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The Aerial Survey index of abundance, updated to include the 2005 survey

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Abstract

A scientific line-transect aerial survey for juvenile SBT was conducted in the GAB in 2005. The survey follows similar surveys conducted in 1993-2000, and resumes a time-series of abundance indices for juvenile SBT. New analysis methods were developed, and all data were re-analysed, including the 2005 data. Because of bad weather, the 2005 survey flew very few transects in March and this month was omitted from the analyses for all years. Based on the analyses, an index of abundance was constructed for the surveys in 1993-2000 and the most recent survey in 2005. Results are presented and discussed.

Introduction

One of the key aspects of the Recruitment Monitoring Program is the development of a fishery-independent index of juvenile SBT recruitment based on a scientific aerial survey in the Great Australian Bight (GAB). The aerial survey was conducted in the GAB between 1991 and 2000, but was suspended in 2000-01 due to logistic problems of finding trained, experienced spotters and spotter/pilots. The suspension also allowed for further data analysis and an evaluation of the effectiveness of the survey. Analysis of the data was completed in 2003 and it showed that the scientific aerial survey does provide a suitable indicator of SBT abundance in the GAB (Bravington 2003).

Given the logistic problems of finding spotters and spotter/pilots to conduct the scientific line-transect survey, the feasibility of using experienced commercial tuna spotters to collect data on SBT sightings in the GAB during and between commercial operations, was explored after the suspension of the line-transect survey. This approach consisted of two parts:

- (1) a voluntary reduced line-transect component based on the 2000 scientific aerial survey design (Cowling, 2000), and
- (2) a 'commercial' spotting component based on SBT sighted per unit of searching effort (a SAPUE index) (see CCSBT-ESC/0509/23).

The voluntary nature of the reduced line-transect component led to it being both substantially reduced and highly ad-hoc in terms of the timing, location and number of transects flown. This, together with the high variability in estimates resulting from reduced effort (CV ~45-154%), suggests that an ad-hoc reduced survey would not provide a reliable indicator of juvenile SBT abundance. Given this, a full scientific line-transect aerial survey in the GAB was re-established in 2005. This report summarises the field procedures and data collected during the 2005 season, and provides some results of analyses.

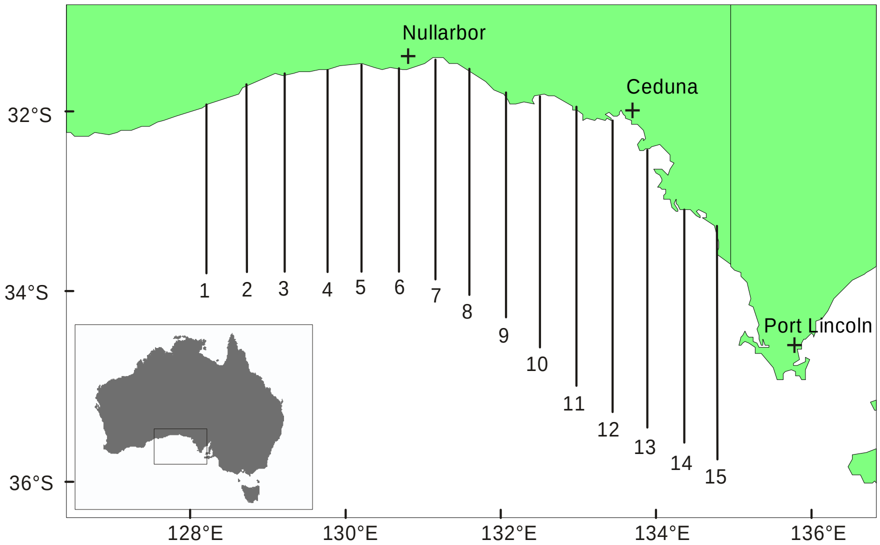
Field procedures

A line-transect aerial survey was conducted in the GAB between 9 January - 27 March 2005. A spotter and data recorder were employed for the survey, and a spotter-pilot and plane were chartered through Australian Fishing Enterprises Pty Ltd. The plane was a Rockwell Aero Commander 500S - the same make of plane used in the 1991-2000 aerial surveys.

The spotter-pilot was very experienced and had participated as either a spotter or spotter-pilot in 8 of the previous scientific aerial surveys (1993-2000). The spotter had not participated in any of the previous surveys, but was very experienced at spotting SBT from the crows-nest of purse seine vessels, and was considered the best available 'spotter' for the survey. During the first 3 flights of the survey (9 lines searched), sightings data was recorded for the spotter-pilot only. During these flights, the spotter-pilot assessed the spotter's ability to identify SBT schools and estimate biomass and fish size, and provided training/guidance as needed. Given that a large number of SBT schools were recorded during these three flights (78 schools with a total biomass of over 2000 tonnes), this was considered sufficient training and all additional sightings were recorded independently by the spotter and spotter-pilot. Note, in the rest of this section we refer to the both the spotter and the spotter-pilot as 'observers'.

