GREAT AUSTRALIAN BIGHT
RESEARCH PROGRAM

RESEARCH REPORT SERIES

Offshore cetacean aerial surveys in the Great Australian Bight

Final Report to SARDI

Peter Gill

Blue Whale Study Inc.

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GREAT AUSTRALIAN BIGHT RESEARCH PROGRAM

The Great Australian Bight Research Program is a collaboration between BP, CSIRO, the South Australian Research and Development Institute (SARDI), the University of Adelaide, and Flinders University. The Program aims to provide a whole-of-system understanding of the environmental, economic and social values of the region; providing an information source for all to use.

OFFSHORE CETACEAN AERIAL SURVEYS

IN THE GREAT AUSTRALIAN BIGHT

2015-16

FINAL REPORT TO SARDI

30 AUGUST 2016

BLUE WHALE STUDY INC.

CONTENTS

EXECUTIVE SUMMARY

Three aerial surveys for cetaceans were carried out between December 2015 and April 2016 in the eastern and central Great Australian Bight (GAB). Survey timing conformed to that in the subcontract between Blue Whale Study (BWS) and SARDI, with surveys in mid-December, late January and mid-April. The first two surveys each were flown over two days and the third was flown over three days.

A total of 9,678 km was flown, of which 4,269 km was on effort (i.e. on designated survey transects in the GAB). This represented an area surveyed of 103,488 km^2 in total, or 46,970 km^2 on effort. Most survey effort was focused on the outer shelf from south-west of Kangaroo Island to south of the Head of Bight. On the third day of the April survey two areas west of Eyre Peninsula were also surveyed, including an area of surface upwelling and likely cetacean habitat.

A total of 58 cetacean sightings was recorded, 27 on effort (from designated transects), and 31 off effort (i.e. sighted in transit or after leaving transects). Eight species were identified, including: blue whales; a fin whale; sperm whales; pilot whales; killer whales; Risso's dolphins; common dolphins; and common or offshore bottlenose dolphins. There were also many sightings of unidentified dolphins ('dolphins sp.'), and a sighting of probable beaked whales of unknown species.

Species diversity and abundance, particularly on the outer shelf in the central-eastern GAB were low during the first two surveys during December and late January, but were several times higher during the April survey. Blue whales were not sighted in the eastern GAB (EGAB) or south of Kangaroo Island (KI) during any surveys, being sighted only along the Bonney Coast between Robe and Portland. Sperm (or 'like sperm') was the only species sighted in the EGAB during all three surveys. 'Dolphins sp.' were the most commonly sighted taxon, while pilot whales occurred in the highest density. Species never or very rarely sighted during previous BWS surveys in the GAB region included a fin whale, killer whales, and Risso's dolphins.

Species' distribution generally concurred with predicted habitat from prior surveys. Sperm whales, pilot whales, killer whales, Risso's dolphins, likely beaked whales and a single fin whale were found on the upper slope, not far outside the shelf break. Sperm whales tended to be in deeper steeper terrain while pilot whales, killer whales, Risso's dolphins, likely beaked whales were in shallower, less steep terrain. The single fin whale was just offshore of the shelf break. Dolphin sightings were widely distributed in shelf and upper slope waters, from close inshore to just offshore of the shelf break.

The 2015-16 upwelling season was relatively strong compared to previous seasons, with sustained upwelling evident from late December to mid-February, and again through much of March. Surface chl-*a* concentrations in the EGAB peaked during March and April, likely explaining the enhanced cetacean diversity and abundance detected during the April survey.

1. INTRODUCTION

The eastern Great Australian Bight (EGAB) is a relatively productive region due to interactions between seasonal upwelling associated with the Flinders Current, and warm intrusions from the Leeuwin Current (Middleton and Cirano 2002, Kämpf *et al.* 2004, McClatchie *et al.* 2006). The EGAB is the western extremity of an extensive upwelling system extending eastwards to the west coast of Tasmania, now sometimes referred to as the Great Southern Australian Upwelling System (Kämpf *et al.* 2004, Kämpf 2015). Large clupeid fisheries and a diversity of other marine fauna are dependent on primary productivity, which drives a food web dominated by schooling fish and squid, with apex predators including otariid seals and seabirds (Goldsworthy *et al.* 2013).

