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Southern bluefin tuna aerial survey in the Great Australian Bight - 2014

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Contents

1 Non-technical Summary

The aerial survey project focuses on the construction of an index of relative abundance for juvenile southern bluefin tuna (SBT) based on a scientific aerial survey in the Great Australian Bight (GAB). The index reflects the relative abundance of 2-4 year olds combined, and is one of the very few fishery independent indices available for assessment and management purposes. In addition, the project coordinates the collation and standardisation of spotter data from commercial spotting operations associated with the Australian purse seine fishery. This report describes the field procedures, data collected, and results for the 2014 scientific aerial survey and commercial spotting data. The results will be presented and reviewed at the CCSBT Extended Scientific Committee meeting in September 2014 (documents attached as Appendix 1 and 2). The aerial survey index will be used in the reconditioning of the SBT operating model (OM) and sensitivity analyses of management Procedure (MP) in the CCSBT OMMP Working Group meeting in Seattle in June.

The scientific aerial survey was conducted between 1 January and 31 March 2014 and followed the protocols established in 2000 and used in all subsequent surveys. The methods of analysis were the same as the last two years. Methods to account for uncertainty in the observer effect estimates for the SpM model have yet to be implemented; thus, the CVs for the relative abundance indices do not yet include uncertainty in the observer effects for the SpM model (i.e., they are underestimates of the true uncertainty).

The estimate of relative juvenile abundance from the 2014 scientific aerial survey is significantly higher than for any previous survey year. The environmental conditions during the 2014 survey were average for the most part, except that the level of haze was higher than in past years. Because increased haze is unfavourable for making sightings, the raw estimate was adjusted upwards slightly in the standardization process. Also, as for past years where there has only been one spotter per plane, the raw estimate was adjusted upwards in the analysis to account for the fact that one spotter tends to make fewer sightings than two spotters. In the past several years (2009-2013), the percentage of schools that were comprised of small fish (<8 kg; estimated to be 1-year-olds) was unusually high, but that was not the case this year.

The second component of the project is the collection of spotting data from experienced commercial tuna spotters during purse seine fishing operations. These data were collected between December 2013 and February 2014 and were used to produce nominal and standardised fishery-dependent indices of SBT abundance (surface abundance per unit effort – SAPUE index). This year, almost all search effort occurred in the eastern GAB between 134° and 138° east; from west of Rocky Island to south of Kangaroo Island.

The standardised SAPUE index for 2014 is higher than the average for the 2003 to 2014 period but slightly below the 2011 estimate which was the highest for all seasons. The environmental conditions experienced during the commercial flights were better relative to recent years. The cloud cover and swell height were well below average while the overall spotting conditions and visibility was above average. The favourable conditions resulted in a decrease in the standardized index estimate compared to the raw estimate.

It is encouraging that the overall patterns of the two indices are similar for the ten overlapping years. This year, both indices are above their long-term averages but the scientific aerial survey index is substantially higher than all previous survey years, while the SAPUE index is slightly below the highest estimate obtained in 2011. The divergence in the most recent year may reflect the different areas covered by the two 'surveys' and/or recent changes in the relative distribution of SBT in the GAB. In addition, the commercial spotting data are obtained in a substantially different way directly associated with the fishing operation, and covers a much smaller spatial area than the line-transect survey. For this reason, we consider the standardised, consistent nature of the scientific aerial survey to be preferable to the commercial spotting data as an approach for estimating an index of juvenile SBT abundance.

2 Acknowledgements

There are many people we would like to recognise for their help and support during this project. We would especially like to thank this year's spotters, pilots and data recorders: Darren Tressider, Derek Hayman, Andrew Merwood, Mattew Grant, Matthew Lucchesi, John Veerhius, Thor Carter and Jim Dell. We also especially thank the commercial spotters and pilots for their continued willingness to collect and record sightings data each fishing season, and the tuna fishing companies in Port Lincoln for their support of the project. This study was funded by the Australian Fisheries Management Authority, the Department of Agriculture, the Commission for the Conservation of Southern Bluefin Tuna (CCSBT), the Australian SBT Industry, and CSIRO's Wealth from Oceans Flagship.

3 Background

Scientific aerial survey

The index of juvenile southern bluefin tuna (SBT) abundance based on a scientific aerial survey in the Great Australian Bight (GAB) is one of the few fishery-independent indices available for monitoring and assessment of the SBT stock. The aerial survey was conducted in the GAB between 1991 and 2000, but was suspended in 2001 due to logistic problems of finding trained, experienced observers (spotters). The suspension also allowed for further data analysis and an evaluation of the effectiveness of the survey. A decision to continue or end the scientific aerial survey could then be made on the merits of the data, in particular the ability to detect changes in abundance.

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). In the light of serious concerns about the reliability of historic and current catch and CPUE data and weak year classes in the late 1990s and early 2000s, this fishery-independent index was considered particularly important (Anon. 2008).

In 2005, the full scientific line-transect aerial survey was re-established in the GAB, and this survey has been conducted each year since. New analysis methods were developed and have subsequently been refined. Based on these methods, an index of abundance across all survey years has been constructed.

In addition, in 2007 a large-scale calibration experiment was initiated with the primary purpose of comparing SBT sighting rates by one observer versus two observers in a plane. This was done in anticipation of the fact that future surveys might have only one observer in a plane (as was the case for one of the two planes flying in the 2010 survey and both planes in 2011). The data provided useful information about differences in sightings between observers (e.g., sightings made by one observer are often missed by another observer). However, it proved difficult to definitively estimate the effect of the number of observers on the index.

In 2008 and 2009 a new calibration experiment was designed and run in parallel with the full scientific aerial survey. This calibration experiment was designed to compare the number of SBT sightings, and the total estimated biomass of SBT observed, by the single observer plane versus the survey plane (with two observers) over the same area and time strata. A method for accounting for the fact that a plane with one observer makes fewer sightings than a plane with two observers was presented in Eveson et al. (2010) based on data from the calibration experiments. These methods were refined in 2011 due to the presence of a high proportion of large schools, since it was acknowledged that a plane with one spotter is less likely to miss very large schools than small schools. The data from the calibration experiments were re-analysed leaving out very small sightings (<2 tonnes) and this led to a revised calibration factor estimate of 0.7 instead of 0.5 (i.e., a plane with only one spotter makes approximately 70% as many sightings as a plane with two spotters). The methods developed were applied in the 2011 to 2013 analyses, and again this year.

Commercial spotting data

In addition to the scientific aerial survey, data on SBT observed by commercial tuna spotters in the GAB are also collected. In the summer of 2001-02 (referred to as “the 2002 season”), a pilot study was conducted to investigate the feasibility of using experienced industry-based tuna spotters to collect data on the sightings of SBT during commercial spotting operations in the GAB. These data provided a preliminary fishery-dependent index of SBT abundance (surface abundance per unit effort – SAPUE index) for that fishing season.

Recognising the importance of time-series of indicators, we continued to collect and analyse SBT sightings data from commercial spotters over the following 11 fishing seasons (2003-2013). Interpretation of the results in terms of how they relate to the actual abundance of juvenile SBT in the GAB is difficult as the data suffers from many of the same problems that affect catch per unit effort (e.g. changes in coverage over time, lack of coverage in areas where commercial fishing is not taking place, and changes in operations over time), but it may provide a qualitative indicator of juvenile SBT abundance in the GAB, particularly if the series can be maintained in a consistent way over a longer period. It has always been recognised, however, that a scientific survey with consistent design and protocols from year to year is highly preferable relative abundance index. In 2014, we continued to collect SBT sightings data from commercial spotters extending the series for this index.

Operating model and management procedures

At the 2008 CCSBT SAG meeting, the scientific aerial survey data were included in the operating model (OM) code for the first time. In 2009, the CCSBT SAG agreed that the aerial survey data would be used in candidate management procedures (MPs) being developed over the following 12 months. In 2010, two candidate MPs were chosen for further evaluation; both of these used the aerial survey index series. In 2011, an MP which combined the best aspects of the two proposed MPs (which included the aerial survey index) was adopted by the CCSBT (Anon. 2011).

4 Need

Developing reliable estimates of SBT recruitment has been recognised as a high priority by the CCSBT Scientific Committee (SC) and SBTMAC. The SC has previously noted serious concerns about the possibility of a series of low recruitment based on stock assessments and a wide range of stock indicators. A review of the status of the SBT stock at the 2011 CCSBT SC meeting confirmed low recruitment in 1999 to 2002, but also noted increasing trends in age classes 3-7 in recent years (although levels are still low and similar to recent years).

The aerial survey recruitment index for juvenile SBT has been undertaken since 1995 (with a 4 year break in 2001-2004) and is recognized as a critical early-warning tool in the event of dramatic changes in juvenile abundance. Thus the annual survey is vital to effectively assess the status and condition of the juvenile population, particularly in light of continuing evidence of 3-4 very weak cohorts.

The SC has continued to note that the aerial survey and commercial spotting indices are high priority aspects of the Scientific Research Program as both are unaffected by the catch uncertainties. The SC also notes that monitoring of recruitment must continue long-term. The aerial survey is now part of the data going into the SBT Operating Model AND the candidate Management Procedure, further supporting the ongoing need for the survey.

5 Objectives

To use the scientific aerial survey to continue the time-series of fishery-independent relative abundance indices of juvenile SBT in the Great Australian Bight, which is being used as an indicator for determining trends in recruitment of the species; to make use of the data from the commercial aerial spotting operations to derive an additional fishery-dependent index of juvenile SBT abundance.

6 Methods

The ‘Methods’ sections in Appendix 1 (scientific aerial survey) and Appendix 2 (commercial spotting data) provide full descriptions of the methods used with respect to all parts of the project, or references to relevant work published elsewhere. A brief summary is provided below.

Scientific aerial survey

The 2014 scientific aerial survey was conducted in the GAB between 1 January and 31 March 2014. Two planes were chartered, one for the full three months (plane 1) and a second for January and February only (plane 2). Each plane contained one observer and a non-spotting pilot. Both observers used in 2014 were employed in previous seasons; one for the 2005 to 2013 surveys and the other in all surveys.

The aerial survey followed the protocols established for the 2000 survey (Cowling 2000) and used in all subsequent surveys. Fifteen north-south transect lines (see Figure 1; Appendix 1) were surveyed. A complete replicate of the GAB consists of a subset of 12 (of the 15) lines divided into 4 blocks. In the past, the remaining 3 lines in a replicate (either: 1, 3 and 14, or 2, 13 and 15) were not searched, as SBT abundance was historically low in those areas and surveying a subset increases the number of complete replicate of the GAB in the survey. In 2009 and 2011-2013, however, the distribution of SBT in the GAB appears to have changed with an increase in abundance in the eastern GAB compared to the western GAB (see Farley and Basson, 2013). Given this, lines 13, 14 and 15 were not routinely omitted on alternative replicates of the GAB.

The 2014 field operation was successful, largely due to the availability of two planes on days suitable for survey. A total of 7 replicates of the GAB were completed, which is similar to 2010-2013, but higher than the 3-5 replicates for the preceding 5 years when only one plane was available for the survey. The data collected from the survey were loaded into the aerial survey database. Analysis of the data was undertaken following Bravington (2003) and the 2005-2013 analyses (e.g. Eveson et al. 2013). The data from recent survey years has included an unusually high proportion of schools of small fish estimated to be less than 8kg, which we assume to be the average weight cut-off between 1- and 2-year olds (see Appendix 1). This was first noted in 2011 (Eveson et al. 2011). In the current year, the proportion of schools comprised of such small fish was much lower and similar to values seen in the late 1990s.

The data were analysed by constructing separate models to describe two different components of observed biomass: i) biomass per patch sighting (BpS) and ii) sightings per nautical mile of transect line (SpM). Each component was fitted using a generalized linear mixed model (GLMM), as described in Appendix 1. Environmental conditions affect what proportion of tuna are available at the surface to be spotted, as well as how visible those tuna are, and different observers can vary both in their estimation of school size and in their ability to spot tuna patches; therefore, the models include ‘corrections’ for environmental and observer effects in order to produce standardized indices that can be meaningfully compared across years.

Commercial spotting data

As in previous years, the field program in 2014 included the collection of spotting data from experienced commercial tuna spotters (observers) in the GAB. Data were collected between December 2013 and February 2014 (referred to as the 2014 fishing season). The data acquisition systems developed in the previous seasons were reinstalled into the spotter planes, and logbooks, protocols and training were provided. Spotters were asked to record the location of all SBT schools observed and estimate the total tonnage and size classes of fish in each school. Environmental observations were recorded at the start and end of each flight and when the conditions changed significantly during the flight. This year, data were collected by three spotters but one had participated in all previous seasons.

The commercial spotting data were used to produce nominal and standardised fishery-dependent indices of SBT abundance (surface abundance per unit effort – a SAPUE index) following the 2013 analyses (Farley and Basson, 2013). The standardised SAPUE was based on fitting a general linear model to the data from all spotters, rather than just for two spotters as was undertaken in past analyses (e.g. Farley and Basson, 2012).

7 Results

The 'Results' and 'Summary' sections in Appendix 1 (scientific aerial survey) and Appendix 2 (commercial spotting data) provide full descriptions of results of the project. A brief summary is provided here.

The estimate of relative juvenile abundance from the 2014 scientific aerial survey is significantly higher than for any previous survey year (Figure 1). The environmental conditions during the 2014 survey were average for the most part, except that the level of haze was higher than usual. Because increased haze is unfavourable for making sightings, the raw estimate was adjusted upwards slightly in the standardization process. As in 2010-2013, the raw estimate was also adjusted upwards to account for having only one observer. Most sightings were made inshore in the eastern half of the survey area. The unusually high percentage of schools comprised of small fish (<8 kg) that were seen in 2009-2013 were not observed this year.

The standardised SAPUE index for 2014 is higher than the average for the 2003 to 2014 period but slightly below the 2011 estimate which was the highest for all seasons (Figure 2). The environmental conditions experienced during the commercial flights were better relative to recent years. The cloud cover and swell height were well below average while the overall spotting conditions and visibility was above average. The favourable conditions resulted in a downward adjustment in the standardization process.

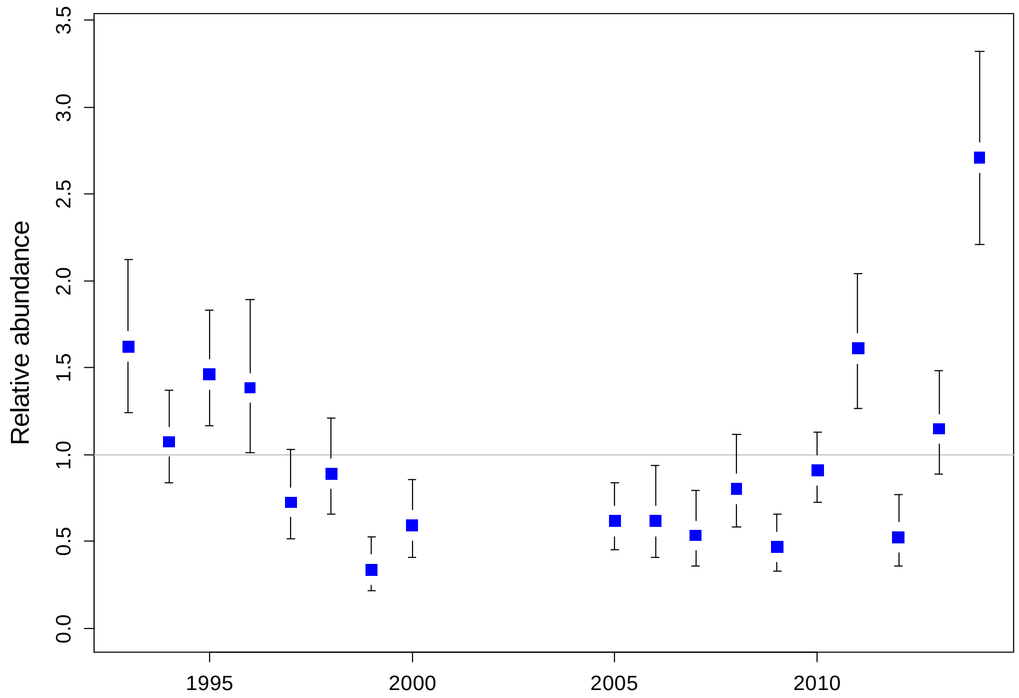

Figure 1. Time series of relative abundance estimates with 90% confidence intervals from the scientific aerial survey. The horizontal line represents the average (mean) over the period of the series.

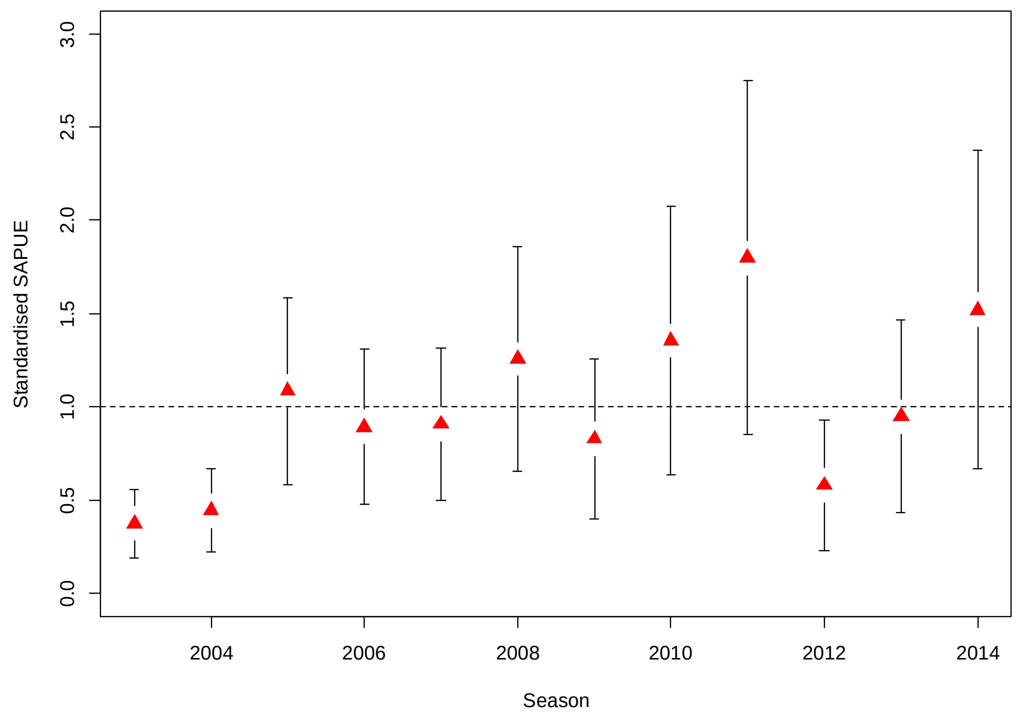

Figure 2. Time series of standardised relative surface abundance per unit effort (+/- 2 standard errors) from the commercial spotting data. The horizontal line represents the average (mean) over the period of the series.

8 Benefits/Adoption

The project provided estimates of the relative abundance of juvenile SBT in the GAB for 2014 which will be presented at the CCSBT Extended Scientific Committee meeting in Auckland in September 2014 and used in the reconditioning of the Operating Model and sensitivity analyses for the Management Procedure at the OMMP Working Group meeting in Seattle in June 2014. The results will also be included in Australia's paper on fishery indicators to the CCSBT SC. The standardised index from the scientific aerial survey is now a critical input to both the management procedure and operating model for SBT, and thus the aerial survey has continued to be endorsed by the CCSBT SC as a recruitment-monitoring index for the fishery. This standardised monitoring of recruitment in the GAB provides the Australian Fisheries Management Authority (AFMA) and the Department of Agriculture confidence that the trends in recruitment to the population and fishery are being monitored and used in a scientifically tested rebuilding program (CCSBT MP). The Australian SBT fishing industry directly benefits from this through the increased certainty in TAC setting arrangements and greater confidence in their investment and future rebuilding of the stock.