The survey followed the protocols used in the 2000 aerial survey regarding the area searched, plane height and speed, environmental conditions, and time of day the survey was conducted (Cowling, 2000). The survey area lies between 128°E and 135°E, running from the coast to just off the continental shelf. Fifteen north-south transect lines (Figure 1) were searched by the observers (i.e. spotter and spotter-pilot). A complete replicate of the GAB consists of only 12 lines divided into 4 blocks. The remaining 3 lines in a replicate (either {1, 3 and 14} or {2, 13 and 15}) were not searched to save on time, and SBT abundance is historically low in these areas. The blocks were flown from west to east, and the lines within each block were flown in a pre-set order (sequence and direction).

Figure 1. Location of the 15 transect-lines for the scientific aerial surveys in the GAB.



The survey was only conducted on days when the environmental conditions were met. The minimum environmental conditions required were: less than 1/3 cover of cloud at or below1500 ft, visibility at 1500 ft must be greater than 7 nautical miles (nm), and wind speed at the sea surface must be 8 knots or less. However, once the survey had started, it continued as long as the wind speed did not exceed 10 knots.

A Garmin 176 GPS was used to log the position of the plane (15 second intervals) and waypoints during the survey. Transects are flown at 120 knots and at an altitude of 1500 ft. Each observer searched the sea surface from straight ahead through to 90° on their side of the plane (abeam of the plane) for surface patches (schools) of SBT. Occasionally the observer would search both sides of the plane if the other observer was unable to observe. A data recorder sat behind them recording environmental and sighting information in a logbook, and monitored the GPS.

When a sighting of SBT was made, a waypoint position (and time) was recorded in the GPS. The plane continued along the transect line until the observer judged that the sighting was at 90° to the plane. At that point, the plane left the transect line and flew directly to the sighting and circled it. Each sighting can contain one or more schools (or patches) of SBT. The two observers independently estimated a range for the size of individual fish in each school (in kg) and the size of each school (in tonnes). Another waypoint was recorded over the school, and then the plane flew back to the point it left the transect to resume searching. For each sighting of SBT, the behaviour of the fish was recorded as “deep” or “shallow” and “feeding”, “rippling” or “fattening”. Information was only collected on those sightings for which some part of the grouping was within 7 nm of the transect line. While flying out to a sighting, the observers refrained from looking at the areas that has not yet been searched. This reduced the possibility of additional (secondary) sightings. If secondary sightings were made when flying off the transect, they were only recorded if they were within the 7 nm limit, and were in areas not already searched. If the secondary sightings could be seen from the transect (when the plane returned), that was recorded. Only secondary sightings that could be seen from the transect were included in the analysis.

Environmental observations were recorded at the start and end of each transect and at 30 minute intervals during the transect flight, or when the conditions changed significantly. The observations include wind speed and direction, air temperature, amount of high and low cloud, glare, haze and swell.

2005 survey year

The line-transect survey was successfully completed in 2005. The survey team was ready to commence on January 1, although poor weather delayed the start until Jan 9. The weather was relatively good in January and February, and three replicates of the GAB were surveyed by late February (36 lines). In March, however, high winds and low cloud reduced the number of days that the survey could be conducted and only an additional 9 lines were surveyed on 3 flying days (75% of the 4th replicate completed). The number of lines searched in 2005 was lower than for any of the previous surveys; the 1993-2000 surveys searched between 56 and 138 lines. However, two planes were used during 7 of these surveys, which doubled the number of lines that could be searched on a particular day. The total flying time for the 2005 survey was 174 hours.

Data preparation

The data collected from the 2005 survey were entered into the aerial survey database maintained by CSIRO, which also contains the data collected from the surveys conducted in 1993 to 2000. The data were checked for any obvious errors or inconsistencies and corrections were made where necessary.

In order for the data and results to be comparable between all survey years, only data collected in a similar manner from a common area are included in the data summaries and analyses presented in this report. For instance, the design of the aerial survey has changed over time, as documented in Cowling et al. (2002) and references therein. The most significant change has been that the “zigzag” lines flown between north/south transect lines during the 1993 to 1998 surveys were discontinued in 1999, and the southern boundary of the survey area was extended slightly in this year. The design of the 2000 and 2005 surveys was the same as the 1999 survey. Thus, in this report, only search effort and sightings made along north/south transect lines in the un-extended survey area are included for any given survey year. Note that in the 3 years that the southern boundary of the survey area was extended slightly (1999, 2000 and 2005), no SBT sightings were made in the extended area so excluding this area only marginally reduces the total time and distance searched; it does not exclude any sighting information.