The EGAB also supports a diversity of cetacean apex predators, yet until recently knowledge about the species present, their distribution and ecology was rudimentary. Probably the best-known species has been the short-beaked common dolphin (*Delphinus delphis*), due to its association with the sardine (*Sardinops sagax*) fishery in the EGAB (Bilgmann *et al.* 2008, Hamer *et al.* 2008), and the southern right whale (*Eubalaena australis*) which fasts while breeding along South Australia's coastline during winter and spring (Burnell and Bryden 1997), outside of the EGAB's productivity. A diversity of other mysticete and odontocete species has also been sighted in this region (Gill *et al.* 2015).

Pygmy blue whales (*Balaenoptera musculus brevicauda*) also aggregate in the EGAB in high densities in some years to forage on the neritic euphausiid (*Nyctiphanes australis*) (Gill *et al.* 2011), which occurs throughout the shelf waters of this upwelling system (Blackburn 1980). At times the EGAB has appeared to be a more important blue whale foraging ground than the adjacent Bonney Upwelling, a term often applied to shelf waters from Cape Otway, Victoria, to west of Robe in South Australia (Butler *et al.* 2000).

The cetaceans in the EGAB have rarely been surveyed. Aerial surveys are the most effective method for surveying such large areas. Since late 2003 the Blue Whale Study (BWS) has conducted aerial surveys for blue whales in shelf and upper slope waters to the south and west of Kangaroo Island. During these surveys cetacean abundance was characterised by high variability. Blue whales were abundant in December 2003 and 2005, but in low densities or not sighted during other months and years (Gill *et al.* 2011, BWS unpublished data). Similar variability was also apparent for other species, mostly odontocetes (Gill *et al.* 2015).

BWS was subcontracted by the South Australian Research and Development Institute (SARDI), as part of the *Offshore cetacean, large teleost and pelagic shark surveys* component of the Great Australian Bight Research Program, to conduct three aerial surveys for cetaceans on the outer shelf and upper slope in the central and eastern Great Australian Bight during the 2015-16 summer- autumn upwelling season.

The proposed survey dates outlined below spanned the upwelling season:

- 15 December 2015
- 30 January 2016
- 15 March 2016

The objective was to carry out aerial surveys each of 3 days in duration, weather permitting, as described below:

- Day 1: survey known or likely areas used by cetaceans in the eastern GAB, on the shelf and slope southwest and west of Kangaroo Island. This area has been surveyed by BWS multiple times in other years, including monthly in the 2011/12 season, and large numbers of blue whales have been sighted there in some years.
- Day 2: survey an extension area into the central GAB. If no whales were seen in the survey area on Day 1, fly parallel just outside and just inside shelf break (on outward/return legs), for maximum distance coverage; this repeats 2011/12 survey pattern. If whales were seen in the survey area on Day 1, pickup and continue the saw tooth pattern westward from the Day 1 end point. If no whales are seen after a reasonable distance, change to shelf break-parallel track to complete survey.
- Day 3: if the weather window persists for a third day, and if whales were sighted in the extension survey on Day 2 and further westward survey could likely shed light on westward distribution, then continue the extension westwards as far as logistically practical either by parallel or sawtooth transects (alternative 1); or (alternative 2) survey an additional area of potential cetacean habitat identified from near-real-time remote sensed data (SST, chl-a) and/or prior knowledge of the region's biological oceanography and/or bathymetry and/or knowledge of previous or recent cetacean activity, preferentially using a saw-tooth pattern and including a randomly selected control area en route. One such possible area is the upwelling plume off the west coast of Eyre Peninsula. Survey activities on this day would be informed by information from the previous two days, and by logistic constraints (weather, distance to area of interest, aircraft endurance, pilot duty hours).