9 Conclusions

The project was able to meet all of its objectives. There are now ten years of overlap between the scientific aerial survey and SAPUE indices (2005-2014). While the qualitative patterns of the two series are similar, there are substantive differences among years over the comparable period for each series. In 2013 there was a slight divergence in the indices as the scientific aerial survey index was above the survey average, while the SAPUE index was average. This year, both indices are above their long-term averages but the standardised aerial survey index is substantially higher than all previous survey years, while the SAPUE index is slightly below the highest estimate obtained in 2011. As noted in Farley and Basson (2013), the divergence may reflect the different areas covered by the two 'surveys' and/or recent changes in the relative distribution of SBT in the GAB. In addition, the commercial spotting data are obtained in a substantially different way, which is directly associated with fishing operations of the purse seine fleet, and covers a much smaller spatial area than the line-transect survey. For these reasons, we consider the scientific aerial survey to be preferable to the commercial spotting data as an approach for estimating an index of juvenile SBT abundance.

10 References

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11 Appendices

Appendix 1:

Eveson, P., Farley, J., Bravington, M. 2014. The aerial survey index of abundance: updated results for the 2012/13 fishing season. **DRAFT** Report prepared for the CCSBT Extended Scientific Committee for the 19th Meeting of the Scientific Committee 1-6 September 2014, Auckland, New Zealand.

Appendix 2:

Farley, J., Eveson, P., Basson, M. 2014. Commercial spotting in the Australian surface fishery, updated to include the 2012/13 fishing season. **DRAFT** Report prepared for the CCSBT Extended Scientific Committee for the 19th Meeting of the Scientific Committee 1-6 September 2014, Auckland, New Zealand

APPENDIX 1

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The aerial survey index of abundance: updated results for the 2013/14 fishing season

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CCSBT-ESC/14XX/XX

DRAFT

Prepared for the CCSBT Extended Scientific Committee for the 19th Meeting of the Scientific Committee 1-6 September 2014, Auckland, New Zealand

APPENDIX 1

Wealth from Oceans Flagship

CSIRO Marine and Atmospheric Research

Citation

Eveson P, Farley J, Bravington M (2014). The aerial survey index of abundance: updated results for the 2013/14 fishing season. CCSBT-ESC/14XX/XX, 19th Meeting of the Scientific Committee, 1-6 September 2014, Auckland, New Zealand.

Copyright and disclaimer

Important disclaimer

Acknowledgments

There are many people we would like to recognise for their help and support during this project. We would especially like to thank this year's observers (spotters), pilots and data recorders; Darren Tressider, Derek Hayman, Andrew Merwood, Mattew Grant, Matthew Lucchesi, John Veerhius, Thor Carter and Jim Dell. We also appreciate the support given to us by the commercial tuna spotters and pilots during the survey especially for providing information on weather condition during flights. This study was funded by the Australian Fisheries Management Authority, the Department of Agriculture, the Commission for the Conservation of Southern Bluefin Tuna (CCSBT), the Australian SBT Industry, and CSIRO's Wealth from Oceans Flagship.

Contents

Abstract

The estimate of relative juvenile abundance from the 2014 scientific aerial survey is significantly higher than for any previous survey year and the highest in the history of the series. The environmental conditions during the 2014 survey were average for the most part, except that the level of haze was higher than in past years. Because increased haze is unfavourable for making sightings, the raw estimate was adjusted upwards slightly in the standardization process. Also, as for past years where there has only been one spotter per plane, the raw estimate was adjusted upwards in the analysis to account for the fact that one spotter tends to make fewer sightings than two spotters. In the past several years (2009-2013), the percentage of schools that were comprised of small fish (<8 kg; estimated to be 1-year-olds) was unusually high, but that was not the case this year. The updated series was exchanged for the reconditioning of the OM at the OMMP Working Group meeting in Seattle in June.

Introduction

The index of juvenile southern bluefin tuna (SBT) abundance based on a scientific aerial survey in the Great Australian Bight (GAB) is one of the few fishery-independent indices available for monitoring and assessment of the SBT stock. The aerial survey was conducted in the GAB between 1991 and 2000, but was suspended in 2001 due to logistic problems of finding trained, experienced observers (spotters). The suspension also allowed for further data analysis and an evaluation of the effectiveness of the survey. A decision to continue or end the scientific aerial survey could then be made on the merits of the data, in particular the ability to detect changes in abundance.

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). In the light of serious concerns about the reliability of historic and current catch and CPUE data and weak year classes in the late 1990s and early 2000s, this fishery-independent index was considered even more important (Anon 2008). Thus, in 2005, the full scientific line-transect aerial survey was re-established in the GAB, and this survey has been conducted each year since. New analysis methods were developed and have subsequently been refined. Based on these methods, an index of abundance across all survey years has been constructed.

Up until 2010, all planes that flew in the survey had two spotters – a spotting pilot and a dedicated spotter – each searching his own side of the plane. Due to the retirement of the two spotting pilots involved in recent surveys, and the impossibility to replace them, one of the two planes flying in the 2010 survey and both planes flying in the 2011 to 2013 surveys had only one spotter (along with a non-spotting pilot). Solo spotters need to search both sides of the plane and are likely to miss more sightings than two spotters. In anticipation of this significant change to the survey, calibration experiments were run in parallel with the full scientific aerial survey in 2007-2009 (see Eveson et al. 2007, 2008, 2009 for details). The 2007 experiment served as a pilot study that led to improvements in the design of the 2008 and 2009 experiments. These latter experiments were designed to compare the number of SBT sightings and total estimated biomass of SBT observed by a single spotter in the calibration plane versus two spotters in the survey plane over the same area and time strata. Based on data from these experiments, a method for accounting for the fact that a plane with one observer makes fewer sightings than a plane with two observers was developed in Eveson et al. (2009, 2010) and refined in Eveson et al. (2011). These methods have been applied to the analysis since 2011.

This report summarises the field procedures and data collected during the 2014 season, describes the current methods for analysing the data (which remained the same as in the previous two years), and presents results from applying these methods to the data from all survey years.

APPENDIX 1

Methods

Field procedures

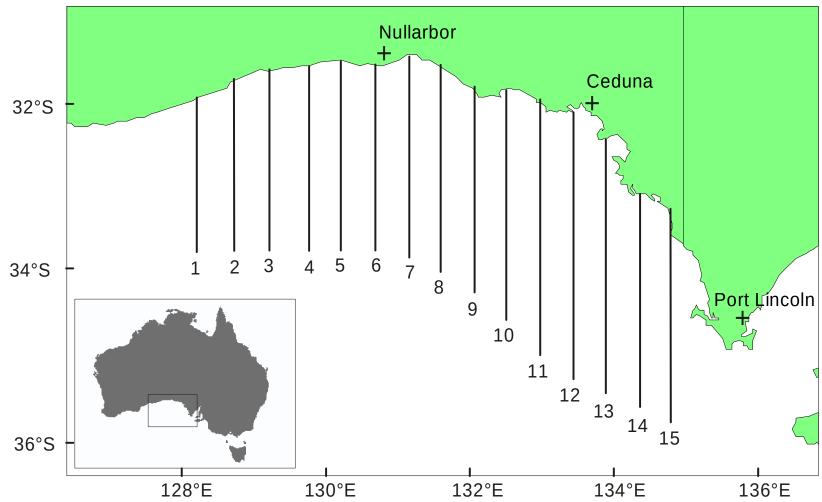
The 2014 aerial survey was conducted in the GAB between 1 January and 31 March. As in previous surveys, two Rockwell Aero Commander 500S were chartered for the season. One aircraft was chartered for the full three months and a second for January and February only. Each plane contained one observer (spotter) and a non-spotting pilot. Both observers used in 2014 were employed in previous seasons; one for the 2005 to 2013 surveys and the other in all surveys.

The aerial survey followed the protocols established for the 2000 survey (Cowling 2000) and used in all subsequent surveys with respect to the area searched, plane flying height and speed, minimum environmental conditions, time of day the survey lines were flown, and data recording protocols. Fifteen north-south transect lines (Figure 1) were surveyed. A complete replicate of the GAB consists of a subset of 12 (of the 15) lines divided into 4 blocks. In the past, the remaining 3 lines in a replicate (either: 1, 3 and 14, or 2, 13 and 15) were not searched, as SBT abundance was historically low in those areas and surveying a subset increases the number of complete replicate of the GAB in the survey. In 2009 and 2011-2013, however, the distribution of SBT in the GAB appears to have changed with an increase in abundance in the eastern GAB compared to the western GAB (see Farley and Basson, 2013). Given this, lines 13, 14 and 15 were not routinely omitted on alternative replicates of the GAB.

When flying along a line, the single observer searched the sea surface for patches of SBT from his side of the plane (the right side) through 180° to the other side of the plane (the left side). When both planes were surveying, they always surveyed neighbouring blocks. The blocks were chosen with the aim of allowing both planes to complete each block at least once per replicate. When conditions allowed for only one plane to survey (e.g. only one block was suitable), then preference was given to the plane with the observer that had not surveyed that block.

The 2014 field operation was successful, largely due to the availability of two planes on days suitable for survey. This year, 7 replicates of the GAB were completed which is similar to 2010-2013, but higher than the 3-5 replicates for the preceding 5 years when only one plane was available for the survey.

Figure 1. Location of the 15 north-south transect lines for the scientific aerial survey in the GAB.



Data preparation

The data collected from the 2014 survey were loaded into the aerial survey database and checked for any obvious errors or inconsistencies and corrections made as necessary. In order for the analyses to be comparable between all survey years, only data collected in a similar manner from a common area were included in the data summaries and analyses presented in this report. In particular, only search effort and sightings made along north/south transect lines in the unextended (pre-1999) survey area and sightings made within 6 nm of a transect line were included (see Basson et al. 2005 for details). In cases where a sighting consisted of more than one school, then the sighting was included if at least one of the schools was within 6 nm of the line. We excluded secondary sightings and any search distance and sightings made during the aborted section of a transect line (see Eveson et al. 2006 for details).

The data from recent survey years (2009-2013) included an unusually high proportion of schools of small fish estimated to be less than 8kg, which we assume to be the average weight cut-off between 1- and 2-year olds (Table 1). This was first noted in 2011 (Eveson et al. 2011). In the current year, the proportion of schools comprised of such small fish was much lower and similar to values seen in the late 1990s (Table 1). In the CCSBT operating model (OM) and management procedures (MP), the aerial survey index is assumed to provide a relative time series of age 2-4 abundance in the Great Australian Bight. Thus, for consistency with the OM and MP as well as general consistency in interpretation of the index across years, schools estimated to be comprised of 1-year-old fish (i.e., that had an average fish size estimate of less than 8 kg) are omitted from the analysis (see Eveson et al. 2011).

Table 1. Percent of schools in each survey year comprised of fish estimated to be less than 8kg on average (assumed to be 1-year-olds).

YEAR	%	YEAR	%
1993	0.2	2006	0.7
1994	7.4	2007	0.0
1995	8.8	2008	0.7
1996	3.7	2009	13.1
1997	8.2	2010	16.1
1998	6.2	2011	30.7
1999	1.4	2012	25.3
2000	0.8	2013	17.7
2005	2.1	2014	4.1

Search effort and sightings

A summary of the total search effort and SBT sightings made in each survey year is given in Table 2. All of the values are based on raw data, which have not been corrected for environmental factors or observer effects. This table, and all summary information and results presented in this report, include only the data outlined in the previous section as being appropriate for analysis. Recall that we are omitting schools comprised of fish less than <8 kg on average. Also note that the summary statistics include data from all flights, some of which had only one observer in 2010 and all of which had only one observer in 2011 to 2014 (with the exception of two flights in 2012 and four flights in 2013).

The total distance searched in 2014 was again very high due to the continued (since 2010) availability of two survey planes and reasonably good flying conditions. The raw sightings rate (number of sightings per 100 nm) was above average (Table 2). Similarly, since the sightings were quite large on average (Figure 2), the total biomass per nm was also higher than average, although still not as high as in 2010 and 2011 (Table

2). ***It is important to keep in mind that the statistics for 2010-2014 include data from flights with only one observer, so caution must be used in comparing them directly with previous years for which all flights had two observers because we have shown previously that the sightings rate tends to be lower for flights with only one observer.***

The distribution of sightings was similar to 2013, with most being made in inshore and in the eastern half of the survey area (Figure 3). Note however that there was also a greater percent of sightings along the 6 westernmost lines than since 2006 (Figure 3).

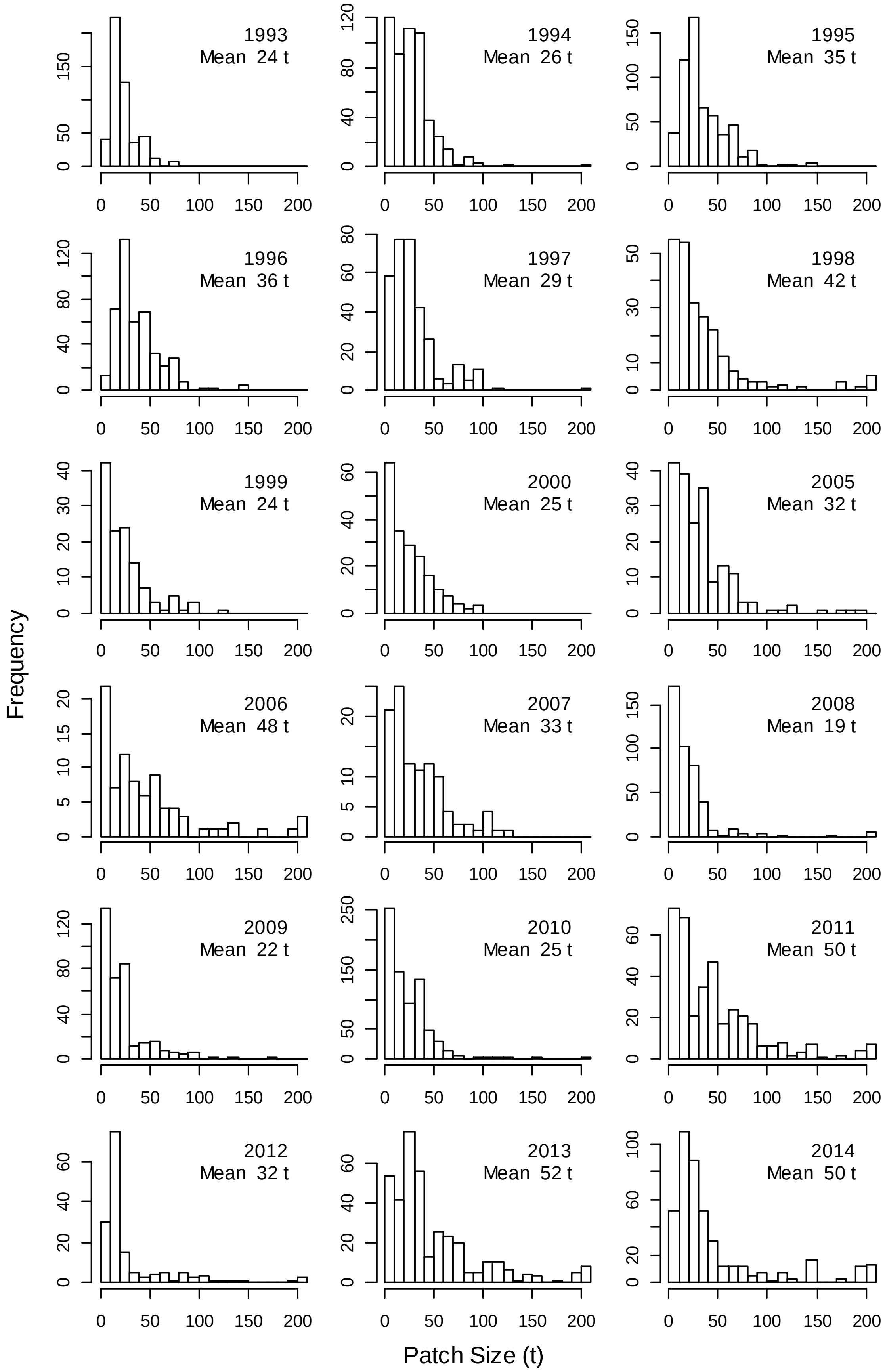
Table 2. Summary of aerial survey data by survey year. Only data considered suitable for analysis (as outlined in text) are included. All biomass statistics are in tonnes. All values in the table are based on raw data, which have not been corrected for environmental factors or observer effects.

SURVEY YEAR	TOTAL DISTANCE SEARCHED (NM)	NUMBER SBT SIGHTINGS	SIGHTINGS PER 100NM	TOTAL BIOMASS	BIOMASS PER NM	AVERAGE PATCHES PER SIGHTING	MAX PATCHES PER SIGHTING	AVERAGE BIOMASS PER PATCH	MAX BIOMASS PER PATCH
1993	7603	129	1.70	12219	1.61	4.0	76	24.5	203
1994	15180	160	1.05	13978	0.92	3.3	23	26.4	247
1995	14573	165	1.13	20149	1.38	3.5	38	34.7	225
1996	12284	110	0.90	16047	1.31	4.0	46	36.5	147
1997	8813	101	1.15	9154	1.04	3.2	18	28.5	203
1998	8550	104	1.22	9764	1.14	2.2	21	42.1	966
1999	7555	50	0.66	2998	0.40	2.5	21	24.2	122
2000	6775	76	1.12	4812	0.71	2.6	17	24.8	100
2005	5968	79	1.32	6043	1.01	2.4	17	32.1	198
2006	5150	43	0.83	4068	0.79	2.0	8	47.9	272
2007	4872	41	0.84	3538	0.73	2.6	11	33.4	123
2008	7462	121	1.62	8009	1.07	3.5	24	19.0	314
2009	8101	145	1.79	7964	0.98	2.5	22	22.3	172
2010[1]	10559	184	1.74	18477	1.75	4.0	41	24.9	539
2011[2]	10148	135	1.33	18559	1.83	2.7	37	50.2	400
2012[2]	10777	48	0.45	4939	0.46	3.2	45	32.1	507
2013[2]	12889	124	0.96	19127	1.48	3.0	18	52.0	634
2014[2]	12238	175	1.43	21213	1.73	2.4	25	49.7	481

[1] Data comes from flights with one observer as well as flights with two observers.
[2] All data comes from flights with one observer (with the exception of one flight in 2012 and 3 flights in 2013).

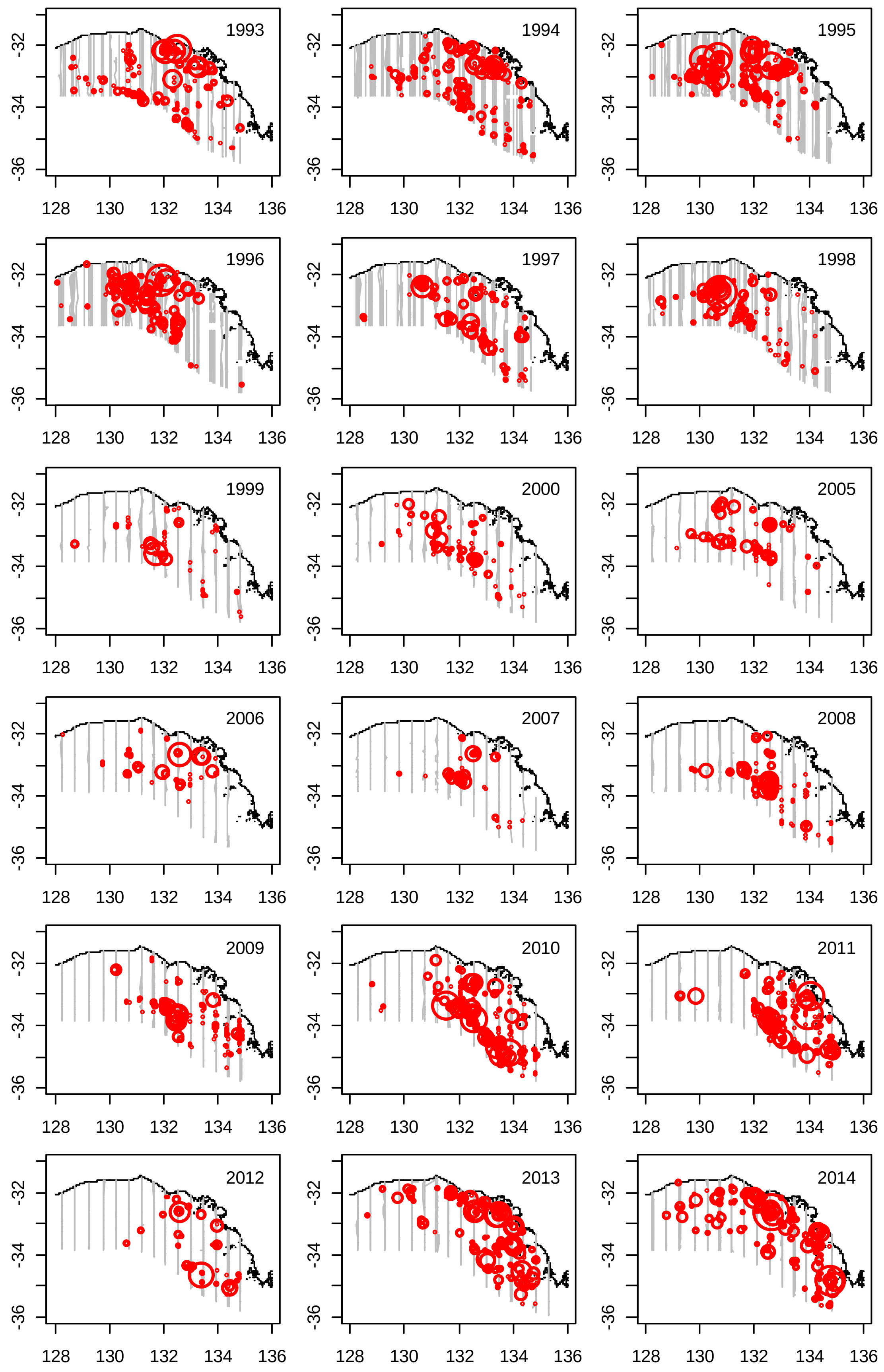
APPENDIX 1

Figure 2. Frequency of SBT patch sizes (in tonnes) by survey year.