The best choice of strip width to use for line-transect analyses was investigated in Cowling et al. (2002). Half-widths of 4, 5 and 6 nm were considered. The results suggested no reduction in detectability of SBT in the 4-6 nm range, so it was decided that a truncation distance of 6 nm on each side of a transect line would be used in all strip-width analyses. We adhere to this decision and only include sightings made within 6 nm of a transect line in any of the data and analyses presented in this report. Note that if a sighting consists of more than one patch, then the sighting is included as long as any one of the patches is within 6 nm of the line.

Search effort and SBT sightings

A summary of the total search effort and SBT sightings made in each survey year is given in Table 1 (recall that only suitable search effort and sightings data, as detailed in the previous section, are included in all results shown). The total distance searched was lowest in 2005, but the sighting rate was slightly above average. The distribution of SBT sightings appear to be more concentrated inshore and along the southern boundary (shelf break) in 1993, 1994, 1997 and 2005 than in other years (Figure 2).

The average number of patches per sighting was lower in 2005 than in all previous survey years except 1998 (Table 1); however, the median size of a patch was larger than average, with more patches over 100t being recorded than in previous survey years (Figure 3). Although the average size of fish within a patch is estimated by both observers, previous investigations have found little correspondence between fish size estimates made by different observers (Cowling et al. 2002). As such, to look at how fish size may have varied between survey years, we consider size estimates made by a single observer who has operated in all survey years. We assume that fish size estimates should be comparable for the same observer even if they are not comparable between observers. According to this observer, the mean size of SBT present in the survey area tended to increase from 1994 to 2000 (there are too little data in 1993 to be meaningful), but were back to about the average in 2005 (Figure 4).

Table 1. Summary of search effort and sightings of SBT in the aerial survey by survey year (Jan-Mar). Only data from search effort along north/south transect lines, and only data from sightings made within 6nm of a transect line, are included.

Survey year	Total distance searched (nm)	Number SBT sightings	Number sightings per 100nm	Average patches per sighting	Median biomass per patch (tonnes)	Maximum biomass per patch (tonnes)
1993	7630	131	1.7	4.3	18.5	200
1994	15220	181	1.2	3.3	20.0	245
1995	14995	188	1.3	3.7	27.5	215
1996	12776	120	0.9	4.0	25.0	145
1997	9244	119	1.3	3.1	20.0	175
1998	8691	109	1.3	2.3	19.5	858
1999	6930	56	0.8	2.7	20.0	120
2000	7032	80	1.1	2.6	19.5	100
2005	5935	81	1.4	2.4	25.0	200

Figure 2. Distribution of SBT sightings made during the aerial surveys conducted in 1999-2000 and 2005 (Jan-Mar). Red circles show the locations of SBT sightings and grey lines show the north/south transect lines that were searched.