The primary survey area spanned from south of Cape du Couedic, Kangaroo Island (136° 40' E) westward to south of Head of Bight (131° 30' E) (Figure 1). A secondary survey area was off the west coast of Eyre Peninsula in a region that often displays a surface upwelling plume. The surveys were designed to detect blue whales, but the area covered also encompasses known sperm, beaked whale, pilot whale, and dolphin habitat.

The purpose of this report is to summarise the sightings information, including:
a) relative abundance estimates for whales calculated from either encounter rates, or distance sampling;
b) cetacean distribution and density, including as far as possible, intra- and inter-seasonal comparisons;
c) relationships between cetacean occurrence and environmental variables.

2. METHODS

2.1 Aerial survey methods

Aerial survey methods are detailed in Gill *et al.* (2011). High-wing twin-engine Aero Commander 500 aircraft suitable for offshore survey work were used. A team of three observers (two searching, one recording) scanned the survey area and recorded positions of cetaceans and associated attributes (e.g. group size, behaviour) and environmental conditions (e.g. sea state, glare, upwelling fronts). Sightings of other marine fauna were also recorded. Surveys were conducted in 'passing' mode, in which the aircraft remained on course along transects, and for each sighting a GPS position on the trackline and a vertical angle (by clinometer) were recorded as the sighting passed abeam (at 90° to the aircraft's track). Vertical angles corresponded to distances off track, so actual positions of sightings could be post-calculated. If diversions from survey transects were required to confirm species identification or group size, the aircraft left transects in 'closing mode' and circled the sighting until the desired data were obtained, before resuming the transect.

The methods were designed to assess the occurrence and relative abundance (including density) of blue whales and other cetaceans inhabiting outer shelf and upper slope environments.

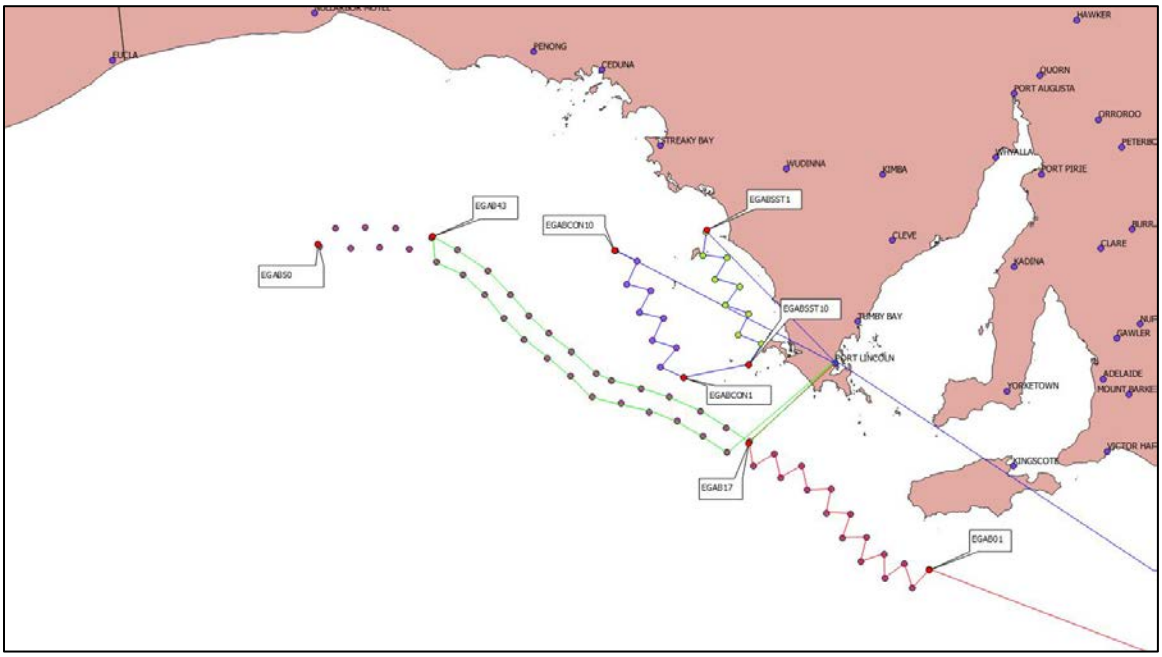


Figure 1. Aerial survey tracks used for the GAB cetacean surveys. The surveys continued west to EGAB50.