APPENDIX 1

Figure 3. Distribution of SBT sightings made during each aerial survey year. Red circles show the locations of SBT sightings, where the size of the circle is proportional to the size of the sighting, and grey lines show the north/south transect lines that were searched.



Environmental variables

Table 3 and Figure 4 summarize the environmental conditions that were present during valid search effort in each survey year. All the environmental variables presented were recorded by the survey plane(s), with the exception of sea surface temperature (SST), which was extracted from the 3-day composite SST dataset produced by CSIRO Marine and Atmospheric Research's Remote Sensing Project (see Eveson et al. 2006 for more details).

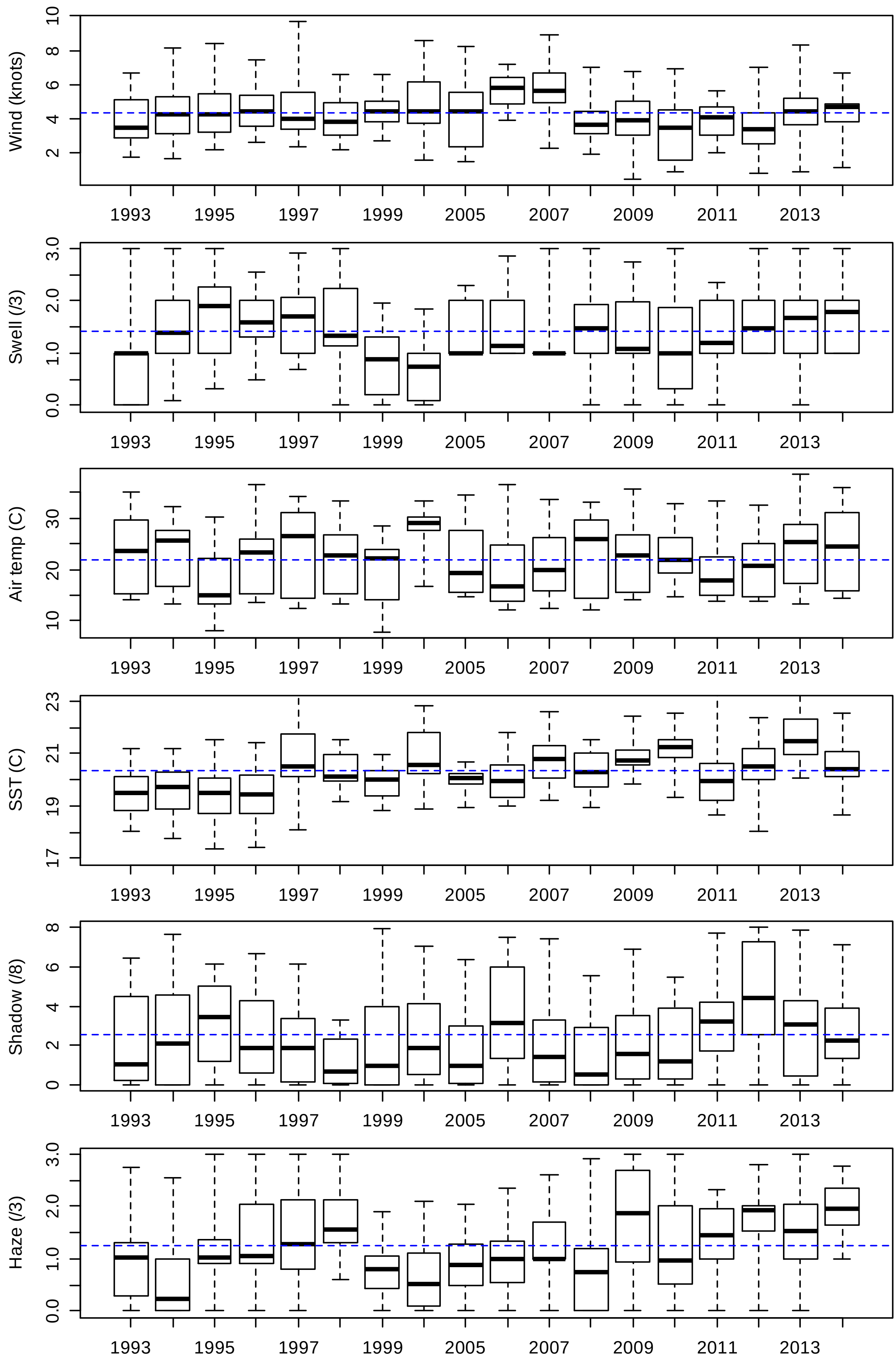
The environmental conditions during the 2014 survey were close to average in terms of SST and wind speed; however, the level of haze was significantly higher than average (Table 3; Figure 4). Increased haze makes it more difficult to observe surface schools, so we expect the observed sightings rate to be increased in the standardization process (to adjust for the fact that more sightings would likely have been made with less haze).

Table 3. Average environmental conditions during search effort for each aerial survey year.

SURVEY YEAR	WIND SPEED (KNOTS)	SWELL HEIGHT (0-3)	AIR TEMP (°C)	SST (°C)	SEA SHADOW (0-8)	HAZE (0-3)
1993	3.9	0.8	24.4	19.6	1.9	0.9
1994	4.1	1.5	22.7	19.7	2.8	0.5
1995	4.4	1.7	18.7	19.6	2.7	1.1
1996	4.5	1.6	22.9	19.6	2.1	1.2
1997	4.1	1.7	25.3	21.1	1.6	1.3
1998	3.7	1.7	22.3	20.4	0.9	1.7
1999	4.1	0.9	22.0	19.9	2.9	0.7
2000	4.3	0.6	27.5	20.7	2.6	0.7
2005	4.7	1.5	21.7	20.1	1.6	0.8
2006	5.6	1.5	20.0	20.1	3.5	1.0
2007	5.8	1.3	21.6	20.8	2.0	1.3
2008	3.8	1.4	24.2	20.4	1.4	0.9
2009	3.8	1.4	22.3	21.0	2.2	1.7
2010	3.5	1.1	23.6	21.2	1.8	1.2
2011	3.9	1.3	20.2	20.3	2.8	1.4
2012	3.7	1.6	20.7	20.5	4.3	1.8
2013	4.2	1.6	24.6	21.7	2.6	1.6
2014	4.3	1.8	24.0	20.6	2.4	1.9

APPENDIX 1

Figure 4. Boxplots summarizing the environmental conditions present during valid search effort for each aerial survey year. The thick horizontal band through a box indicates the median, the length of a box represents the inter-quartile range, and the vertical lines extend to the minimum and maximum values. The dashed blue line running across each plot shows the average across all survey years.



APPENDIX 1

Method of analysis

The methods of analysis used this year were exactly the same as the past two years. We give a brief description of the methods here, but details can be found in Appendix A.

Generalized linear models were fit to two different components of observed biomass—biomass per sighting (BpS) and sightings per nautical mile of transect line (SpM). We included the same environmental and observer variables in both models as last year (note that sea shadow was added to the SpM model last year). Specifically, the models can be expressed as:

BpS model: logE(Biomass) ~ Year*Month*Area + SST + WindSpeed

SpM model: logE(N_sightings) ~ offset{log(Distance) + log(ObsEffect)} + Year*Month*Area + SST + WindSpeed + Swell + Haze + MoonPhase + SeaShadow

Note that, as of 2011, we include "observer effect" as an offset (i.e., as known) in the SpM model rather than as a linear covariate. The reason for this is discussed in Appendix A of Eveson et al. (2011). Because of this, we need to account for uncertainty in the observer effect estimates through other methods. Such methods have been developed for application to similar problems, but they are computer intensive and we have had difficulties implementing them successfully in this context. Thus, the standard errors, CVs and confidence intervals for the relative abundance indices reported in Table 4 do not include uncertainty in the observer effects for the SpM model (meaning they are slightly too small).

In both models, Year, Month and Area were fit as factors, as was MoonPhase in the SpM model. All other explanatory variables were fit as linear covariates. Note that the term Year*Month*Area encompasses all 1-way, 2-way and 3-way interactions between Year, Month and Area (i.e., it is equivalent to writing Year + Month + Area + Year:Month + Year:Area + Month:Area + Year:Month:Area).

In both models, the 2-way and 3-way interaction terms between Year, Month and Area were fit as random effects, whereas the 1-way effects were fit as fixed effects. Many of the 2-way and 3-way strata have very few (sometimes no) observations, which causes instabilities in the model fits when treated as fixed effects. One main advantage of using random effects is that when little or no data exist for a given level of a term (say for a particular area and month combination of the Area:Month term), we still have information about it because we are assuming it comes from a normal distribution with a certain mean and variance (estimated within the model).

Data from the single-observer flights in 2010 to 2014 can be included in the BpS model without any changes, except that there is only one biomass estimate per school so it is not necessary to take an average over the estimates made by two observers (refer to "Biomass per sighting (BpS) model" section in Appendix A). With regard to the SpM model, we know from the calibration experiments conducted in 2008 and 2009 that a plane with only one observer makes fewer sightings than a plane with two observers. Based on an updated analysis of the calibration experiment data conducted in 2011 (Eveson et al. 2011), we estimate that, on average, a plane with one observer will make about 70% as many sightings as a plane with two observers. We refer to this factor as the "calibration factor". The calibration factor is used to estimate the relative sighting ability (i.e., an "observer effect") for solo observers. Recall that the "observer effect" estimates for the SpM model are calculated based on a pair-wise observer analysis to estimate the relative sighting abilities of all observer pairs that have been involved in past surveys (see Appendix A). In order to estimate a relative sighting ability for a solo observer, we took the average of the relative sighting ability estimates from when this observer flew as part of a pair, and multiplied it by the estimated calibration factor. For example, one of the observers who flew as a solo observer in the 2010 and 2011 surveys has flown as part of two different observer pairs in past surveys, with relative sighting ability estimates of 0.90 and 0.92. If we take the average of these two relative sighting ability estimates and multiply it by the calibration factor of 0.7, this gives a relative sighting ability estimate for this observer when flying solo of 0.64. This gives us "observer effect" estimates for all observer combinations, so we can proceed with fitting the SpM model in the usual way.

Once the models were fitted, the results were used to predict what the number of sightings per mile and the average biomass per sighting in each of the 45 area/month strata in each survey year would have been under standardized environmental/observer conditions. Using these predicted values, we calculated an abundance estimate for each stratum as 'standardized SpM' multiplied by 'standardized average BpS'. We then took the weighted sum of the stratum-specific abundance estimates over all area/month strata within a year, where each estimate was weighted by the geographical size of the stratum in nm2, to get an overall abundance estimate for that year. Lastly, the annual estimates were divided by their mean to get a time series of relative abundance indices.

We emphasise that it is important to have not only an estimate of the relative abundance index in each year, but also of the uncertainty in the estimates. We used the same process as in the last three years to calculate CVs for the indices, which take into account uncertainty in the calibration factor estimate. Details can be found in Appendix B. Recall from above that there is still uncertainty in the observer effect estimates for the SpM model which is not currently being accounted for.

We calculated confidence intervals for the indices based on the assumption that the logarithm of the indices follows a normal distribution, with standard errors approximated by the CVs of the untransformed indices.

Results

(Results and diagnostics for the BpS and SpM models are provided in Appendix C.)

Figure 5 shows the estimated time series of relative abundance indices with 90% confidence intervals. The point estimates and CVs corresponding to Figure 5 are given in Table 4. Recall from the Methods section that all of the confidence intervals are being slightly underestimated because they do not account for uncertainty in the observer effect estimates.

The 2014 point estimate is the highest of all survey years, and significantly higher when taking confidence intervals into account.

Figure 5. Time series of relative abundance estimates with 90% confidence intervals.

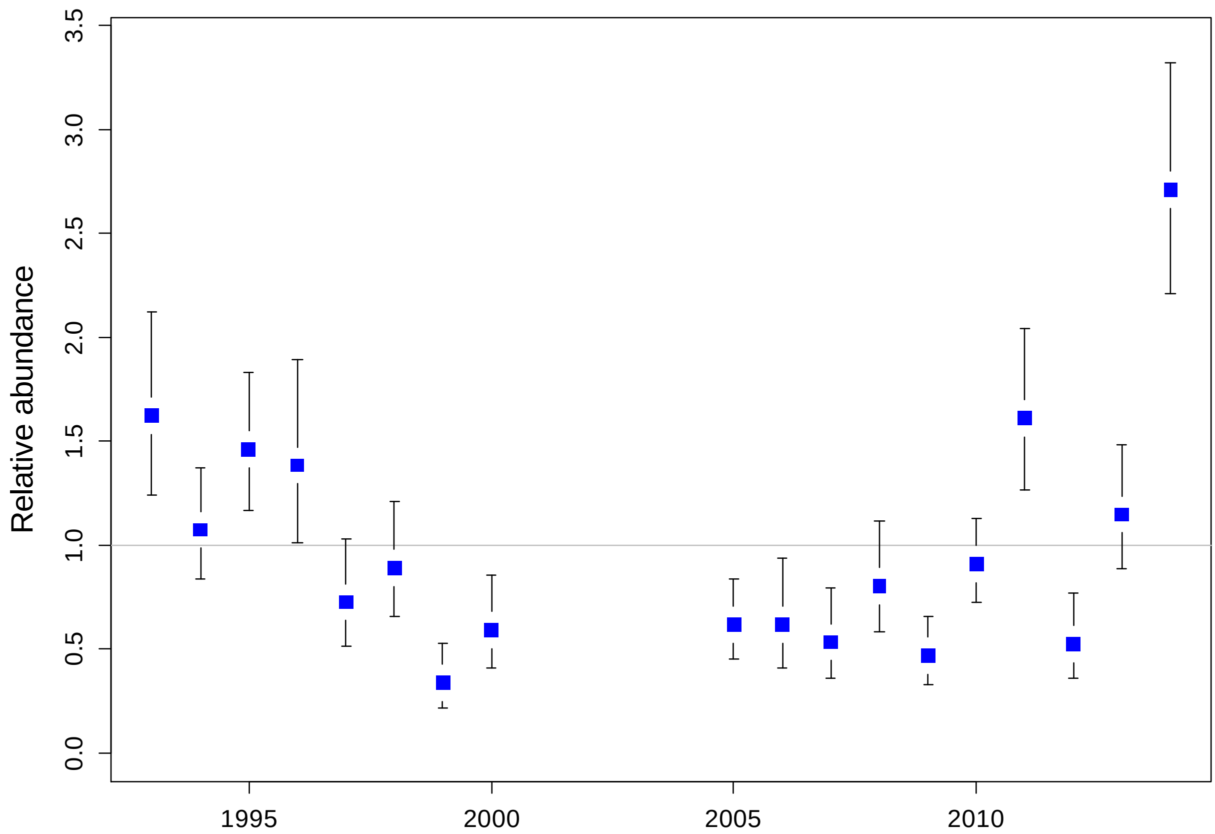


Table 4. Results from the aerial survey analysis.

YEAR	INDEX	SE	CV	CI.05	CI.95
1993	1.62	0.26	0.16	1.24	2.12
1994	1.07	0.16	0.15	0.84	1.37
1995	1.46	0.20	0.14	1.17	1.83
1996	1.38	0.26	0.19	1.01	1.89
1997	0.72	0.15	0.21	0.51	1.03
1998	0.89	0.17	0.19	0.65	1.21
1999	0.34	0.09	0.27	0.21	0.53
2000	0.59	0.13	0.23	0.41	0.86
2005	0.61	0.11	0.19	0.45	0.83
2006	0.62	0.16	0.25	0.41	0.93
2007	0.53	0.13	0.24	0.36	0.79
2008	0.80	0.16	0.20	0.58	1.12
2009	0.46	0.10	0.21	0.33	0.66
2010	0.91	0.12	0.13	0.73	1.13
2011	1.61	0.23	0.15	1.27	2.04
2012	0.52	0.12	0.23	0.36	0.77
2013	1.15	0.18	0.16	0.89	1.48
2014	2.71	0.34	0.12	2.21	3.32

Index = relative abundance point estimates; SE= standard error; CV = coefficient of variation; CI.05 and CI.95 = lower and upper range of 90% confidence interval.

Summary

The estimate of relative juvenile abundance from the 2014 scientific aerial survey is significantly higher than for any previous survey year.

The methods of analysis used this year were exactly the same as last two years (Eveson et al. 2012, 2013). Methods to account for uncertainty in the observer effect estimates for the SpM model have yet to be implemented; thus, the CVs for the relative abundance indices do not yet include uncertainty in the observer effects for the SpM model (i.e., they are slightly too small).

The environmental conditions during the 2014 survey were average for the most part, except that the level of haze was higher than usual. Most sightings were made inshore in the eastern half of the survey area. The unusually high percentage of schools comprised of small fish (<8 kg) that were seen in 2009-2013 were not observed this year.

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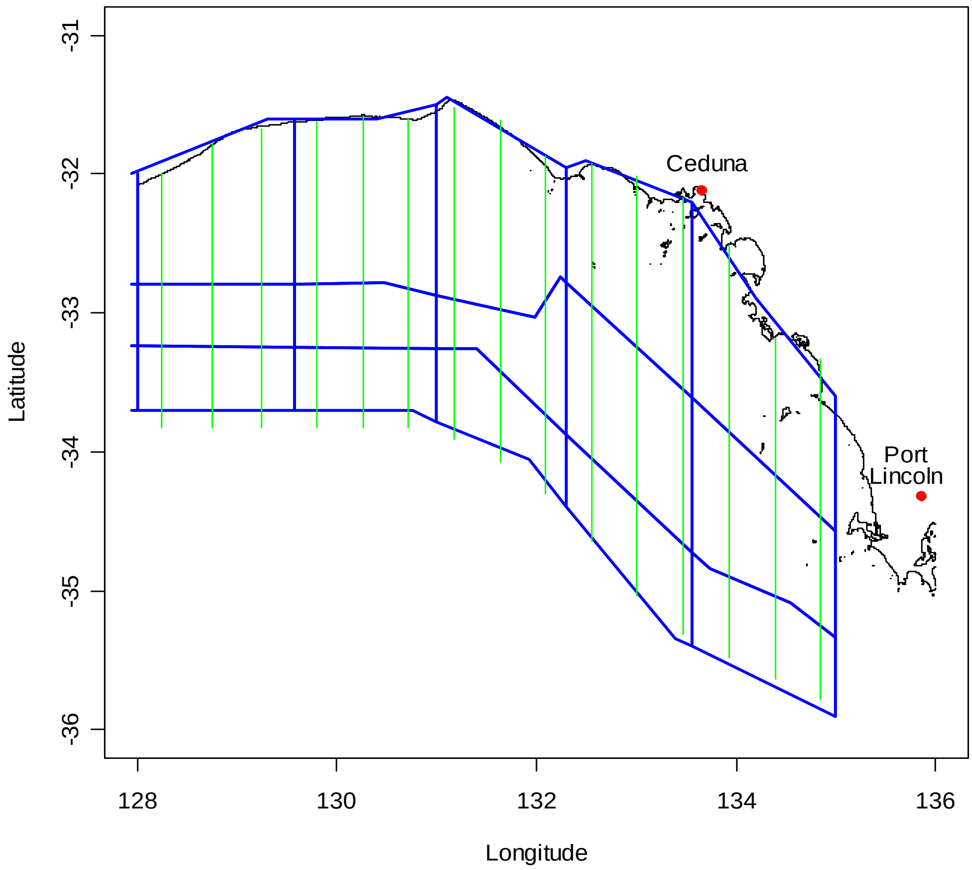
Appendix A - Methods of analysis

Separate models were constructed to describe two different components of observed biomass: i) biomass per patch sighting (BpS) and ii) sightings per nautical mile of transect line (SpM). Each component was fitted using a generalized linear mixed model (GLMM), as described below. Since environmental conditions affect what proportion of tuna are available at the surface to be seen, as well as how visible 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 models include 'corrections' for environmental and observer effects in order to produce standardized indices that can be meaningfully compared across years.