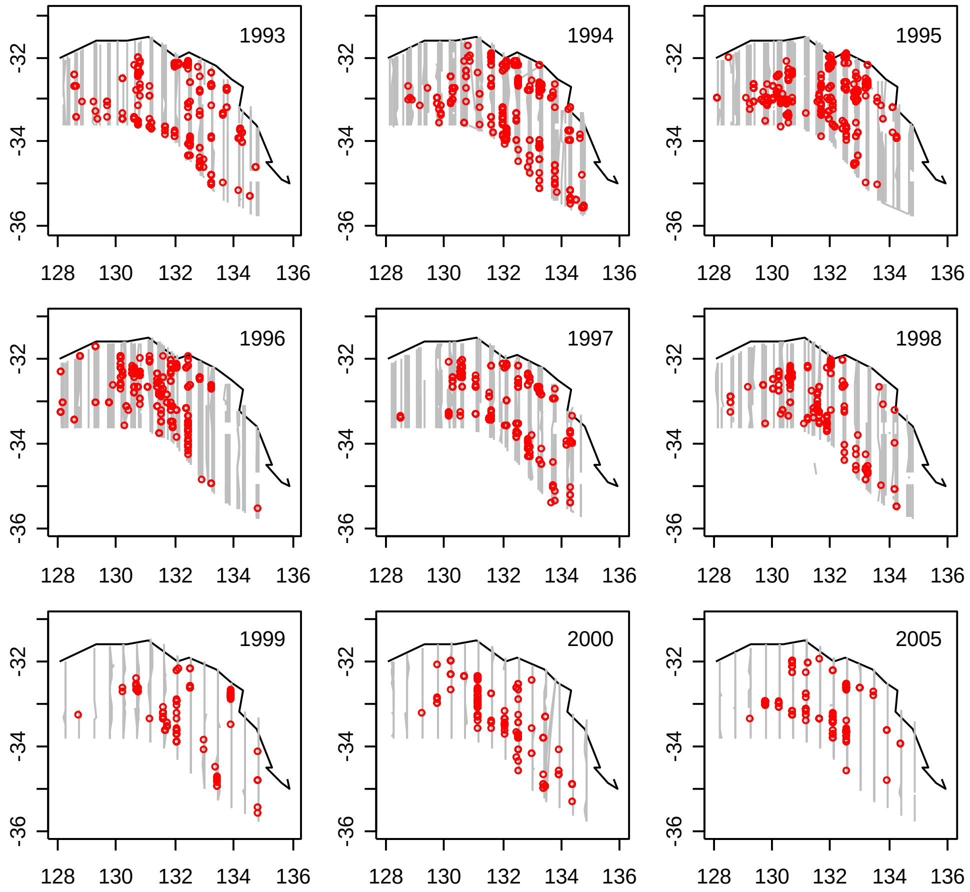


Figure 3. Frequency of SBT patch sizes (in tonnes) by survey year.

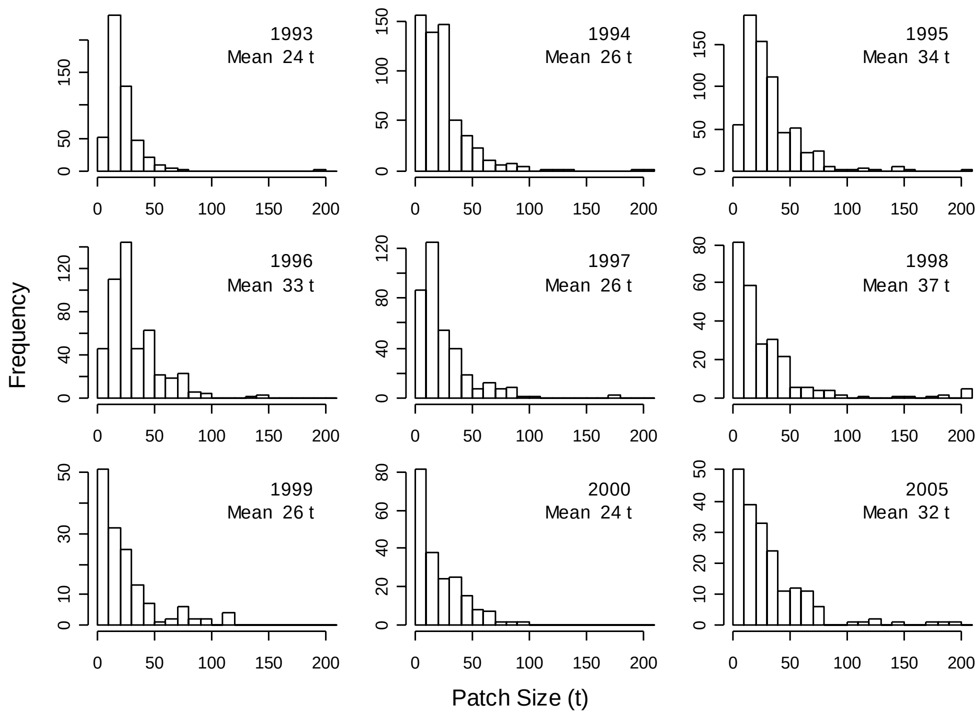
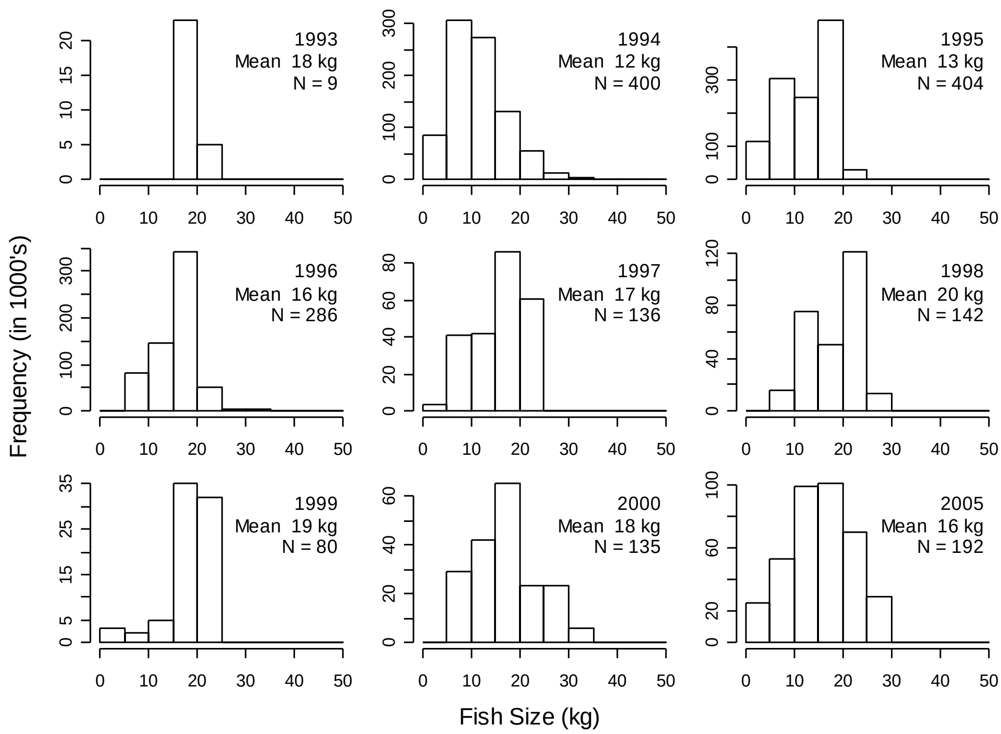