2.2 Measures of abundance

For each species, using distance sampling to estimate abundance requires at least 60 sightings (Buckland *et al.* 2005). Since the total number of sightings for all species was 58, distance sampling was not a valid method. Measures used were encounter rate (ER), defined as animals sighted per 1000 km of trackline on effort (e.g. see Gill *et al.* 2011), and density (number of

animals sighted per area surveyed on effort, assuming a strip width coverage of 11 km), in other words the ER divided by 11, or animals per 1000 km^2. ER and density for all on effort sightings are shown in Table 3.

2.3 Environmental variables

A preliminary investigation of the influence of environmental variables was restricted to two variables: an upwelling intensity index (UII), and surface chlorophyll-*a* concentrations.

UII was derived from daily (1500 h) windstress data from Cape Nelson weather station, Victoria, using the methods of Van Ruth (2010). Despite its distance from the EGAB, upwelling synchrony occurs across the broader upwelling system at the scale of pressure systems and wind fields (Kämpf *et al.* 2004), so the Cape Nelson data can be regarded as representative of the upwelling system as a whole. Five-day means were used to smooth the data.

Mean monthly composite MODIS AQUA chl-*a* data for the 2015-16 upwelling season was downloaded from the NOAA ERDDAP site[1]. The sampling area was bounded by 34°-36°S, 133°-137°E, and includes most of the 'Kangaroo Island pool' and the upwelling plume west of Eyre Peninsula, where enhanced concentrations of chl-*a* may be expected after upwelling (Ward *et al.* 2006).

[1] Sourced from http://coastwatch.pfeg.noaa.gov/erddap/wms/erdMHchlamday/index.html

3 RESULTS

3.1 Summary of surveys

All surveys started and ended at Portland, Victoria. Details of surveys are summarised in Table 1.

Table 1. Survey summary, 2015-16 EGAB aerial surveys.

Survey #	Dates	Total km	Total km^2 surveyed	On effort km	On effort km^2 surveyed	Days on effort completed
15-12-1 (EGAB1)	09-11 Dec 2015	2,960	29,590	1,272	13,992	2 of 3
16-1-1 (EGAB2)	31 Jan-02 Feb 2016	3,007	33,077	1,278	14,058	2 of 3
16-4-1 (EGAB3)	18-20 April 2016	3,711	40,821	1,720	18,920	3 of 3
TOTAL		9,678	103,488	4,269	46,970	7 of 9

A total of 4,269 km on effort trackline allowed on effort survey coverage of 46,970 km^2, based on the an 11 km strip width and the effective range of visibility at 457 m altitude.

The second day in all three surveys was flown in transects that were parallel to and either side of the shelf break, extending west to waypoint EGAB50. The third day on survey EGAB3 (20 April) was flown on the sawtooth transects (EGABSST) west of Eyre Peninsula, and the sawtooth control transects further offshore (EGABCON).

Seven of the nine days that were planned for aerial surveys were completed. The first two surveys were reduced to two days due to unforeseeable bad weather. During surveys EGAB1 (mid-December) and EGAB2 (late January-early February), after good survey conditions prevailed on the first two days of each survey, the weather deteriorated on the final day.

3.2 Summary of cetacean sightings

A total of 58 cetacean sightings were recorded. Sightings are shown in Figure 2 and summarised in Tables 2 and 3, and in Appendix A.

There were 27 ‘on effort’ sightings recorded while on survey transects, and 31 sightings ‘off effort’, either in transit to and from survey areas, or when closing with on effort sightings. Off effort sightings include all blue whale sightings recorded in transit between Portland, Victoria, and Robe, S.A.

