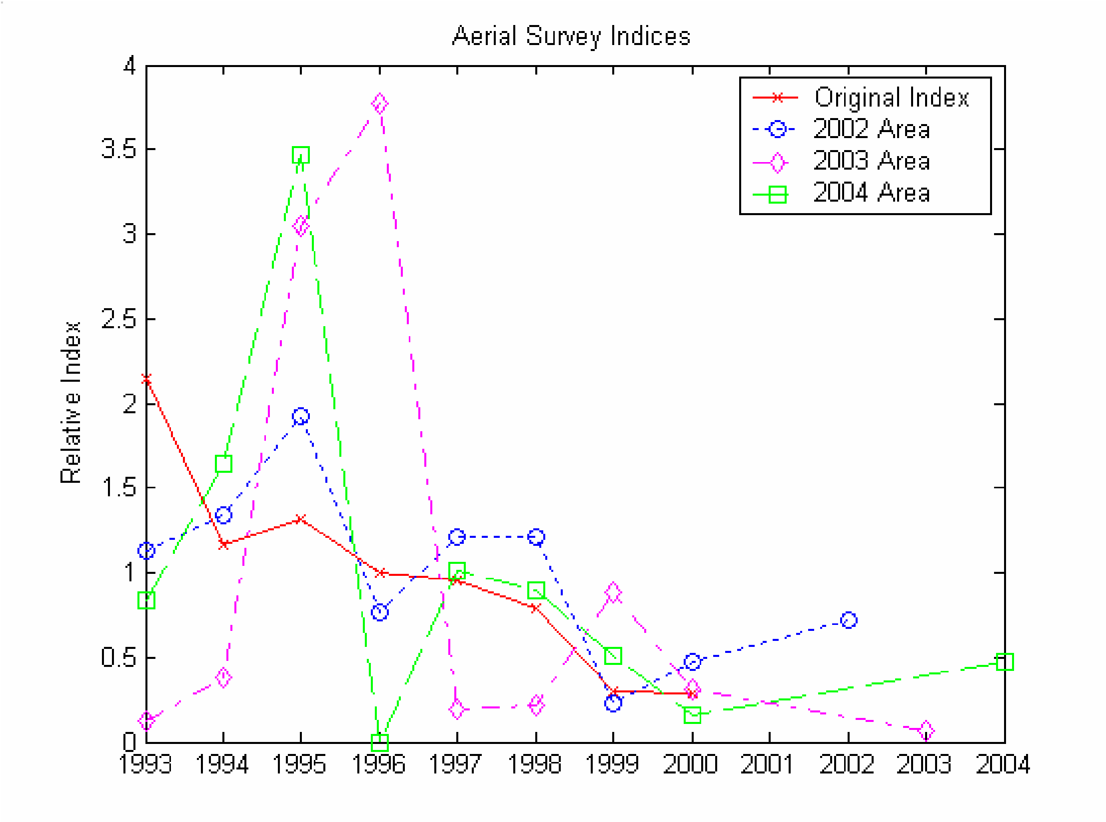


Figure 14. Juvenile SBT abundance indices calculated for the 1993-2000 scientific line-transect survey. Indices are shown for the full survey (all months) and those corresponding to the areas that were surveyed in 2002, 2003 and 2004. Estimates are also shown for the 2002-2004 reduced ad-hoc line-transect survey.



Appendix B

Detailed results of each SAPUE index calculated by fishing season. U is unweighted, W is weighted. Distance is in nautical miles and time is in minutes. 'Core (Klaer) refers to the core area analysed in Klaer et al. (2002) (131-133ºE, 33-34ºS).

2002 fishing season

Abundance Index	Std. Dev.	Conf. Int+/-	Sampling unit	Effort measure	Area analysed
1.09	1.51	0.32	Flight	distance flown (U)	Total
1.01	1.30	0.27	Flight	distance flown (W)	Total
2.42	3.35	0.71	Flight	time flown (U)	Total
2.29	2.96	0.62	Flight	time flown (W)	Total
0.54	2.42	0.16	0.1 deg	distance flown (U)	Total
1.26	5.48	0.37	0.1 deg	time flown (U)	Total
1.15	1.99	0.42	Flight	distance flown (U)	Core area
0.99	1.44	0.30	Flight	distance flown (W)	Core area
2.56	4.42	0.93	Flight	time flown (U)	Core area
2.18	3.24	0.68	Flight	time flown (W)	Core area
0.74	1.67	0.21	0.1 deg	distance flown (U)	Core area
1.68	3.84	0.47	0.1 deg	time flown (U)	Core area
1.05	2.20	0.47	Flight	distance flown (U)	Core (Klaer)
0.80	1.22	0.26	Flight	distance flown (W)	Core (Klaer)

2003 fishing season

Abundance Index	Std. Dev.	Conf. Int+/-	Sampling unit	Effort measure	Area analysed
0.41	3.98	0.77	Flight	distance flown (U)	Total
0.70	5.21	1.01	Flight	distance flown (W)	Total
0.97	9.42	1.83	Flight	time flown (U)	Total
1.51	11.83	2.30	Flight	time flown (W)	Total
0.27	1.36	0.09	0.1 deg	distance flown (U)	Total
0.62	3.21	0.20	0.1 deg	time flown (U)	Total
0.82	2.11	0.41	Flight	distance flown (U)	Core area
0.59	1.14	0.22	Flight	distance flown (W)	Core area
1.78	4.40	0.86	Flight	time flown (U)	Core area
1.25	2.51	0.49	Flight	time flown (W)	Core area
0.48	2.00	0.24	0.1 deg	distance flown (U)	Core area
1.11	4.81	0.57	0.1 deg	time flown (U)	Core area
0.84	2.20	0.44	Flight	distance flown (U)	Core (Klaer)
0.55	1.06	0.21	Flight	distance flown (W)	Core (Klaer)

2004 fishing season

Abundance Index	Std. Dev.	Conf. Int+/-	Sampling unit	Effort measure	Area analysed
0.50	1.21	0.22	Flight	distance flown (U)	Total
0.51	1.01	0.18	Flight	distance flown (W)	Total
1.09	2.60	0.47	Flight	time flown (U)	Total
1.09	2.18	0.39	Flight	time flown (W)	Total
0.18	1.09	0.08	0.1 deg	distance flown (U)	Total
0.41	2.66	0.19	0.1 deg	time flown (U)	Total
0.38	0.52	0.09	Flight	distance flown (U)	Core area
0.46	0.59	0.11	Flight	distance flown (W)	Core area
0.82	1.14	0.21	Flight	time flown (U)	Core area
0.96	1.27	0.23	Flight	time flown (W)	Core area
0.24	0.78	0.09	0.1 deg	distance flown (U)	Core area
0.52	1.85	0.22	0.1 deg	time flown (U)	Core area
0.40	0.55	0.10	Flight	distance flown (U)	Core (Klaer)
0.48	0.61	0.11	Flight	distance flown (W)	Core (Klaer)