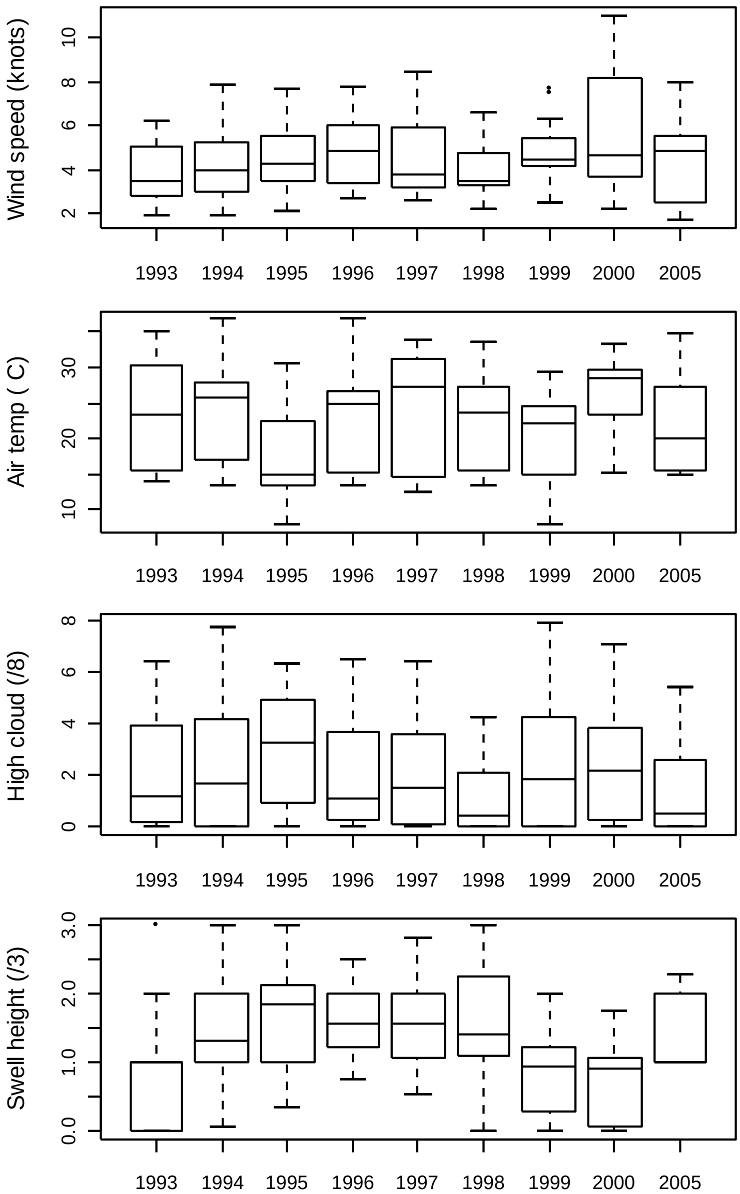
Figure 4. Size frequency of SBT (in kg) recorded by one observer by survey year. Data are weighted by patch size. N = number of patches from which fish size was estimated.



Environmental variables

Figure 5 summarizes the environmental conditions that were present in each survey year during times while north/south transect lines were being searched. Only a subset of variables – those expected to have the greatest effect on sightability of SBT – are shown. In general, conditions during the 2005 survey were average compared to other years. Conditions during the 2000 survey appear to have been more different than the other years; for example, relatively more high wind speed, high air temperature, and low swell height recorded.