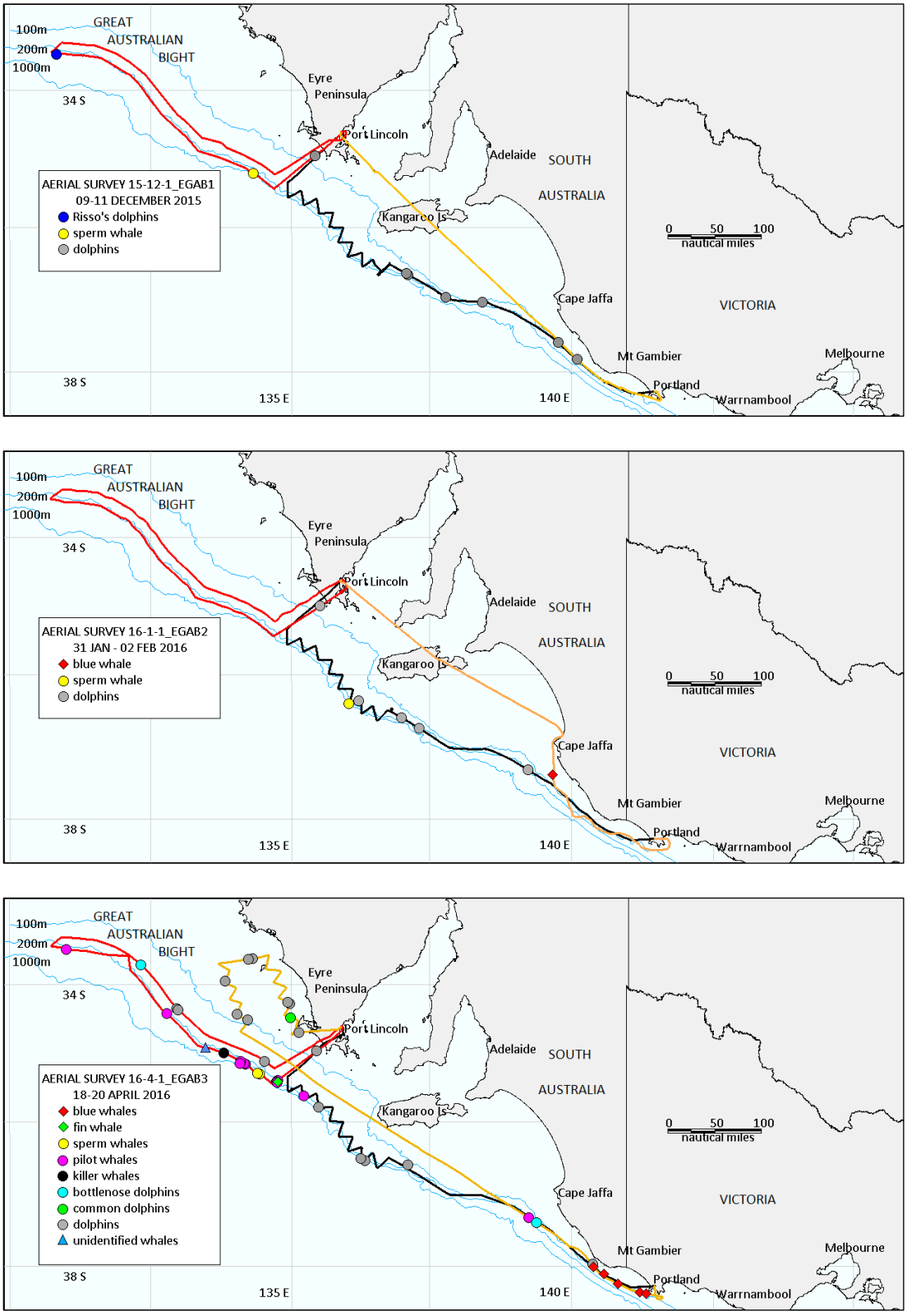


Figure 2. Maps for the three multi-day aerial surveys. In each survey the first day's track is shown in black; the second day's in red; and the third in orange.