For the purposes of analysis, we defined 45 area/month strata: 15 areas (5 longitude blocks and 3 latitude blocks, as shown in Figure A1) and 3 months (Jan, Feb, Mar). The latitudinal divisions were chosen to correspond roughly to depth strata (inshore, mid-shore and shelf-break).

Figure A1. Plot showing the 15 areas (5 longitudinal bands and 3 latitudinal bands) into which the aerial survey is divided for analysis purposes. The green vertical lines show the official transect lines for the surveys conducted in 1999 and onwards; the lines for previous survey years are similar but are slightly more variable in their longitudinal positions and also do not extend quite as far south (which is why the areas defined for analysis, which are common to all survey years, do not extend further south).



A.1 Biomass per sighting (BpS) model

For the BpS model, we first estimated relative differences between observers in their estimates of patch size (using the same methods as described in Bravington 2003). As in Bravington (2003), we found good consistency between observers. In particular, patch size estimates made by different observers tended to be within about 5% of each other, except for one observer, say X, who tended to underestimate patch sizes relative to other observers by about 20%. The patch size estimates were corrected using the estimated observer differences (e.g. patch size estimates made by observer X were scaled up by 20%). Because the observer differences were estimated with high precision, we treated the corrected patch size estimates as exact in our subsequent analyses. The final biomass estimate for each patch was calculated as the average of the two corrected estimates (recall that the size of a patch is estimated by both observers in the plane). The final patch size estimates were then aggregated within sightings to give an estimate of the total biomass of each sighting. It is the total biomass per sighting data that are used in the BpS model.

The BpS model was fitted using a GLMM with a log link and a Gamma error structure. We chose to fit a rather rich model with 3-way interaction terms between year, month and area. This is true not only for the BpS model but also for the SpM model described below. In essence, the 3-way interaction model simply corrects the observation (the total biomass of a sighting in the case of the BpS model; the number of sightings in the case of the SpM model) for environmental effects, which are estimated from within-stratum comparisons (i.e. within each combination of year, month and area).

The 2-way and 3-way interaction terms between Year, Month and Area were fit as random effects, whereas the 1-way effects were fit as fixed effects. Many of the 2-way and 3-way strata have very few (sometimes no) observations, which causes instabilities in the model fits when treated as fixed effects. One main advantage of using random effects is that when little or no data exist for a given level of a term (say for a particular area and month combination of the Area:Month term), we still have information about it because we are assuming it comes from a normal distribution with a certain mean and variance (estimated within the model).

Based on exploratory plots and model fits, we confirmed that SST has a significant effect on the biomass per sighting, and that wind speed has a lesser but still significant effect (p-value 0.02; see Appendix C.1). Thus, the final model fitted was

logE(Biomass) ~ Year*Month*Area + SST + WindSpeed

where Year, Month and Area are factors, and SST and WindSpeed are linear covariates (note that E is standard statistical notation for expected value).

A.2 Sightings per mile (SpM) model

For the SpM model, we first ran the pairwise observer analysis described in Bravington (2003), based on within-flight comparisons of sighting rates between the various observers. This analysis gives estimates of the relative sighting efficiencies for the 18 different observer pairs that have flown at some point in the surveys. The observer pairs ranged in their estimated sighting efficiencies from 72% to 97% compared to the pair with the best rate.

We include the (logged) estimates of relative observer pair efficiencies as an offset when fitting the SpM model (i.e., as a predictor variable with a known, rather than estimated, coefficient). Appendix A of Eveson et al. 2011 discusses this in more detail. As such, we need to account for the uncertainty in these estimates through other methods. Such methods have been developed for other applications but have proven difficult to implement in this context. Thus, the standard errors and CVs for the relative abundance indices reported in Table 4 do not include uncertainty in the observer effects for the SpM model (which means they are slightly too small). We will continue to pursue methods of accounting for observer uncertainty in the coming year.

The data used for the SpM model were accumulated by flight and area, so that the data set used in the analysis contains a row for every flight/area combination in which search effort was made (even if no sightings were made). Within each flight/area combination, the number of sightings and the distance flown were summed, whereas the environmental conditions were averaged. The SpM model was fitted using a GLMM with the number of sightings as the response variable, as opposed to the sightings rate. The model could then be fitted assuming an overdispersed Poisson error structure[3] with a log link and including the distance flown as an offset term to the model (i.e. as a linear predictor with a known coefficient of one).

As we did for the BpS model, we included terms for year, month and area, as well as all possible interactions between them, in the SpM model, and we fitted the 2-way and 3-way interaction terms as random effects (see BpS model section). We determined what environmental variables to include in the model based on exploratory plots and model fits. The final model fitted was:

logE(N_sightings) ~ offset(log(Distance) + log(ObsEffect)) + Year*Month*Area + SST + WindSpeed + Swell + Haze + MoonPhase + SeaShadow

where Year, Month and Area are factors, MoonPhase is a factor (taking on one of four levels from new moon to full moon), and all other terms are linear covariates. Note that MoonPhase is no longer coming out significant (see Appendix C.2) but we chose to keep it in the model for consistency with previous years.

A.3 Combined analysis

The BpS and SpM model results were used to predict what the number of sightings per mile and the average biomass per sighting in each of the 45 area/month strata in each survey year would have been under standardized environmental/observer conditions[4]. Using these predicted values, we calculated an abundance estimate for each stratum as 'standardized SpM' multiplied by 'standardized average BpS'. We then took the weighted sum of the stratum-specific abundance estimates over all area/month strata within a year, where each estimate was weighted by the geographical size of the stratum in nm^2, to get an overall abundance estimate for that year. Lastly, the annual estimates were divided by their mean to get a time series of relative abundance indices.

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[3] Note that the standard Poisson distribution has a very strict variance structure in which the variance is equal to the mean, and it would almost certainly underestimate the amount of variance in the sightings data, hence the use of an overdispersed Poisson distribution to describe the error structure.

[4] In our predictions, we used average conditions calculated from all the data.

Appendix B - CV calculations

This appendix provides details of how CVs for the aerial survey abundance indices were calculated.

Let $\hat{B}_{ijk}$ be the predicted value of BpS in year *i*, month *j* and area *k* under standardized environmental/observer conditions (see footnote 4), and $\hat{\sigma}\left(\hat{B}_{ijk}\right)$ be its estimated standard error. Similarly, let $\hat{S}_{ijk}$ be the predicted value of SpM in year *i*, month *j* and area *k* under the same environmental/observer conditions, and $\hat{\sigma}\left(\hat{S}_{ijk}\right)$ be its estimated standard error. Then,

$$\hat{A}_{ijk} = \hat{S}_{ijk}\hat{B}_{ijk}$$

is the stratum-specific abundance estimate for year *i*, month *j* and area *k*.

Since $\hat{B}_{ijk}$ and $\hat{S}_{ijk}$ are independent, the variance of $\hat{A}_{ijk}$ is given by

$$\begin{aligned} V\left(\hat{A}_{ijk}\right) &= V\left(\hat{S}_{ijk}\hat{B}_{ijk}\right) \\ &= V\left(\hat{S}_{ijk}\right)E\left(\hat{B}_{ijk}\right)^2 + V\left(\hat{B}_{ijk}\right)E\left(\hat{S}_{ijk}\right)^2 + V\left(\hat{S}_{ijk}\right)V\left(\hat{B}_{ijk}\right) \\ &\approx \hat{\sigma}^2\left(\hat{S}_{ijk}\right)\hat{B}_{ijk}{}^2 + \hat{\sigma}^2\left(\hat{B}_{ijk}\right)\hat{S}_{ijk}{}^2 + \hat{\sigma}^2\left(\hat{S}_{ijk}\right)\hat{\sigma}^2\left(\hat{B}_{ijk}\right) \end{aligned}$$

The annual abundance estimate for year *i* is given by the weighted sum of all stratum-specific abundance estimates within the year, namely

$$\hat{A}_i = \sum_j \sum_k w_k \hat{A}_{ijk}$$

where w_k is the proportional size of area *k* relative to the entire survey area ($\sum_k w_k = 1$).

If the $\hat{A}_{ijk}$'s are independent, then the variance of $\hat{A}_i$ is given by

$$V\left(\hat{A}_i\right) = \sum_j \sum_k w_k{}^2 V\left(\hat{A}_{ijk}\right)$$

Unfortunately, the $\hat{A}_{ijk}$'s are NOT independent because the estimates of BpS (and likewise, the estimates of SpM) are not independent between different strata. This is because all strata estimates depend on the estimated coefficients of the environmental/observer conditions, so any error in these estimated coefficients will affect all strata. Thus, we refit the BpS and SpM models with the coefficients of the environmental/observer covariates (denote the vector of coefficients by θ[5]) fixed at their estimated values ($\hat{\theta}$). The predictions of BpS and SpM made using the 'fixed environment' models should now be independent between strata, so the stratum-specific abundance estimates calculated using these predictions – which we will denote by $\hat{A}_{ijk}\left(\hat{\theta}\right)$ – should also be independent between strata. Thus, we can

[5] θ contains the environmental/observer coefficients from both the BpS and SpM models; i.e. $\theta = (\theta_{\text{BpS}}, \theta_{\text{SpM}})$

calculate the variance of $\hat{A}_i$ conditional on the estimated values of the environmental/observer coefficients as

$$V\left(\hat{A}_i \mid \hat{\theta}\right) = \sum_j \sum_k w_k{}^2 \, V\left(\hat{A}_{ijk}\left(\hat{\theta}\right)\right)$$

where $V\left(\hat{A}_{ijk}\left(\hat{\theta}\right)\right)$ is calculated using the formula given above for $V\left(\hat{A}_{ijk}\right)$ but using the BpS and SpM predictions and standard errors obtained from the 'fixed environment' models.

To calculate the unconditional variance of $\hat{A}_i$, we make use of the following equation:

$$\begin{aligned} V\left(\hat{A}_i\right) &= E_\theta\left(V\left(\hat{A}_i \mid \theta\right)\right) + V_\theta\left(E\left(\hat{A}_i \mid \theta\right)\right) \\ &\approx V\left(\hat{A}_i \mid \hat{\theta}\right) + V_\theta\left(\hat{A}_i\right) \end{aligned}$$

where the first term is the conditional variance just discussed and the second term is the additional variance due to uncertainty in the environmental coefficients. The second term can be estimated as follows

$$V_\theta\left(\hat{A}_i\right) \approx \left(\frac{\partial \hat{A}_i}{\partial \theta}\right)' \mathbf{V}_\theta \left(\frac{\partial \hat{A}_i}{\partial \theta}\right)$$

where $\left(\frac{\partial \hat{A}_i}{\partial \theta}\right)$ is the vector of partial derivatives of $\hat{A}_i$ with respect to θ (which we calculated using numerical differentiation), and $\mathbf{V}_\theta$ is the variance-covariance matrix of the environmental coefficients[6].

Now, to account for the additional variance due to uncertainty in the calibration factor, we use a similar approach as above to account for additional variance due to uncertainty in the environmental coefficients. Namely, from the GLM used to estimate the calibration factor, which we will call α, we get an estimate of its variance, which we will call V_α. Then, the variance in the abundance estimates due to uncertainty in α can be estimated by

$$V_\alpha\left(\hat{A}_i\right) = \left(\frac{\partial \hat{A}_i}{\partial \alpha}\right)' V_\alpha \left(\frac{\partial \hat{A}_i}{\partial \alpha}\right)$$

where $\left(\frac{\partial \hat{A}_i}{\partial \alpha}\right)$ is the derivative of $\hat{A}_i$ with respect to α (in essence, it is the amount that the abundance estimate $\hat{A}_i$ changes when the calibration factor is tweaked slightly). Thus, we revise our estimate of $V\left(\hat{A}_i\right)$ by adding on to it $V_\alpha\left(\hat{A}_i\right)$.

[6] Recall that θ contains the environmental/observer coefficients from both the BpS and SpM models, so $\mathbf{V}_\theta = \begin{bmatrix} \mathbf{V}_{\theta_{\mathrm{BpS}}} & \mathbf{0} \\ \mathbf{0} & \mathbf{V}_{\theta_{\mathrm{SpM}}} \end{bmatrix}$. The variance-covariance matrices for the individual models are returned from the model-fitting software.

So we have variance estimates for the abundance estimates, but we also want to calculate the variance for the mean-standardized estimates (referred to as the relative abundance indices), calculated as:

$$\hat{I}_i = \frac{\hat{A}_i}{\frac{1}{n}\sum_{i=1}^{n}\hat{A}_i}$$

Using the delta method, we can approximate the variance of $\hat{I}_i$ by

$$V\left(\hat{I}_i\right) \approx \left(\frac{\partial \hat{I}_i}{\partial \hat{A}_i}\right)^2 V\left(\hat{A}_i\right)$$

Then, the standard error of $\hat{I}_i$ is given by

$$\sigma\left(\hat{I}_i\right) = \sqrt{V\left(\hat{I}_i\right)}$$

and the coefficient of variation (CV) of $\hat{I}_i$ is given by

$$\mathrm{CV}\left(\hat{I}_i\right) = \frac{\sigma\left(\hat{I}_i\right)}{\hat{I}_i}.$$

Appendix C - Results and diagnostics

C.1 Biomass per sighting (BpS) model

Figure C1 shows plots of observed biomass per sighting (logged) versus the environmental covariates being included in the BpS model. From these plots, it appears that the size of a sighting tends to increase as SST increases, and possibly decrease as wind speed increases (in a roughly linear fashion in both cases when on a log scale). The relationship with SST appears to be strongest, as supported by the model results (below).

Extract from the output produced by the software used to fit the model (the gam function in the R statistical package mgcv):

```
Family: Gamma
Link function: log

Formula:
Biomass ~ factor(Year) + factor(Month) + factor(Area) + SST + WindSpeed +
Y.M + Y.A + M.A + Y.M.A - 1

Parametric Terms:
```

Covariate	Estimate	SE	t-value	p-value
SST	0.116	0.037	3.16	0.002
WindSpeed	-0.053	0.023	-2.33	0.020

```
R-sq.(adj) =  0.0711   Deviance explained = 36.3%
GCV score =  1.964  Scale est. = 1.7348    n = 1984
```

The results support our observations made based on Figure C1; size of a sighting tends to increase as SST increases and decrease as wind speed increases, but that relationship with SST has greater statistical significance.

Figure C2 shows some standard diagnostic plots for generalized linear models, and Figure C3 shows the residuals plotted against a number of factors. These plots do not suggest major problems with the model fit. Ideally there should be no trend in the plots of the square root of the absolute residuals against the fitted values (i.e., lower half of Fig. C2, with left-hand side being on the link scale and the right-hand side being on the response scale); although there is a small kink revealed by a smooth through the data (red line), there is not a consistent increasing or decreasing trend.

APPENDIX 1

Figure C1. Plots of observed biomass per sighting, on a log scale, versus the covariates included in the model; shown is the mean +/- 2 standard deviations.

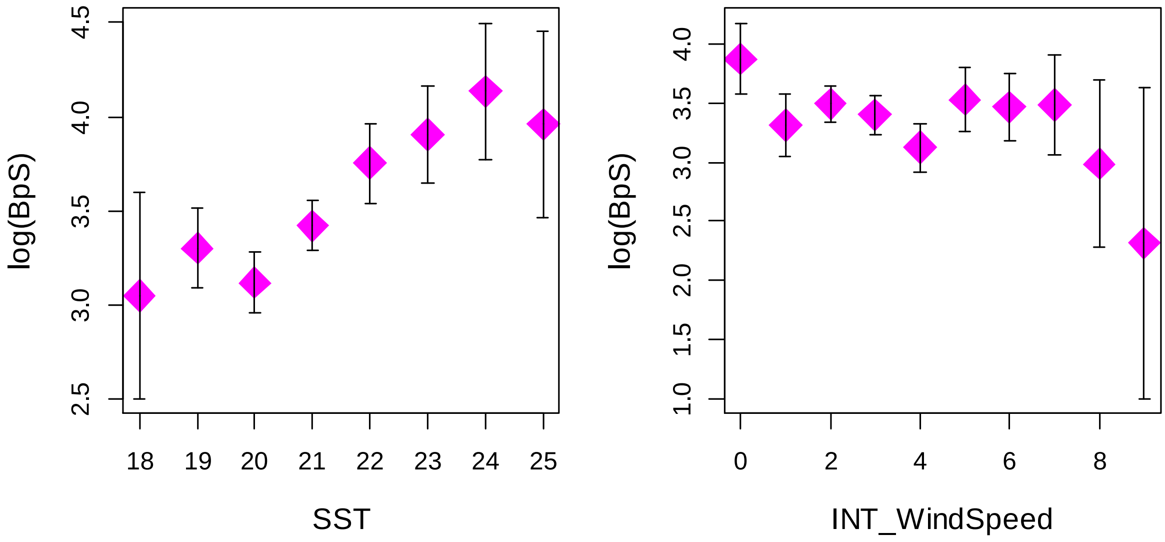


Figure C2. Standard diagnostic plots for biomass per sighting (BpS) model.