Figure 5. Boxplots summarizing the environmental conditions during the aerial survey for survey years 1999-2000 and 2005 (Jan-Mar). Note that only observations recorded during search effort on north/south transect lines are included. The horizontal line through a box indicates the median, the length of a box gives the inter-quartile range, and the vertical lines extend to the minimum and maximum values.



Methods of analysis

Because of bad weather, the 2005 survey flew very few transects in March. March has been a problematic month for many of the GAB aerial surveys, with indices being very variable even when good weather was available. In order to concentrate on producing a stable index for 2005 that is comparable with previous years, we ultimately decided to use only January and February data in the results below.

Bravington (2003) analysed the 1993 to 2000 aerial survey data to produce a relative abundance index and corresponding estimates of precision; note that the motivation behind that study was to investigate the general reliability of the aerial survey, rather than to come up with a definitive index series. Separate models were constructed to describe three different components of observed biomass: biomass per patch (BpP), patches per sighting (PpS), and sightings per nm of transect line (SpM). Since environmental conditions affect what proportion of tuna are available at the surface to be seen, as well as how sightable those tuna are, and since different observers can vary both in their estimation of school size and in their ability to see tuna patches, the raw data needs to be corrected for environmental and observer effects in order to produce standardized indices that can be meaningfully compared across years.

For this report, we used the same three-component structure, but in the interests of speed and simplicity, we avoided the most complicated aspects. As far as possible, we aimed at calculating stratum-specific means directly, with corrections for known distortions due to environmental conditions, rather than at space/time interpolation; the motivation was to minimize any risk of model bias from inappropriate interpolation, rather than to minimize estimated variance.

Specifically:

- We defined 45 area/month strata: 15 areas (5 longitude blocks and 3 latitude blocks) and 3 months (Jan, Feb, Mar).
- We did not re-investigate covariate selection (except for the SpM model; see below)
- The BpP model from 2003 contains only an observer effect term (apart from space & time stratification). In the 2003 analysis, there was no evidence of any difference except for one particular observer, who did not fly in 2005. There was no evidence of any difference between the observers in 2005 so we did not re-fit this model.
- The PpS model from 2003 includes only windspeed (apart from space & time stratification). We did not re-fit this model since new data from 2005 on windspeed effects would add very little information to that already available.
- Within each stratum, we "corrected" each BpP observation for observer effects and took the average
- Within each stratum, we "corrected" each PpS observation for wind speed and took the average
- We re-fitted the 2003 "direct" pairwise comparison model for observer effects on sighting rate, and treated the point estimates of "observer pair effect" as exact in subsequent SpM analysis.
- For SpM, we bypassed the continuous-time sighting model of 2003, instead fitting a simpler quasi-Poisson GLM. Based on inspection of residual diagnostics, we estimated the parameters associated with the following covariates: "observer pair effect" (from previous step), windspeed, swell (factor), moon, factor(lowCloud), area*year, area*longitude*month. It was not possible to fit a full area*month*year

model (i.e. "direct stratum means") because there were too few sightings in some area/month/year combinations.

- For each stratum we calculated (fitted SpM) x (average corrected PpS) x (average corrected BpP) to get an abundance index for that stratum.
- We then took the weighted average of abundance indices over all strata within a month and year, where each index was weighted by the geographical size of the stratum in nm2, to get an overall abundance index for that month and year.
- CVs were obtained by the delta-method, and confidence intervals by assuming a log-normal distribution for the uncertainty in the index.

Results

Figure 6 shows a preliminary estimate of the time series of relative abundance estimates, based on January and February data only and the methods described above. The general impression is that the 2005 survey estimate is lower than the mid-1990s average (1994-1998, when the survey was "stable"), but higher than the 1999 estimate. However, the uncertainty on individual years is *large*, particularly for 1999 and 2000. The dominant uncertainty, as in past analyses, is the relative sighting power of different observers. To see this, note that in Figure 6 the 2000 estimate is higher than the 2005 estimate, whereas Table 1 shows that both sighting rates and average patch biomass were actually higher in 2005. The reason is that the sighting power of the observer teams in 1999 is estimated to be low, so the raw sighting rate needs to be substantially corrected upwards. As noted below, the size of the appropriate correction cannot be estimated very precisely, and the 1999 and 2000 estimates are likely to remain difficult benchmarks for comparison even if more data is collected in future. Nevertheless, based on our explorations of alternative models, we do not expect large changes in the 2005 estimate even with different models for observer and/or environmental effects, because observer effects and environmental conditions for 2005 seem fairly typical. The general width of the 2005 confidence interval is also unlikely to change much. The time series of point estimates in Figure 6 does differ slightly from e.g. Figure 11 of Bravington (2003). This is partly due to the exclusion of March data in the current analysis, and partly to the changes noted above in the current analysis methods, in particular with respect to observer effects.