Table 2. Summary of all sightings (on and off effort) for each survey and for all surveys combined.

Survey dates	# sight-ings	# species	Sight-ings/ species	Species	No.	Mean group size	Mean depth m	Mean slope m/km
09-11 Dec 2015	9	3	1	Sperm whale	1	1	756	4.5
			1	Risso's dolphins	60	60	458	1.3
			7	Dolphins sp.	265	37	114	0.9
31 Jan-02 Feb 2016	9	3	1	Blue whale	1	1	59	0.1
			1	Like[2] sperm whale	1	1	1371	10.9
			7	Dolphins sp.	343	49	131	0.6
18-20 April 2016	40	9	5	Blue whales	5	1	90	0.3
			1	Fin whale	1	1	225	4.3
			2	Sperm whales	3	1.5	1281	4.1
			11	Pilot whales	646	58	515	2.9
			1	Killer whales	10	10	494	2.5
			2	Bottlenose dolphins	525	263	123	0.3
			1	Common dolphins	3	3	76	0.2
			16	Dolphins sp.	239	15	172	1.9
			1	Unidentified whales	3	3	461	3.0
All surveys combined	58	9	6	Blue whales	6	1	85	0.2
			1	Fin whale	1	1	225	4.3
			4	Sperm & like sperm	5	1.3	1172	5.9
			11	Pilot whales	646	58	515	3.0
			1	Killer whales	10	10	494	2.5
			1	Risso's dolphins	60	60	458	1.3
			2	Bottlenose dolphins	525	263	123	0.3
			1	Common dolphins	3	3	76	0.2
			30	Dolphins sp.	847	28.2	149	1.4
			1	Unidentified whales	3	3	461	3.0

Table 3. Summary of on effort cetacean sightings for each aerial survey and for all surveys combined, 2015-16. Distance and area surveyed are shown on Table 2. ER = encounter rate.

Survey dates	Species	N sights	N animals	Mean group size	ER (animals/ 1000km)	Density (animals/ 1000km^2)
09-11 Dec 2015	Sperm whale	1	1	1	0.8	0.07
	Risso's dolphins	1	60	60	47.2	4.30
31 Jan-02 Feb 2016	Like sperm whale	1	1	1	0.8	0.07
	Dolphins sp.	1	5	5	3.9	0.36
18-20 Apr 2016	Sperm whales	2	3	1.5	1.7	0.16
	Pilot whales	7	206	72	119.8	10.89
	Killer whales	1	10	10	5.8	0.53
	Bottlenose dolphins	1	25	25	14.5	1.32
	Common dolphins	1	3	3	1.7	0.16
	Dolphins sp.	11	224	20.4	130.2	11.84
	Unidentified whales	1	3	3	1.7	0.16
All surveys combined	Sperm & like sperm whales	4	5	1.3	1.2	0.11
	Pilot whales	7	266	38	62.3	5.66
	Risso's dolphins	1	60	60	14.1	1.28
	Killer whales	1	10	10	2.3	0.21
	Bottlenose dolphins	1	25	25	5.9	0.53
	Common dolphins	1	3	3	0.7	0.06
	Dolphins sp.	12	229	18.8	53.6	4.88
	Unidentified whales	1	3	3	0.7	0.06

[2] The term 'like sperm (or other) whale' is used in cetacean research to denote an animal that has not been identified but resembles a sperm whale.

3.3 SPECIES ACCOUNTS:

3.3.1 Pygmy blue whales *Balaenoptera musculus brevicauda*

Although the importance of the shelf break zone south and west of Kangaroo Island to foraging blue whales is well established (Gill *et al*. 2011), blue whales were not sighted in the EGAB. This is consistent with previous seasons' surveys in the region (Table 4) in which blue whales were abundant only during December 2003 and December 2005.