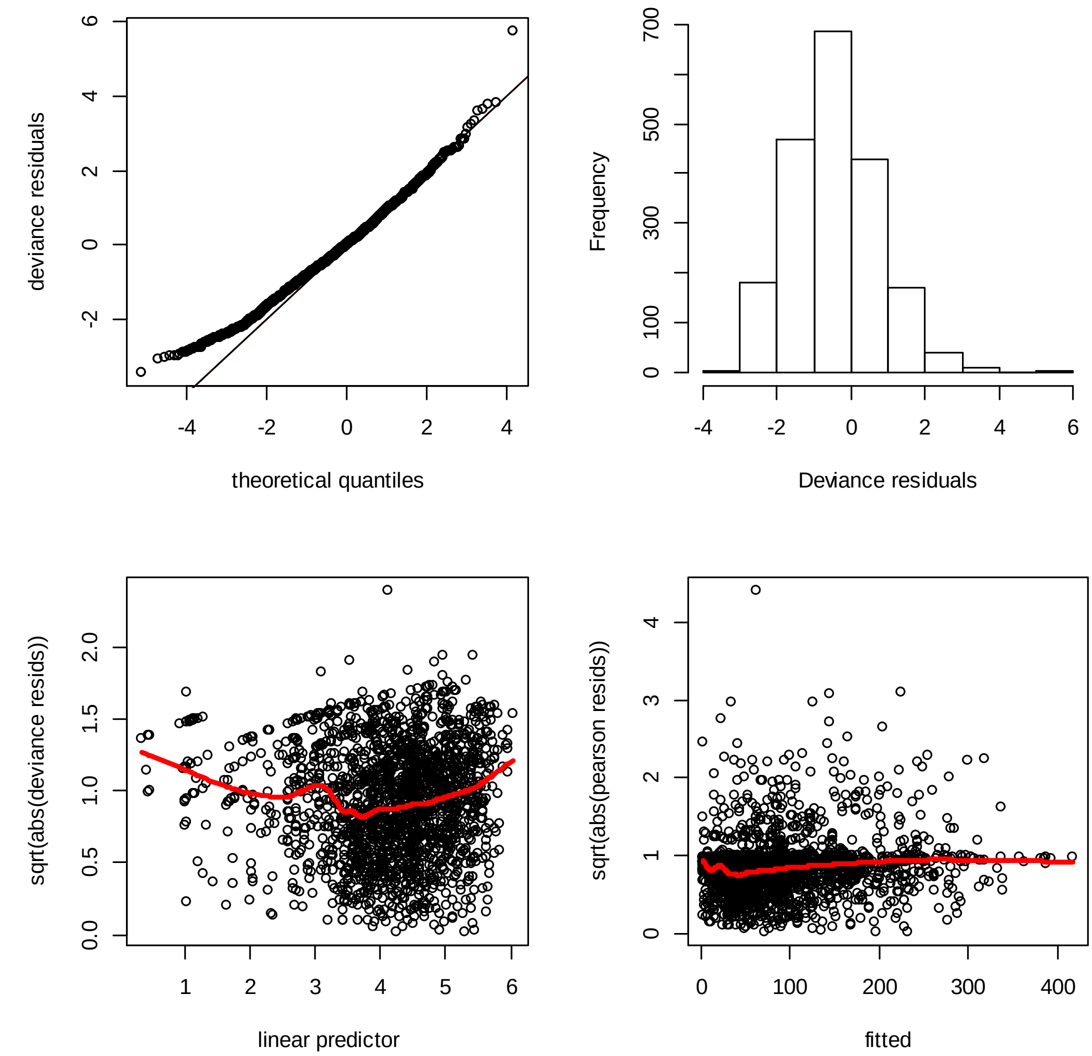
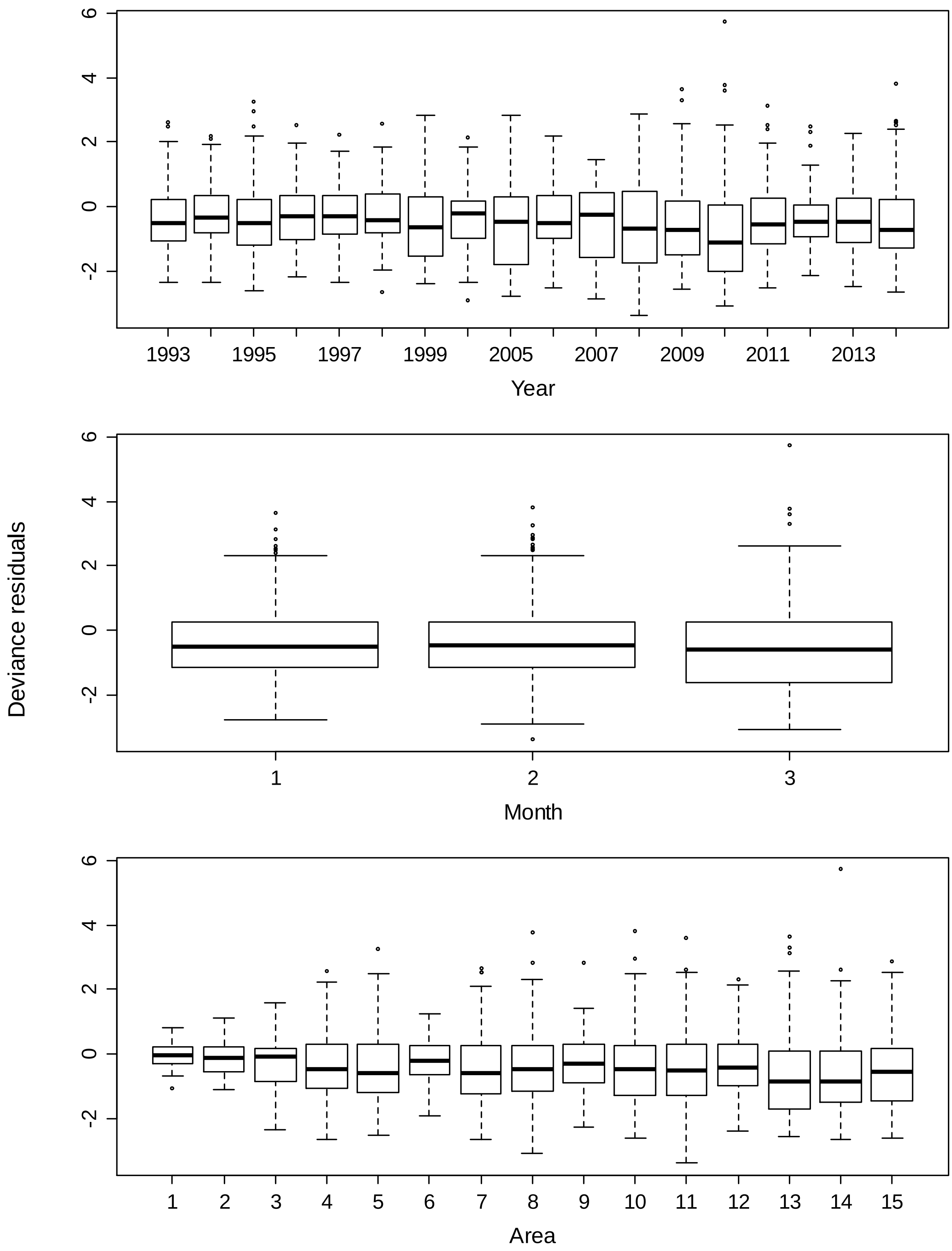


Figure C3. Boxplots of deviance residuals by year, month and area for biomass per sighting (BpS) model.



C.2 Sightings per mile (SpM) model

Figure C4 shows plots of observed number of sightings per mile (logged) versus the environmental covariates being included in the SpM model. There appears to be a strong tendency for the rate of sightings to increase as SST increases, and to decline as wind speed, haze, swell and sea shadow increase. With the exception of wind speed, the relationship appears to be linear, and this is even true for wind speed in the range of 1 to 7 knots (where most of the observations occur). Moon phase also appears to influence the sightings rate, with the rate being greatest when the moon phase is 1 (fraction of moon illuminated is 0-25%) or 4 (fraction of moon illumination is 75-100%), but the variance is large so the relationship may not be statistically significant.

Extract from the output produced by the software used to fit the model (the gam function in the R statistical package mgcv):

```
Family: quasipoisson
Link function: log

Formula:
N_sightings ~ offset(log(as.numeric(Distance))) + factor(Year) +
factor(Month) + factor(Area) + Y.M + Y.A + M.A + Y.M.A +
log(ObserverEffect) + AvgWindSpeed + AvgSST + AvgSwell + AvgHaze +
factor(MoonPhase) - 1

Parametric Terms:
```

Covariate	Estimate	SE	t-value	p-value
AvgWindSpeed	-0.271	0.020	-13.38	0.000
AvgSST	0.192	0.032	6.06	0.000
AvgSwell	-0.167	0.049	-3.44	0.001
AvgHaze	-0.159	0.043	-3.66	0.000
AvgSeaShadow	-0.065	0.014	-4.54	0.000
factor(MoonPhase)2	-0.078	0.086	-0.91	0.361
factor(MoonPhase)3	-0.102	0.111	-0.92	0.358
factor(MoonPhase)4	0.072	0.075	0.96	0.336

```
R-sq.(adj) =  0.492   Deviance explained = 66.4%
GCV score = 1.3997  Scale est. = 1.1475    n = 2133
```

The results again suggest that there is a tendency for the rate of sightings to increase as SST increases, and to decline as wind speed, haze, swell and sea shadow increase (all highly significant). The relationship with moon phase is more complex, with the sightings rate being greater when the moon phase is 1 (fraction of moon illuminated is 0-25%) or 4 (fraction of moon illumination is 75-100%), but this relationship is no longer coming out significant at the 0.05 level.

Figure C5 shows some standard diagnostic plots for generalized linear models, and Figure C6 shows the residuals plotted against a number of factors. The Q-Q plot (top left) suggests lack of fit at the tails of the distribution, which is common; however it also has a strange kink in the centre. Otherwise there are no indications of serious problems with the model fit. The plots of the square root of the absolute residuals against the fitted values (i.e., lower half of Fig. C5, with left-hand side being on the link scale and the right-hand side being on the response scale) look a bit odd, but this is expected because we are modelling count data. A smooth line through these data is reasonably flat, as desired, except for where it follows the residuals for the zero response values (i.e., where the observed number of sightings was zero).

Figure C4. Plots of observed sightings per mile, on a log scale, versus the covariates included in the model; shown is the mean +/- 2 standard deviations.

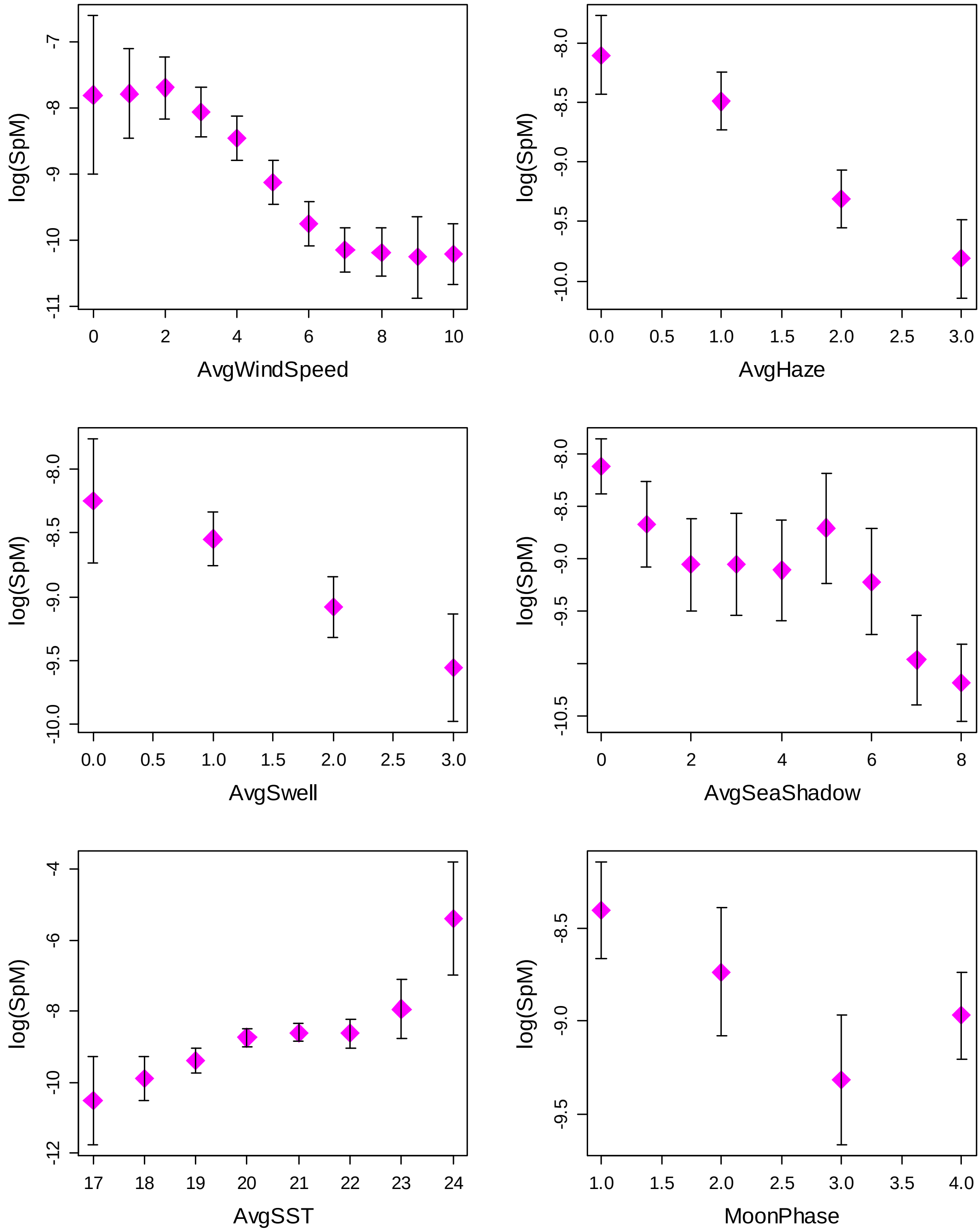


Figure C5. Standard diagnostics plots for sightings per mile (SpM) model.

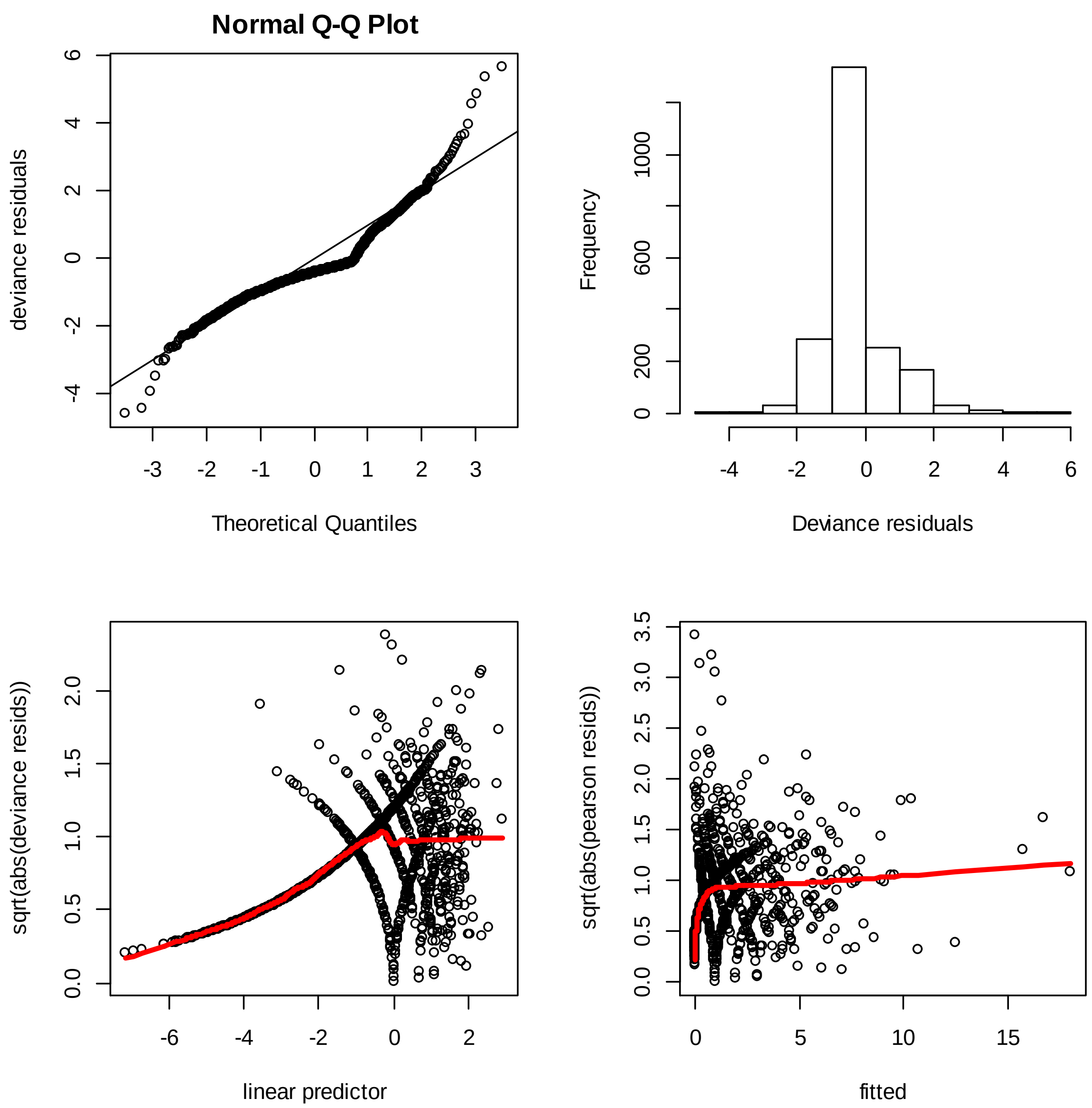
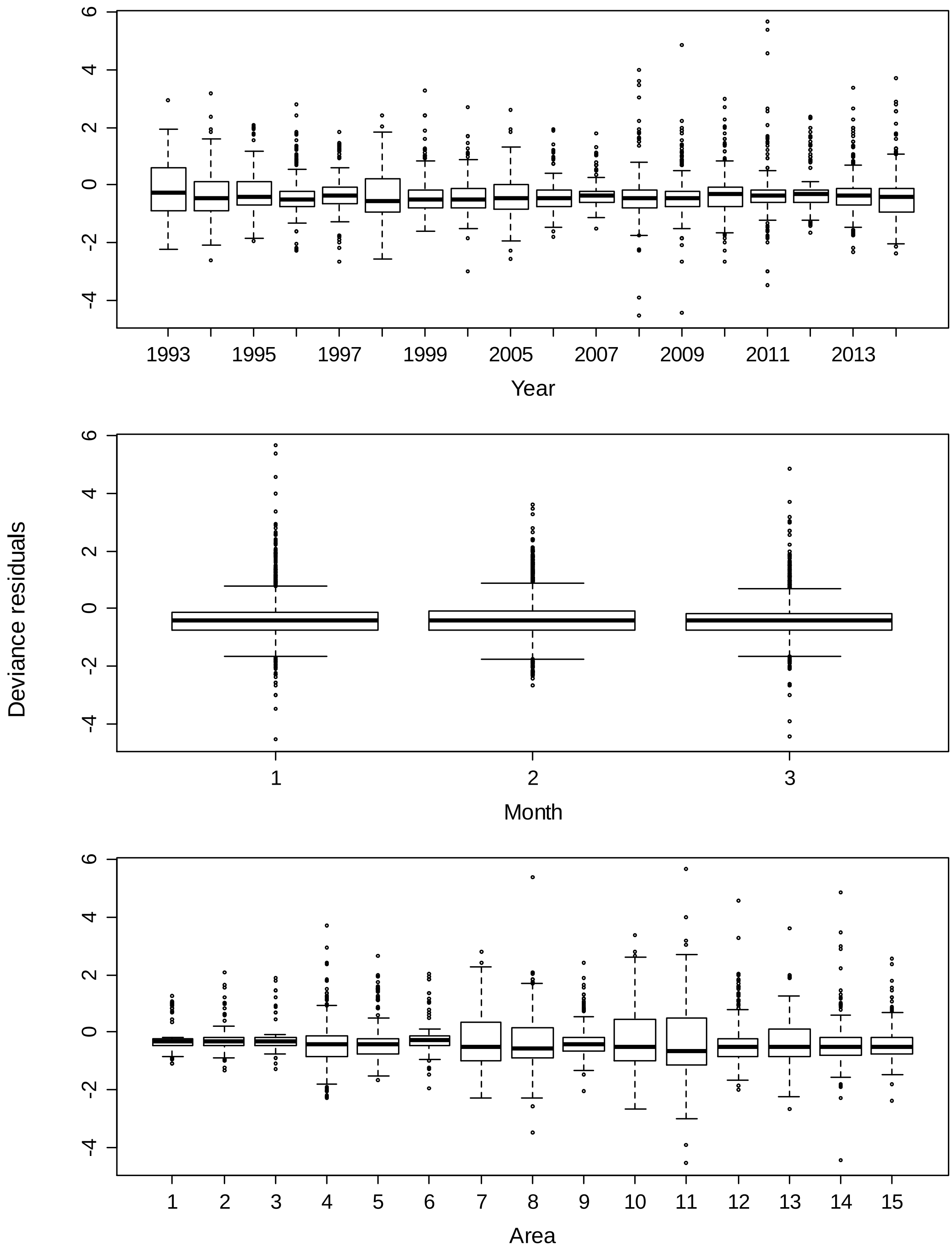


Figure C6. Boxplots of deviance residuals by year, month and area for sightings per mile (SpM) model.