Figure 6. Time series of relative abundance estimates based on January and February (not March), with 90% confidence intervals.

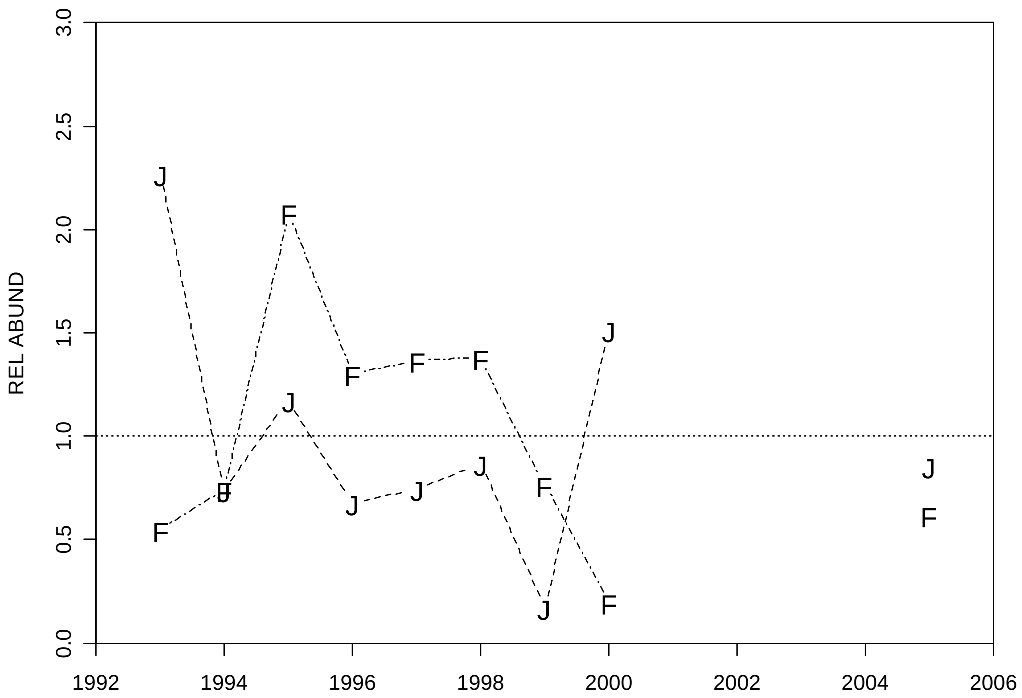
The point estimates and CVs corresponding to Figure 6 are reproduced in Table 2. The 2005 CV is higher than in the mid-1990s, because of the relatively low number of transects that could be flown with only one plane available; however, it is considerably lower than the 1999 or 2000 CVs, which are dominated by uncertainty about observer effects. The CVs in the Table are probably on the low side since they do not reflect model-choice uncertainty about observer effects.

Table 2. Point estimates and CVs as per Figure 6

	1993	1994	1995	1996	1997	1998	1999	2000	2005
Estimate	1.38	0.74	1.64	1.00	1.06	1.13	0.48	0.84	0.73
CV%	29	30	31	34	33	37	70	45	38

It is also interesting to consider the time series indices by month (Figure 7). Obviously there is only half as much data per month as per year (ignoring March), so the individual month series are bound to be noisier than the combined series. Even so, the difference between January and February estimates in the same year is often very substantial. The magnitude of difference between the estimates is generally consistent with the aggregate CVs calculated e.g. in Figure 6, except perhaps in 1993; between 1995 and 1999 the two indices in fact follow very similar tracks.

Figure 7. Indices calculated separately for J(anuary) and F(ebruary). No confidence intervals shown.



Uncertainty about observer effects

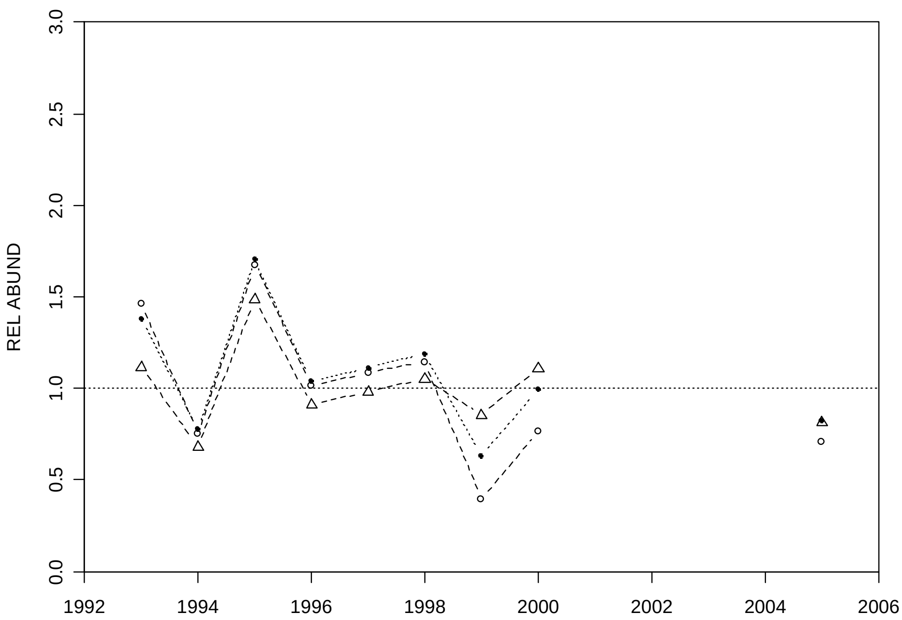
The 2005 survey used a single plane and a new observer. This creates extra uncertainty in calibrating this survey against the historical time series. Previous analyses have shown generally good consistency between experienced observers in terms of estimating Biomass-per-Patch (with some exceptions), and clearly there is no “observer effect” in the number of Patches-per-Sighting. However, the ability to actually detect a sighting in the first place can vary substantially between observers, so care is necessary in interpreting raw data on Sightings-per-Mile.

The protocol for the survey is for the pilot to concentrate on the right-hand side of the plane, while the observer concentrates on the left. In theory, only a few sightings should be recorded on the “wrong” side, i.e. seen first by the observer on the right, or seen first by the pilot on the left. If this protocol was followed strictly, calibration would be straightforward. Over the course of numerous flights, about as many potential sightings will be available on the left as on the right, so the ratio of numbers seen by the observer versus numbers seen by the pilot would be an index of their relative sighting power. However, there are obviously some logistical difficulties on maintaining a strict separation over who looks where and, although the protocol seems to have been followed quite closely in 2005 and to some extent in 2000 and 1999, in earlier years quite a high proportion of sightings are wrong-sided. This necessitates more complicated modelling to intercalibrate the full set of observers, and the more complicated model is inevitably sensitive to assumptions about what protocol was really followed onboard. The apparent change in “real” protocol is an additional complication.

In previous years, additional information on relative performance of different teams of observers (spotter/pilot and spotter) could also be gleaned indirectly by comparing average numbers of sightings between planes, after making allowance for environmental conditions, time of year, and location. This is not possible for the single-plane 2005 survey. However, uncertainty about observer effects is actually worst for the 1999 and 2000 surveys, when each trainee made few flights and saw very few sightings; also, one of the (experienced) pilots in 1999-2000 never flew with the other experienced observers, so sighting rates could not be directly compared. The 2000 point estimate is particularly prone to uncertainty about observer effects (not fully reflected in the preliminary CVs in Table 2), and many models show a 2000 point estimate below the 2005 point estimate. In the 2005 survey, enough sightings were made to allow a more accurate calibration, but observer effects are still the dominant component of uncertainty with the aerial survey time series.

A full analysis of observer effects along the lines proposed in Bravington, 2003 is complex, and there has not been enough time do this yet; the 2003 approach needs some revision in respect of the awkward method used to combine different analyses. Figure 6 shows results under our current "best working" model, but other models are possible. As an indication of how observer effects can change the estimates, Figure 8 shows three different versions of the time series calculated using different plausible estimates of observer effects. It can be seen that the effects on the 2005 estimate are not too large (at least with the limited range of different versions considered here), but the effects on the 1999 and 2000 estimates are really substantial. As noted above, this means that a comparison between the 2005 index and values in the mid-1990s is more reliable than that between 2005 and 1999 or 2000.

Figure 8. Three different time series, using three different plausible sets of observer effects.



Summary

Results from the line transect survey suggest that the abundance of 2-4 year olds in the GAB in 2005 was lower than it was in the mid-90s, but perhaps higher than in 1999. Unadjusted sighting rates and patch biomasses were higher in 2005 than in either 1999 or 2000, but the efficiency of the observer teams in 1999 and 2000 is very uncertain and makes direct comparisons difficult. The comparison with the mid-90s is therefore more reliable. If further surveys are to be conducted, it will be essential to keep the same observers as far as possible, in order to ensure comparability of results.

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