APPENDIX 2

WEALTH FROM OCEANS
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Commercial spotting in the Australian surface fishery, updated to include the 2013/14 fishing season

Jessica Farley, Paige Eveson and Marinelle Basson

CCSBT-ESC/14XX/XX

DRAFT

Prepared for the CCSBT Extended Scientific Committee for the 19th Meeting of the Scientific Committee 1-6 September 2014, Auckland, New Zealand

APPENDIX 2

Wealth from Oceans Flagship

CSIRO Marine and Atmospheric Research

Citation

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Copyright and disclaimer

Important disclaimer

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Contents

Abstract

Data on the sightings of SBT schools in the Great Australian Bight (GAB) were collected by experienced tuna spotters during commercial spotting operations between December 2013 and February 2014 (fishing season 2014). Spotting data has now been collected over 13 fishing seasons (2002 to 2014). In 2002-2008 and 2010, the location of SBT sightings varied little, with the area of highest SBT sighted per nautical mile searched occurring within the same 'core fishing area' inside of the continental shelf break between the 130° and 133°east. In 2009 and 2011-2013 a significant amount of search effort occurred to the east of this core area following the shelf break. In 2014, almost all search effort occurred between 134° and 138° east; from west of Rocky Island through to south of Kangaroo Island. The surface abundance of SBT (per unit of search effort) in 2014 was spread throughout the search area, rather than being concentrated near the shelf break as observed in previous years.

The commercial spotting data was used to produce nominal and standardised fishery-dependent indices of SBT abundance (surface abundance per unit effort – a SAPUE index). Due to the changes in spotter effort each season, it was most appropriate to include data for all spotters in the analysis as done last year. We only include data for 2003-2014 since both target and visibility seem to be important, and they were not recorded in 2002. The estimated SAPUE index for 2014 is higher than the average for the 2003 to 2014 period but slightly below the 2011 estimate which was the highest for all seasons.

Introduction

In the summer of 2001/02 (called the 2002 season), a pilot study was conducted to investigate the feasibility of using experienced industry-based tuna spotters to collect data on the sightings of SBT during commercial spotting operations in the Great Australian Bight. The data provided a preliminary fishery-dependent index of SBT abundance (surface abundance per unit effort – a SAPUE index) for that fishing season.

Recognising the importance of time-series of indicators, we have continued to collect and analyse SBT sightings data from commercial tuna spotters over the following 12 fishing seasons (2003-2014). Interpretation of the results are difficult as the data suffers from many of the same problems that affect catch per unit effort (e.g. changes in coverage over time, lack of coverage in areas where commercial fishing is not taking place, and changes in operations over time), but it may provide a qualitative indicator of juvenile SBT abundance in the GAB. It has always been recognised, however, that a scientific survey with consistent design and protocols from year to year is highly preferable. This report summarises the field procedures and data collected, with emphasis on the 2014 season, and provides results of analyses for all 13 seasons (2002-2014).

Field procedures

As for previous years, the field program in 2014 included the collection of spotting data from experienced commercial tuna spotters in the GAB. (Note, in this report we use the terminology 'spotter', not 'observer'). Data were collected on SBT patches (schools) sighted by spotters engaged between December 2013 and February 2014 (called the 2014 fishing season). This year, data were collected by 3 spotters, and one spotter had participated in all previous seasons (Table 1).

The spotting data collected in 2014 were collected following the protocols used in the previous fishing seasons. Within each plane there was a spotter and pilot. For most flights, the spotter searched the sea surface on both sides of the plane for surface patches of SBT. During some flights, the pilot also searched for patches. When a "sighting" of SBT was made, a waypoint (position and time) was recorded over the patches (or patches). The spotter estimated a range for the size of fish in the patches (in kg) and the biomass of each patch (in tonnes). It is important to note that many SBT patches are recorded as single patches (~35-60% by season). Some schools, however, are recorded in groups of 2-10 or even 50+ schools. Environmental observations were recorded at the start and end of each flight and when the conditions changed significantly during the day. The environmental observations included wind speed and direction, air temperature, cloud, visibility, spotting conditions and swell. The target species of each flight (SBT, skipjack tuna, mackerel, or a combination of these) was also recorded. There were no restrictions on the environmental conditions for commercial spotting operations.

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

SEASON	SPOTTER 1	SPOTTER 2	SPOTTER 3	SPOTTER 4	SPOTTER 5	SPOTTER 6	SPOTTER 7
2002	61.3	7.6	11.7	-	5.6	13.9	-
2003	20.2	11.5	33.2	1.2	4.4	29.5	-
2004	42.2	15.2	19.4	-	-	23.2	-
2005	39.7	9.3	19.5	-	5.0	26.5	-
2006	44.2	11.6	-	-	14.8	29.5	-
2007	38.0	11.1	-	-	22.1	28.8	-
2008	37.3	23.7	-	-	-	39.0	-
2009	39.0	9.0	-	-	-	41.4	10.7
2010	28.9	16.4	-	-	4.0	50.7	-
2011	47.1	-	-	-	-	52.9	-
2012	47.8	-	-	-	-	52.2	-
2013	55.3	-	-	-	17.4	-	27.3
2014	50.4	-	-	-	21.0	-	28.6

Results

Search effort and SBT sightings

Data were collected for 57 commercial spotting flights in the 2014 fishing season (Table 2). The number of flights recorded was lower than for seasons 2011 to 2013, and the second lowest since 2002. The details of search effort and SBT sightings are also given in Table 2. SBT were recorded on 82.5% of the flights in 2014 which is about average for the 2002 to 2014 period (84.7%). Note that the total biomass shown in Table 2 does not represent the total biomass of SBT present in the survey area, as many schools were potentially recorded several times (either by different spotters on the same day or over several days).

Figure 1 and Figure 2 show the spatial distribution of search effort and surface abundance of SBT. As noted in previous reports, in 2002-2008 and in 2010, the location of SBT search effort and sightings varied little with the area of highest SBT effort/sighting occurring within the same ‘core’ fishing area (130.2-132.9°E and 32.7-34.0°S). In 2009, and again in 2011 to 2013, a significant amount of search effort occurred well outside the core area closer to Port Lincoln. In these years, the search effort by spotters moved to the eastern GAB during the season as SBT became more difficult to find in the core. The timing of this shift occurred relatively late in the fishing season in 2009 (mid-March) but earlier in the season in 2011 and 2013 (Farley and Basson, 2013). The percent of total search effort occurring in the core area decreased from ~80-89% in 2002-2008, to less than 60% in 2009 and 2011, and 14% in 2012 (Table 2). In 2013, only 4.1% of effort occurred in the core area, with only 0.5% of the SBT biomass recorded. In 2014, only 0.5% of effort was in the core area and no SBT were sighted. Almost all search effort occurred between 134° and 138° east; from west of Rocky Island to south of Kangaroo Island. The surface abundance per unit effort in 2014 (Figure 2) shows SBT were more generally spread throughout the search area, rather than being concentrated inside of the continental shelf break as observed in previous years (Figure 2).

Note that flight path data for four of the 57 flights were not available in 2014 and thus the proportion of search time and biomass sighted in the 'core' fishing area are currently unknown for these flights, although the total search effort and biomass for the flights are known and are included in the standardisation analysis (below).

Table 2. Search effort and SBT sighted by commercial spotters in the 2002-2014 fishing seasons. The 'core' is bounded by 130.2-132.9°E and 32.7-34.0°S.

FISHING SEASON	NO. FLIGHTS	SEARCH EFFORT (HRS)	% FLIGHTS WITH SBT RECORDED	TOTAL NUMBER OF SCHOOLS	TOTAL BIOMASS[1] RECORDED	% OF EFFORT IN THE CORE[2]	% OF BIOMASS IN THE CORE[2]
2002	86	325	83.7	1182	44626	80.6	87.7
2003	102	425	82.4	1301	38559	78.9	76.5
2004	118	521	77.1	1133	33982	88.9	90.4
2005	116	551	94.0	2395	87447	88.5	83.2
2006	102	452	82.4	1554	50524	83.1	73.4
2007	120	600	91.7	2600	94018	86.5	80.0
2008	93	451	80.6	2529	100341	94.2	92.6
2009	114	527	77.2	1353	41514	54.2	67.7
2010	49	210	83.7	918	32907	72.3	68.3
2011	64	328	95.3	1472	75887	57.3	70.8
2012	73	378	87.7	799	31959	14.0	11.1
2013	77	362	83.1	1529	67811	4.1	0.5
2014	57	260	82.5	1948	87536	0.5	0.0

[1] The total biomass recorded does not represent the total biomass of SBT present in the survey area, as many schools were potentially recorded several times (either by different spotters on the same day or over several days).

[2] Does not include data for flights where flight path data was not obtained; e.g. 4 flights in 2014 (see above).

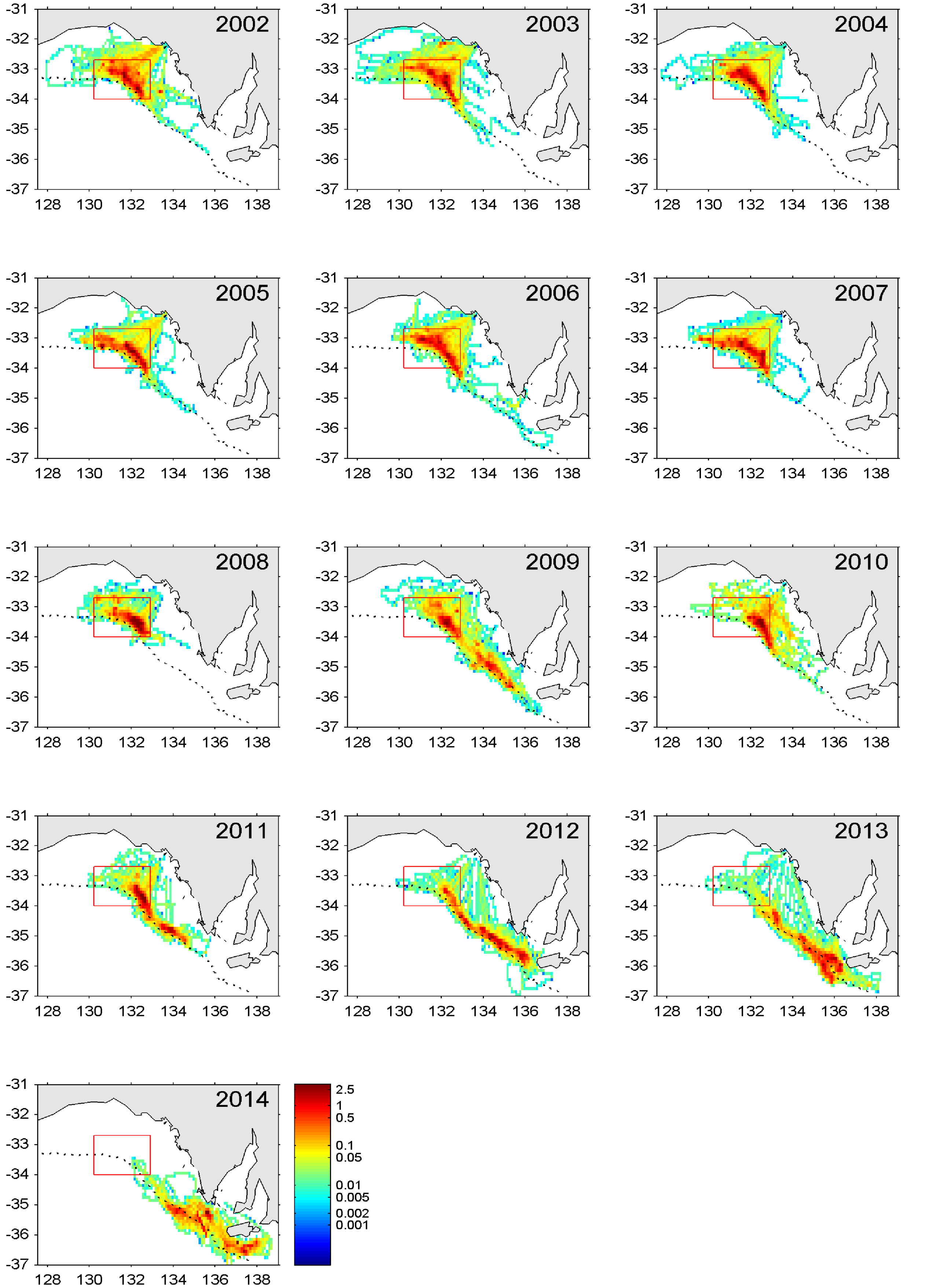

Figure 1. Search effort (nm flown/0.1° square) in the GAB by fishing season. Note the log scale. The 2002-2010 'core fishing area' is shown by a red square.

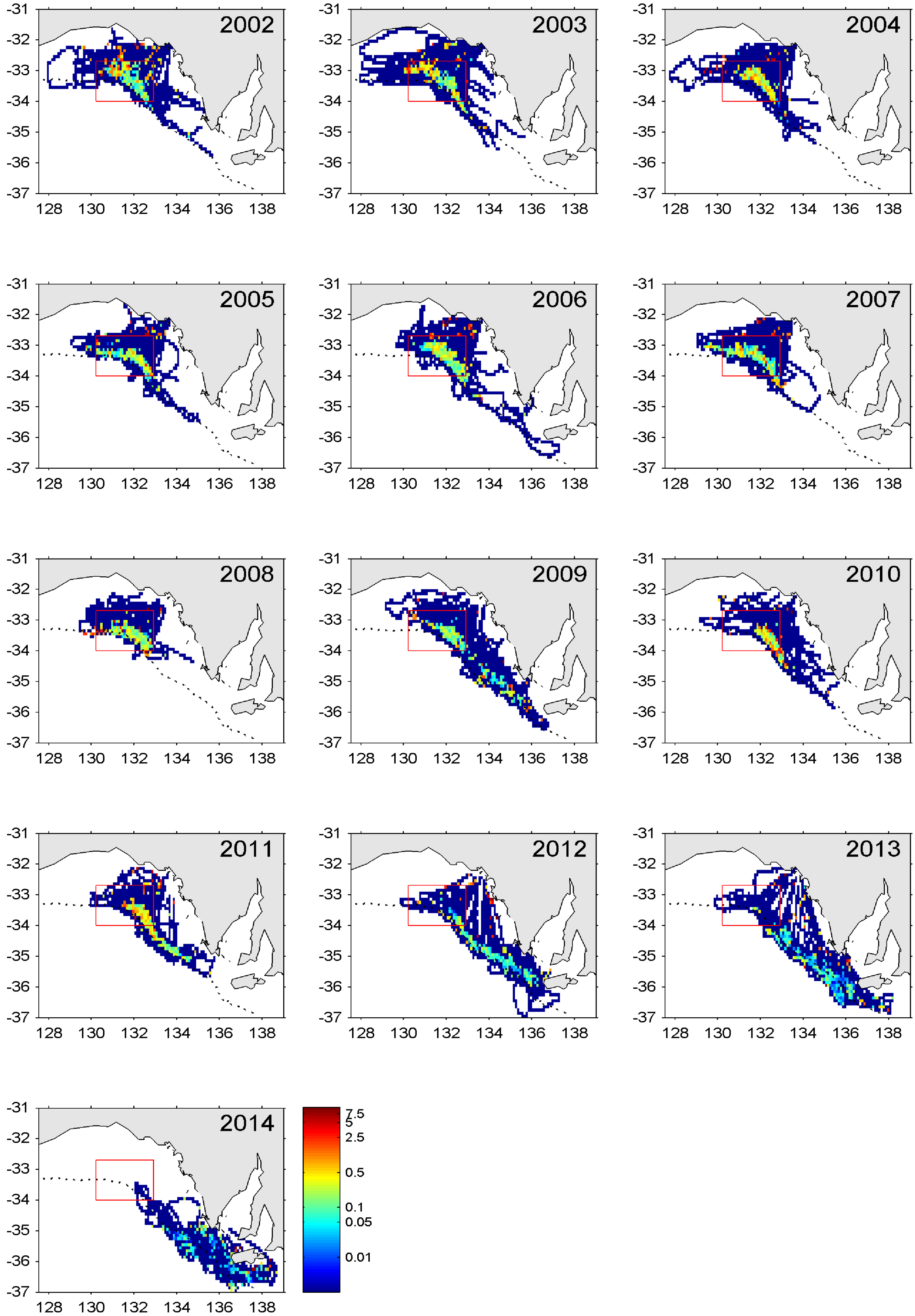

Figure 2. SAPUE (tonnes/nm/0.1° square) in the GAB by fishing season. SAPUE data are displayed as the % of total effort for the season. Areas of darkest blue in the SAPUE plot indicate zero SAPUE. Note the log scale. The 2002-2010 'core fishing area' is shown by a red square.

Figure 3 and Figure 4 show the size of SBT schools and fish recorded by Spotter 1 between 2002 and 2014. Using data from one spotter removes the problem of differences between spotters in their estimates of school and fish size. Spotter 1 was selected because he had collected data on the greatest number of SBT schools each season and is now the only spotter to collect data in each season. The mean size of schools recorded has varied over time, but was at its lowest in 2009 (30.0 tonnes) and highest in 2011 (61.1 tonnes). In 2014, the majority (56.9%) of fish were in schools of 10-20 tonne in size and the mean size of schools was 31.4 tonnes (Figure 3). The mean size of fish recorded was 20.6 kg (Figure 4) which is about average for the 2002-2014 period.

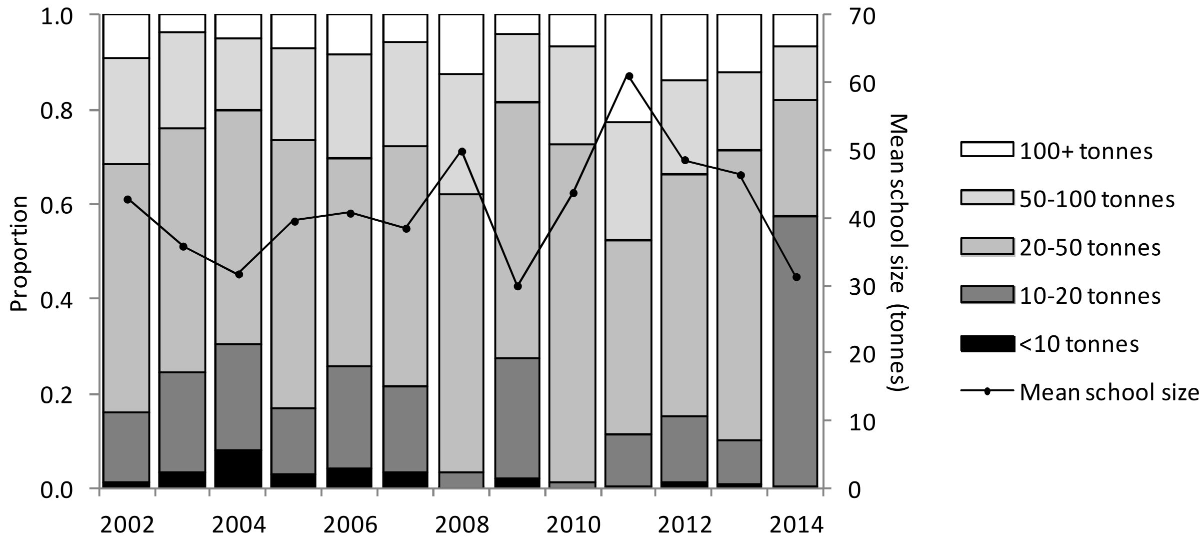

Figure 3. Proportion of SBT schools by size class (bars) and mean school size (line) recorded by one commercial spotter in the 2002-2014 fishing seasons. Total number of school size estimates = 9,923.

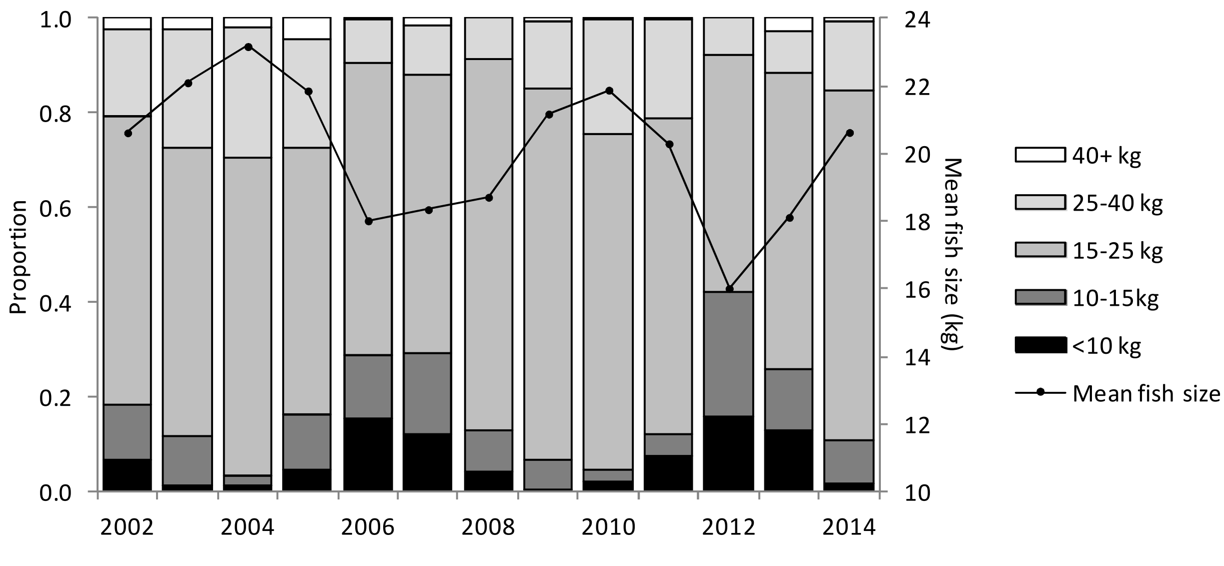

Figure 4. Proportion of SBT by fish weight class (bars) recorded by one commercial spotter in the 2002-2014 fishing seasons. Data are weighted by school size.

Nominal SAPUE

As for previous years, the duration of "search" sectors during flights were calculated using the GPS logged position and time. The logbook data on SBT sightings were summarised to give the total number of sightings, schools, and total biomass per plane per day. The data were extracted to ensure consistency between seasons. Flights were excluded if they were outside the main fishing seasons (December to March) and were less than 30 minutes duration because these were considered too short to have a meaningful SAPUE estimate. As these data were removed for all seasons, it should not affect the relative index of abundance.

Nominal (unstandardised) indices of juvenile SBT abundance (surface abundance per unit effort – SAPUE) were calculated, based on the mean of biomass sighted (tonnes) per unit of search effort (minutes). The SAPUE indices were calculated by geographic area (whole GAB and core fishing area) and for flights where SBT was/was not targeted.

The four nominal SAPUE indices of juvenile abundance are shown in Figure 5. Three of the indices fluctuate similarly between 2002 and 2014. The 2014 indices were higher than for all previous years. The only index that did not follow the same inter-annual pattern was the index for the core fishing area which was much lower in 2013 and 2014 due to the lack of search effort (and thus SBT sighted) in that region.

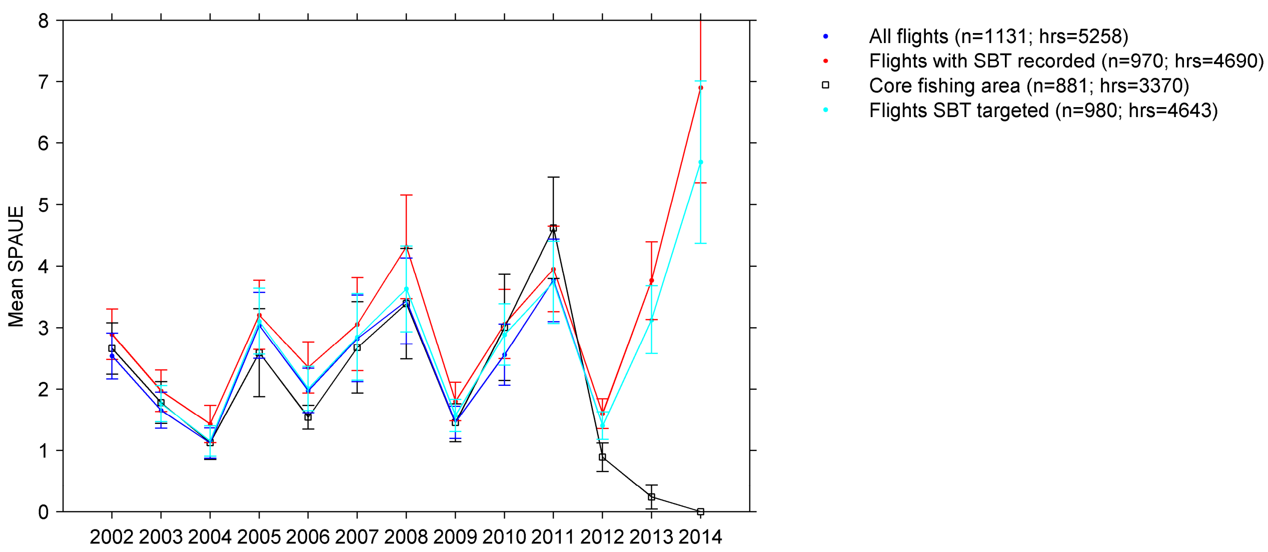

Figure 5. Nominal SAPUE indices (+/-se) (tonnes of SBT sighted per minute searching) for the 2002-2014 fishing seasons for all flights, flights in the core area, and flights that SBT were recorded. Note that only flights in December to March were included, and when search effort was >30 minutes.

Standardised SAPUE

Commercial spotting data are available for 13 seasons. These data can potentially be standardised to obtain an index of juvenile abundance (ages 2-4 primarily) in the GAB between December and March. There have been up to 7 spotters operating at different times since 2002 but unfortunately data were not collected in all months and all years by all spotters (Table 3). The number of spotters required by industry has decreased, as there has been a tendency over time for fewer fishing companies to catch tuna for the other companies in the fishery. In the past, data from only 2 spotters (spotter 1 and spotter 6) were used in standardisation analyses as they had operated in all years (2002-2012; Table 3) (see Farley and Basson, 2012). Last year and again this year, however, only one of these spotters collected data. We have previously explored the sensitivity of results to the inclusion/exclusion of data from different spotters and results showed that the index is not sensitive to this (e.g. Farley and Basson, 2008). Given this, and the changes in spotting effort, data from all spotters were included in last year's analyses and again this year.

As we noted last year, the fact that not all spotters operated and therefore have no data for some seasons means that we cannot fit a model with spotter as a fixed effect unless we leave out seasons where not all spotters have data; this would leave hardly any seasons and is the primary reason why we previously just included data for two spotters in the model. A solution to this is to treat spotter as a random effect. This allows for differences between spotters and it can manage the missing data. Previous analyses (i.e. Basson and Farley, 2005) showed that interactions (for example between month and season) were important for model fit (residuals were better behaved) though the standardised index itself was not sensitive to the inclusion or exclusion of interactions. The main reason why we chose to exclude interactions in the past is again because of missing data. If we treated the interaction as a fixed effect, the model could not be fitted if there were missing data in some strata. Last year, we modified the model to include interactions and treated them as random effects, which allowed us to handle months and years where data were missing (Farley and Basson, 2013). We apply the same approach again this year (see "Modelling approach" section below).

Environmental variables

As noted in the past CCSBT reports, sighting conditions and surfacing behaviour are influenced by weather and environmental variables. The environmental variables recorded by season are summarised in Table 4 and Figure 6. Note that the scientific aerial survey transects are only flown during certain conditions, so that summaries of environmental conditions recorded during the scientific aerial survey and during commercial spotting operations would tend to differ. The data suggests that during the 2014 commercial spotting flights, environmental conditions were better relative to recent years. Although the wind speed and air temperature were about average, the cloud cover and swell height were well below average while the visibility was above average. In addition, the spotters recorded the overall spotting conditions as the best (highest on average) compared to all previous years.

We have also noted previously (e.g. Basson and Farley, 2006) that although the mean air temperature can be quite similar between seasons, the monthly temperatures can be very different. Figure 7 shows the monthly mean temperatures from the data collected over the past 13 seasons. In 2014, the average temperatures increased from December to February. The December average was relatively cold, January was not particularly unusual compared to previous seasons, while the February average was the highest February temperature.

Table 3. Number of days flown by spotter, year and month (Dec-Mar) within a year. Note that the 'season' is the same as the 'year' for all months except December; for example December 2001 will fall in the 2002 Season.

YEAR	MONTH	SPOTTER1	SPOTTER2	SPOTTER3	SPOTTER4	SPOTTER5	SPOTTER6	SPOTTER7
2001	Dec	14		8			4	
2002	Jan	7	5	5			7	
2002	Feb	7	3	3		4	4	
2002	Mar	11						
2002	Dec			10			10	
2003	Jan	10	6	9		5	10	
2003	Feb	2	3	6	2	1	4	
2003	Mar	5		6			4	
2003	Dec			11			10	
2004	Jan	9	7	5			11	
2004	Feb	15	10	9			6	
2004	Mar	16		2			4	
2004	Dec			4			3	
2005	Jan	11	7	9		1	7	
2005	Feb	9	2	10		6	16	
2005	Mar	19		2			8	
2005	Dec	9				3	4	
2006	Jan	8	4			3	8	
2006	Feb	9	8			9	9	
2006	Mar	12				4	10	
2006	Dec	6				2	7	
2007	Jan	15	7			10	14	
2007	Feb	9	6			7	7	
2007	Mar	12				11	6	
2007	Dec	5					11	
2008	Jan	11	11				9	
2008	Feb	11	6				12	
2008	Mar	8	5				4	
2008	Dec						9	
2009	Jan	11	4				13	
2009	Feb	9	7				11	
2009	Mar	15					9	7
2009	Dec						7	
2010	Jan	8	5			1	14	
2010	Feb	4	3			3	4	
2010	Mar							
2010	Dec	8					2	
2011	Jan	11					14	
2011	Feb	8					7	
2011	Mar	3					11	
2011	Dec	10					4	
2012	Jan	8					10	
2012	Feb	15					17	
2012	Mar	3					6	

Table 3 continued.

YEAR	MONTH	SPOTTER1	SPOTTER2	SPOTTER3	SPOTTER4	SPOTTERS5	SPOTTER6	SPOTTER7
2012	Dec	13				1		3
2013	Jan	16				11		12
2013	Feb	9				5		7
2013	Mar							
2013	Dec	14			5			
2014	Jan	11			11			12
2014	Feb	2			1			1
2014	Mar							

Table 4. Average environmental conditions during search effort on commercial flights by season (all companies, Dec-Mar). Note visibility was not recorded in 2002.

FISHING SEASON	WIND SPEED (KNOTS)	SWELL HEIGHT (0-3)	AIR TEMP (°C)	CLOUD COVER (/8)	SPOTTING CONDITION (/5)	VISIBILITY (NM)
2002	7.06	1.46	18.06	4.48	2.64	
2003	6.90	1.18	23.35	3.62	2.81	5.58
2004	7.92	1.65	19.75	3.95	2.64	7.77
2005	6.99	1.59	21.14	4.23	2.55	8.95
2006	7.59	1.95	22.11	4.01	2.75	7.64
2007	6.98	1.87	21.10	3.60	2.78	7.92
2008	7.94	1.48	22.88	2.90	2.91	10.80
2009	8.47	1.53	20.33	3.42	2.72	5.81
2010	8.90	1.85	22.09	2.82	2.41	5.98
2011	8.50	1.56	21.94	4.51	2.64	7.93
2012	8.12	1.50	22.85	3.97	2.69	7.84
2013	7.34	1.62	19.85	3.46	3.09	8.59
2014	7.49	1.13	23.25	1.80	3.38	10.63

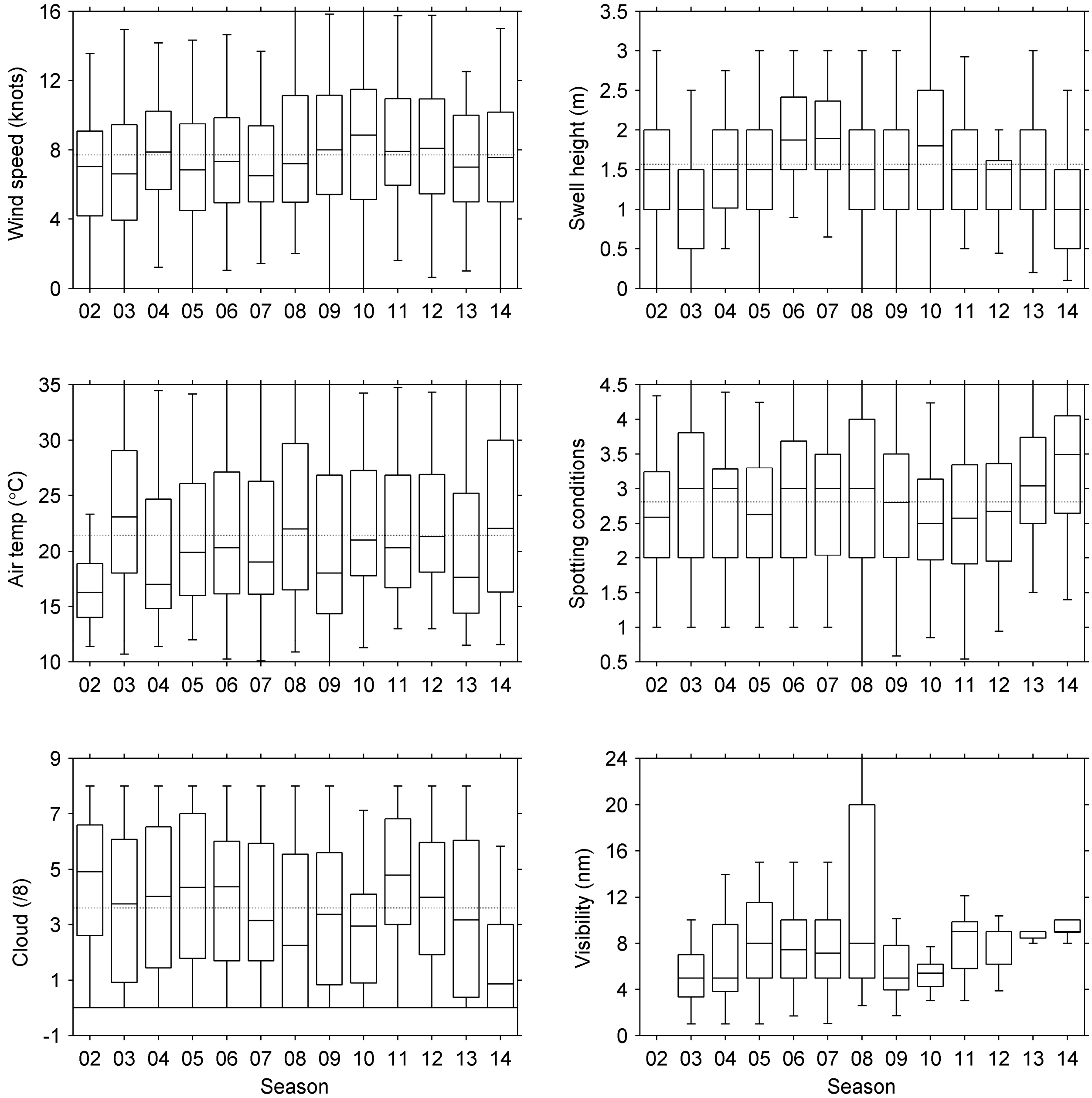

Figure 6. Boxplots summarizing the environmental conditions present during search effort on commercial flights by season (all companies, Dec-Mar). The horizontal band through a box indicates the median, the length of a box represents the inter-quartile range, and the vertical lines extend to the minimum and maximum values. The dashed line running across each plot shows the overall average across all survey years. Note visibility was not recorded in 2002.

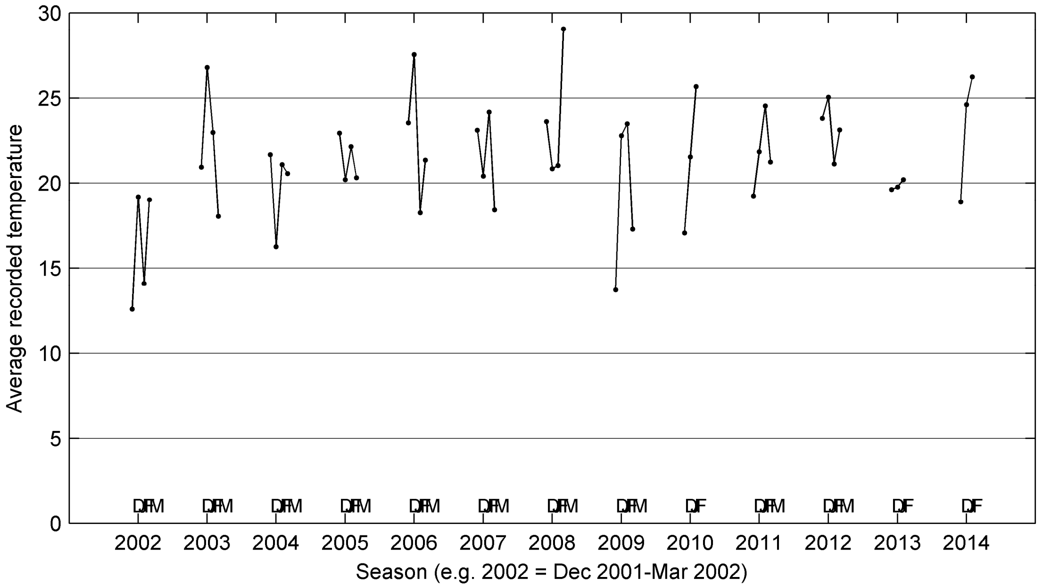

Figure 7. Average monthly temperatures (all companies, Dec to Mar) from the spotting data for the past 13 seasons. DJFM = Dec, Jan, Feb, Mar. Date were only recorded for Dec to Feb in 2010, 2013 and 2014.

The sightings data

The data were compiled as the biomass sighted (tonnes) and search effort flown (hours) on each day by each spotter. We have previously commented on alternative ways of compiling the data at finer spatial and temporal scales for analyses (Basson and Farley, 2005). However, given the complexity of such a task and the availability of data from the aerial survey, we have followed the approach used in the past. The associated environmental variables are taken as the means for that day and spotter. The data were compiled as a set for the entire area and all the analyses were done on the 'whole area' dataset. Table 5 shows a summary of the number of days flown with no biomass sighted. This information could be treated as a simple 'presence/absence' index. The percentage days with no sightings was notably below the average over all years (14.3%) in 2005 and 2007, and the lowest in 2011 (4.7%). It was slightly above average in 2014 (17.5%).

In the 2009 and 2010 seasons there was an increase in the number of flights targeted at Mackerel (Table 6). These flights generally occur outside the core area for SBT and therefore there is less likelihood of spotting SBT than on flights 'targeted' at SBT or even at skipjack. If this is taken into account by excluding flights with target="Mack", then the percentage days with zero biomass are:

2009 16.7 (compared to 18.9 for all flights)

2010 11.4 (compared to 16.3 for all flights)

If flights that target skipjack and mackerel (SKJ/Mack) are also excluded, then the percentage days with zero biomass drops further to 9.3% in 2010. The only other year in which this combination of targeting was recorded is 2006, but the effort was less than 1% (Table 6) and the estimate of percentage zero biomass days is unchanged. In interpreting the targeting information, it is assumed that recording of target has been consistent over time, at least by each spotter. Note though that the effort by spotters has changed considerably over time (Table 3). In 2011 the majority of effort (93.3%) and in 2012 to 2014 all the effort was designated as being targeted at SBT.

Table 5. Number of days flown with no biomass sighted and days with some biomass sighted (all companies, Dec to Mar). Since different levels of effort are associated with each day, the % effort in hours associated with days when no biomass was sighted is also shown. Results are not aggregated over spotters, i.e. on a given day, if one spotter saw 0 biomass it contributes 1 to the 'zero biomass days', and if 2 spotters saw some biomass on the same day, they contribute 2 to the 'Positive biomass days'.

SEASON	ZERO BIOMASS DAYS	POSITIVE BIOMASS DAYS	TOTAL DAYS	% DAYS WITH ZERO BIOMASS	% EFFORT (HOURS) ASSOCIATED WITH ZERO BIOMASS
2002	10	72	82	12.2	10.0
2003	15	76	91	16.5	11.9
2004	25	90	115	21.7	15.7
2005	6	108	114	5.3	4.1
2006	16	84	100	16.0	11.5
2007	9	110	119	7.6	4.8
2008	19	74	93	20.4	17.2
2009	18	77	95	18.9	16.1
2010	8	41	49	16.3	10.8
2011	3	61	64	4.7	3.9
2012	9	64	73	12.3	8.0
2013	13	64	77	16.9	12.3
2014	10	47	57	17.5	17.9

Table 6. Summaries of percentage search effort by 'target' type and season. This information was not recorded in the first season, 2002. (SBT=southern bluefin tuna; SKJ=skipjack; Mack=Mackerel)

TARGET	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
SBT	55.6	82.6	79.8	70.3	87.2	89.7	48.8	76.1	93.3	100	100	100
SBT/SKJ	42.1	2.6	11.4	4.9	1.9	1.1	10.3					
SBT/Mack				9.1	6.8	0.8	22.8	13	4.5			
SBT/SKJ/Mack				3.4	0.7	4.9	11.7					
SKJ	2.4	14.9	8.8	8	2.3	3.4	1.6					
SKJ/Mack				0.6				2.3				
Mack			3.7	1.1			4.8	8.6	2.2			

Modelling approach

We used the same modelling approach as last year (Farley and Basson, 2013), so data for all spotters were included in the analyses. The main intention of modelling of these data is to standardise the raw index (e.g. average biomass per unit effort sighted) for differences between spotters and different environmental, weather and spotting conditions from year to year.

As in the past, data for December through March are included in the analysis. Some of the variables (e.g. temperature) most likely only affect surfacing behaviour of tuna, whereas others (e.g. wind, swell) may affect both spotting ability and surfacing behaviour. Recent work has shown that both targeting and visibility are important and have been included in the standardisation. However, moon illumination, cloud cover and swell are not significant and have not been included.

The "regression model" used must be able to cope with the zero observations, and with the strong dependency of the variance on the mean. A convenient way to do this is to fit GLMs using the Tweedie family of distributions (Jørgensen, 1997; Candy 2004) with a log-link, so that different factors combine multiplicatively. The mean-variance relationship in Tweedie distributions follows a power-law with adjustable exponent Φ, and for Φ<2 there is no problem with zero observations. When fitting the models, the exponent Φ was entered (1< Φ <2). Note that the value of Φ=1 coincides with the Poisson distribution, and a value of Φ=2 with the Gamma distribution. Recent work indicated that a value of Φ=1.47 was appropriate, and sensitivity trials conducted last year confirmed this to be true (Farley and Basson, 2013). Thus, we used a value of Φ=1.47 in our analysis this year.

All analyses were done in R using library (Tweedie) to enable use of "family=tweedie()" in the standard GLM routine.

The model fitted can be expressed as:

log(biomass) ~ spotter + season + month + s(wind) + s(spotcon) + s(temperature) + s(visibility) +

target + season:month + spotter:season + offset(log(SearchEffort)),

where season, month and target are factors fitted as fixed effects, and spotter and the two-way interactions between season and month and season and spotter are fitted as random effects. The environmental covariates (wind, spotting conditions, temperature and visibility) are fitted as smooths. We only include data for 2003-2014 since target and visibility were not recorded in 2002.

Model results

Diagnostics for the model fit (Figure 8) show no trends or patterns in the residuals. The smooth (solid red line) in the lower left panel (Figure 8), i.e. the square root of absolute deviance residuals plotted against the linear predictor, is sufficiently flat to indicate an appropriate value of the Φ-parameter (1.47) for the Tweedie distribution.

Estimated model coefficients are given in Appendix A, and the estimated annual index is shown in Figure 10. The environmental variables wind, spotting condition, and temperature were all highly significant (p-value<0.001), whereas visibility was only marginally significant (p-value=0.034). The estimated relationship between biomass per unit effort (on a log scale) and temperature was dome-shaped, while the relationship with visibility was slightly U-shaped (Figure 9). The estimated relationship between the biomass rate and wind speed was negative, and between sightings and spotting conditions was positive (Figure 9). These results are similar to last year except that the relationship between the biomass rate and visibility was closer to linear and slightly positive, but it was also insignificant.

The year effect was significant (p-value < 0.05) for 2005, 2008, 2010, 2011 and 2014, which coincide with above average standardised index estimates (Figure 10, Table 7). The index value for 2014 is above average for the period 2003-2014, and second highest over that period (with 2011 being highest). It is important, however, to keep in mind that the standard error (SE) estimates for the index values are often quite high, with the SE for 2014 being the second highest (Table 7, Figure 10). Note that the ranges shown in Figure 10 were obtained by taking the predicted values ± 2 SEs on the log scale and then converting to the normal scale, where the SEs themselves take into account the fact that the index has been scaled to the mean.

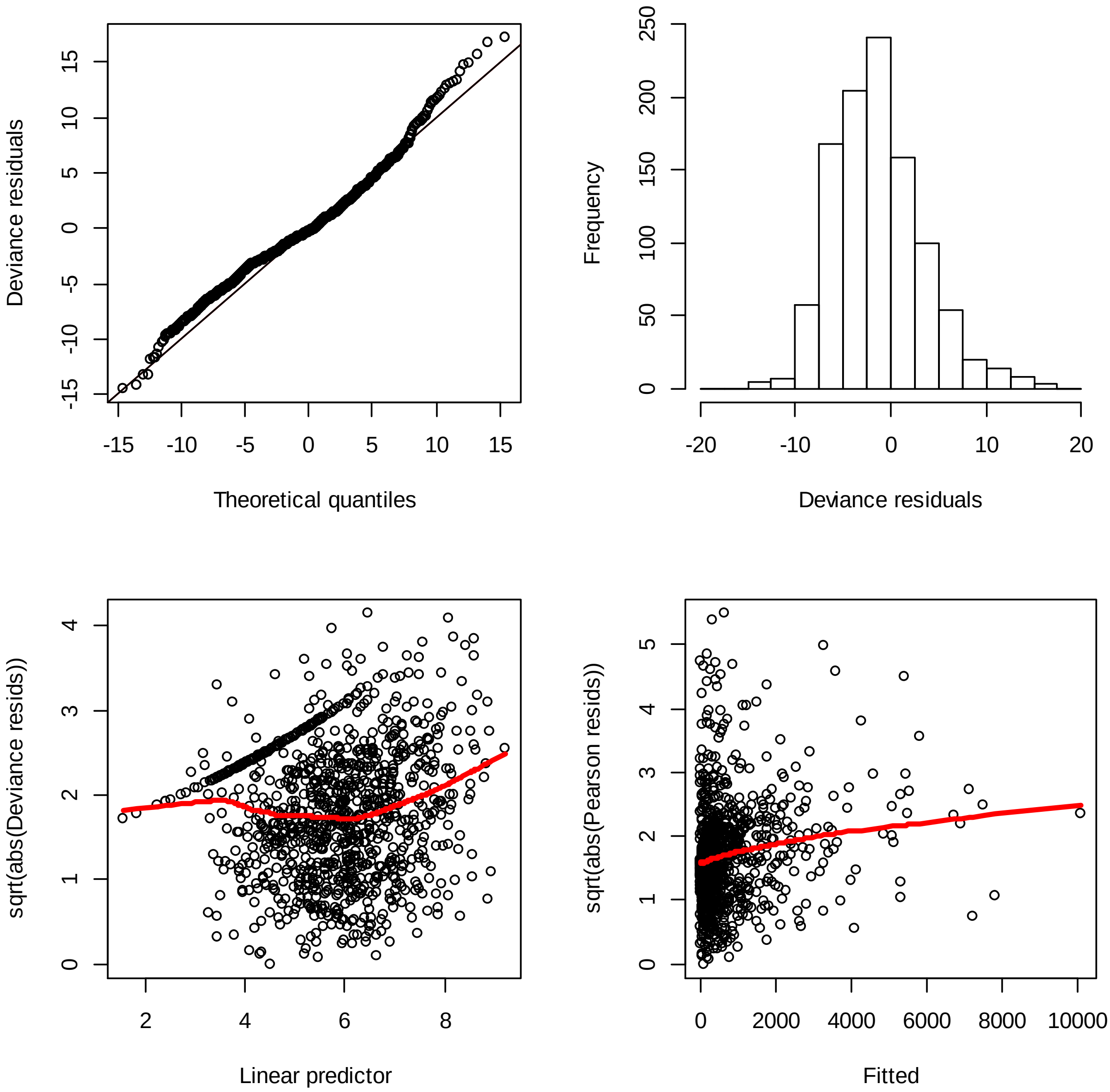

Figure 8. Diagnostic plots for the fitted model (see text above).

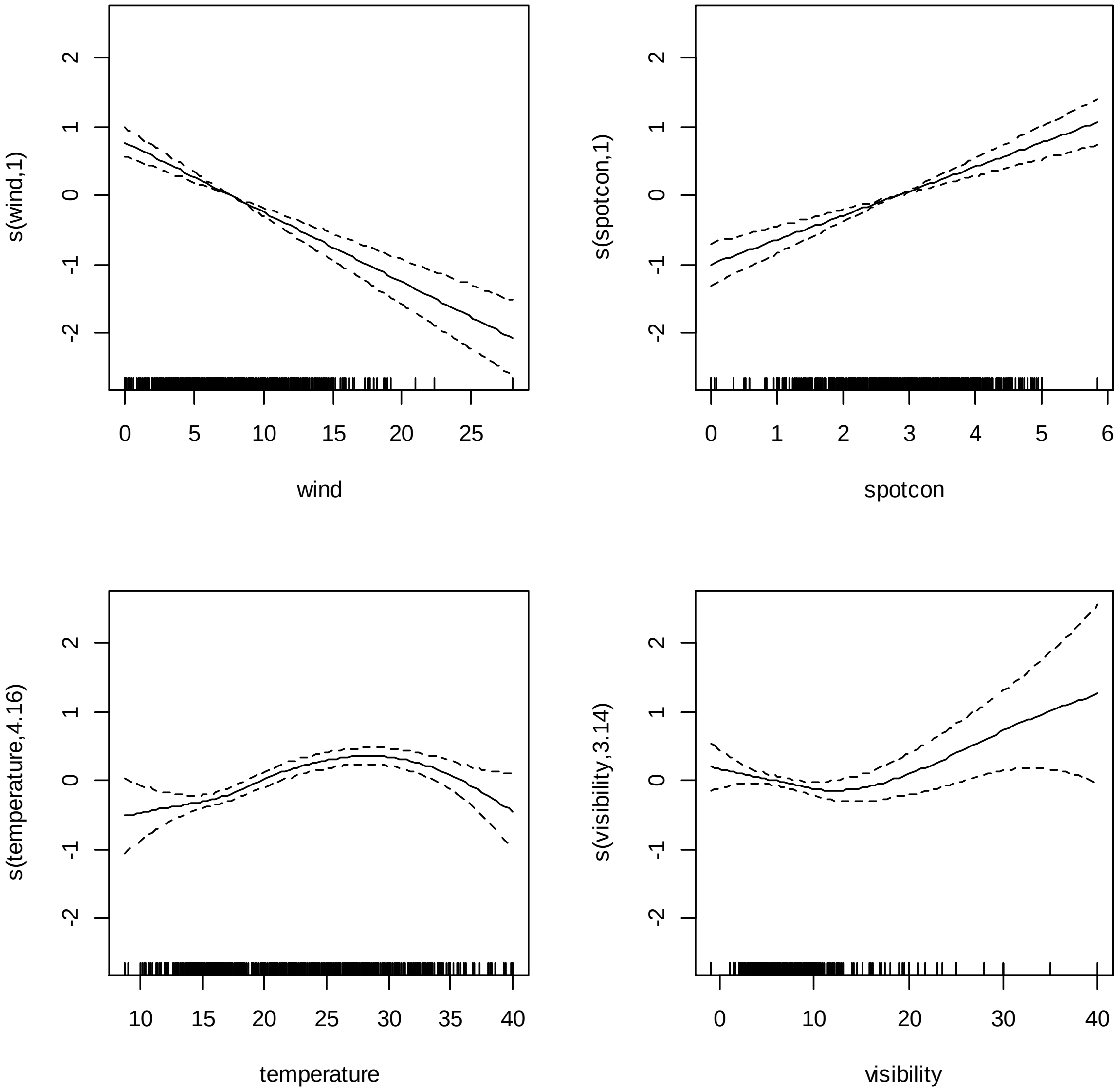

Figure 9. Estimated smooth relationships with 95% CI's between log(biomass/SearchEffort) and covariates 'wind' (windspeed in knots), 'spotcon' (spotting condition between 0 and 5), 'temperature' (air temperature in °C) and 'visibility' (in nautical miles). The 'rug' on the horizontal axis shows where data points are located.

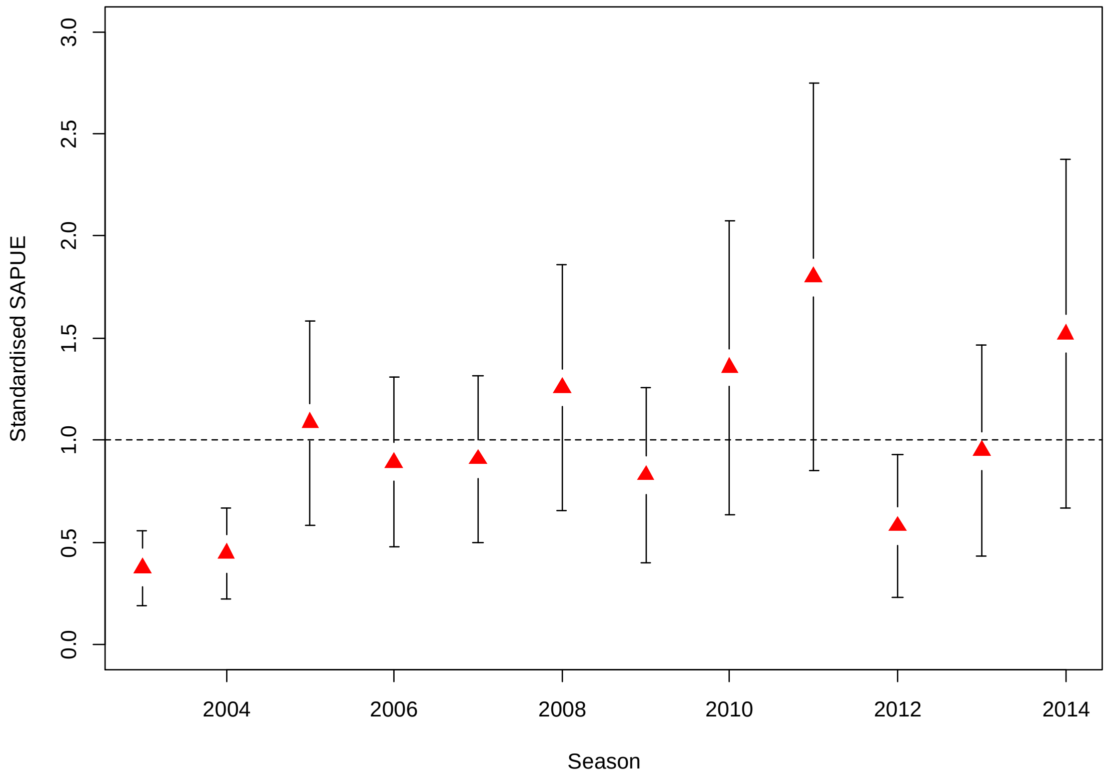

Figure 10. Estimates of standardised surface abundance per unit effort (SAPUE), scaled to the mean over the relevant period (see text for details). Data from all spotters, and months December – March were used. The median and exp(predicted value ± 2 standard errors) are shown. The horizontal line at 1 indicates the mean. Season refers to the second year in a split year, e.g. 2002 refers to the 2001/2002 season.

Table 7. Standardised SAPUE index of juvenile SBT in the GAB. Data from all months (December – March) and all spotters were used. Season refers to the second year in a split year, e.g. 2002 refers to the 2001/2002 season. The estimated values are illustrated in Figure 10 above.

SEASON	SAPUE ESTIMATE	SE
2003	0.38	0.09
2004	0.45	0.11
2005	1.09	0.25
2006	0.89	0.21
2007	0.91	0.20
2008	1.26	0.30
2009	0.83	0.21
2010	1.36	0.36
2011	1.80	0.47
2012	0.58	0.17
2013	0.95	0.26
2014	1.52	0.43

Summary

We present results of a standardised 'surface abundance per unit effort' (SAPUE) index, based on fitting a general linear model to the data. Due to the changes in spotter effort in the past, it is most appropriate to include data for all spotters in the analysis, rather than just spotters 1 and 6 (i.e. Farley and Basson, 2012). We have previously explored the sensitivity of results to the inclusion/exclusion of data from different spotters and results showed that the index is not sensitive to this. The most important environmental variables for this dataset were wind speed, spotting condition, and temperature.

The data suggests that during the 2014 commercial spotting flights, environmental conditions were better relative to recent years. Although the wind speed and air temperature were about average, the cloud cover and swell height were well below average while the visibility was above average. In addition, the spotters recorded the overall spotting conditions as the best (highest on average) compared to all previous years. This resulted in a significant decrease in the standardized index estimate compared to the raw estimate.

The 2012 standardised SAPUE index was the lowest since 2004, but the index increased in 2013 and again in 2014. The 2014 estimate is substantially higher than the long-term (2003-2014) average, and just slightly below the 2011 estimate, which was the highest for all years. The drop in the index between 2011 and 2012 is difficult to explain given that it represents the combined abundance of ages 2-4 years (see Farley and Basson, 2012). Without additional information it was impossible to establish the reason, or reasons, for the drop.

As noted in the past, the index should be treated with caution. We have note that the commercial spotting data can suffer from many of the same hard-to-quantify biases that affect catch per unit effort, for example, changes in coverage over time, lack of coverage in areas where commercial fishing is not taking place –for whatever reasons – and changes in operations over time. From a statistical perspective, the scientific aerial survey, which uses a line transect design and consistent protocols (e.g. Eveson et al., 2013), is far preferable as an approach to an index compared to the commercial spotting. However, these additional (commercial spotting) data can potentially provide further insights given the relatively large amount of effort (hours flown).

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Appendix A: Model output

```
Family: Tweedie(1.47)
Link function: log

Formula:
biomass ~ spotter.re + season + month + s(wind) + s(spotcon) + s(temperature) +
s(visibility) + Target + season.month + spotter.season + offset(log(SearchEffort))

Parametric coefficients (fixed effects only)
                                   Estimate Std. Error t value Pr(>|t|)
(Intercept)                      -2.625e-01  4.834e-01  -0.543 0.587216
season2004                        1.869e-01  4.474e-01   0.418 0.676206
season2005                        1.036e+00  4.407e-01   2.351 0.018926 *
season2006                        8.036e-01  4.515e-01   1.780 0.075406 .
season2007                        8.120e-01  4.475e-01   1.815 0.069891 .
season2008                        1.156e+00  4.611e-01   2.506 0.012362 *
season2009                        7.394e-01  4.622e-01   1.600 0.110008
season2010                        1.244e+00  4.882e-01   2.548 0.011000 *
season2011                        1.419e+00  4.905e-01   2.892 0.003912 **
season2012                        4.013e-01  4.969e-01   0.808 0.419518
season2013                        8.916e-01  4.982e-01   1.789 0.073860 .
season2014                        1.309e+00  5.015e-01   2.609 0.009214 **
month2                           -2.624e-01  1.961e-01  -1.338 0.181144
month3                           -8.622e-01  2.252e-01  -3.829 0.000137 ***
month12                           6.448e-02  2.014e-01   0.320 0.748889
TargetMack/SBT                   -5.941e-01  3.555e-01  -1.671 0.094999 .
TargetMAK/SKJ/SBT                -2.325e+02  7.048e+04  -0.003 0.997369
TargetSBT/Mack/SBT               -5.510e-01  2.145e-01  -2.569 0.010351 *
TargetSBT/SKJ/SBT                 1.763e-01  1.717e-01   1.027 0.304888
TargetSBT/SKJ/Mack/SBT           -3.653e-01  3.400e-01  -1.074 0.283022
TargetSKJ/SBT                    -3.495e-01  1.781e-01  -1.962 0.050025 .
TargetSKJ/Mack/SBT               -7.592e-01  1.545e+00  -0.491 0.623303
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                 edf Ref.df      F  p-value
s(wind)        1.002  1.004 57.369 7.67e-14 ***
s(spotcon)     1.002  1.003 41.870 1.48e-10 ***
s(temperature) 4.158  5.172 11.959 1.86e-11 ***
s(visibility)  3.145  3.929  2.636    0.034 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.457   Deviance explained = 61.9%
REML score =   6789   Scale est. = 25.107    n = 1038
```

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