Variability in blue whale presence was supported by anecdotal, unconfirmed reports from other sources. About 25 blue whales and surface swarms of krill were reported by a fisher around the Murray and Sprigg Canyons during late November-early December. We did not find those whales on 9 December. In December 2015 a group of blue whales was reported in an unidentified location by tuna spotting pilots working in the EGAB, while a further confirmed sighting was reported west of Kangaroo Island in late December. In mid-December 2014 tuna spotting pilots reported a group of 25-30 blue whales within a small area west of Kangaroo Island.

3.3.2 Fin whale *Balaenoptera physalus*

The sighting on 19 April 2016 was the westernmost fin whale sighting recorded by BWS, and our first in the EGAB. There is a record of a fin whale stranding near Port Lincoln in 1999[3]. Fin whales are generalist feeders, preying on schooling krill, fish and squid (Jefferson *et al.* 2008). The fin whale on 19 April was near groups of pilot whales, suggesting the presence of schooling prey.

Figure 3. The fin whale sighted on 19 April 2016, showing the white lower right jaw unique to this species. The distinctive dorsal chevron is also visible between the pectoral fins.

[3] http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=37

3.3.3 Sperm whales *Physeter macrocephalus*

Sperm whales may be abundant in the GAB. BWS has sighted them during aerial surveys in the EGAB/KI region over the years, and they are the only species observed during all three 2015-16 surveys. We have observed them in November, December and April of previous years, but they have been absent from a number of surveys as well (see Table 4). However, deep, long diving odontocete cetaceans such as sperm (and beaked) whales may be under-represented in aerial survey data as they are unavailable for sighting during feeding dives which may last 40 minutes or more (Whitehead 2003). Sperm whales were often detected acoustically but not sighted during a vessel-based cetacean acoustic survey west of KI during autumn 2013 (IFAW 2013).

All BWS' sightings in the EGAB over the years appeared to be of bachelor schools of young adult similar-sized males or mature males (Figure 3), either solitary or in pairs, with no evidence of nursery schools consisting of adult females and young (Whitehead 2003). Mean group size during the 2015-16 surveys was 1.3, somewhat smaller than the mean size of 1.9 from 34 sightings reported by Gill *et al*. (2015) between Bass Strait and the EGAB.

Figure 4. Adult male sperm whale on 19 April 2016, showing the forward-angled blow and large blunt head.

A 'like sperm whale' was sighted on 01 January 2016, which dived as we approached. The position just offshore of the shelf break, the large size and colouration of the whale and the clear sight of a forward-angled blow strongly indicated that this was a sperm whale.

3.3.4 Long-finned pilot whales *Globicephala melas*

The pilot whales sighted in this region were undoubtedly long-finned pilot whales *Globicephala melas*, the only pilot whale known to regularly occur south of 27°S in Australian waters (Ross 2006). Overall they were the most commonly sighted species during the 2015-16 surveys, and were found in higher density than any other species, despite their apparent absence during

EGAB1 and EGAB2 (Table 3). During previous years' surveys they have been sighted in the EGAB during December, February and March (Table 4). Nothing is known of their seasonal movements, if any, within this region, or their affinities with populations observed off Victoria, Tasmania or Western Australia (Ross 2006).

Mean group size was 58, compared with 46 from 40 sightings reported by Gill *et al*. (2015). All groups photographed showed a range of size classes including calves (see photo below). Mean sightings depth was 515 m, compared with 634 m reported by Gill *et al*. (2015), confirming that pilot whales tend to occupy the upper slope inshore of depths favoured by sperm whales. Primarily squid feeders, in the Northern Hemisphere they are also known to consume fish (Jefferson *et al.* 2008); the same may be true in southern Australian waters.

Figure 5. Mixed-size-class group of pilot whales on 20 April 2016. Four calves are in this group.

3.3.5 Killer whales *Orcinus orca*

Killer whales are little known along Australia's southern coast, with only 6 sightings recorded over 12 years during BWS aerial surveys (Gill *et al*. 2015). They are a widespread, yet unpredictable and rarely observed species in our region. The group of 10 sighted on 19 April 2016 was larger than the mean (3.5), and equalled the largest group reported by Gill *et al*. (2015). A calf was present in this group (see below), the first sighted during BWS aerial surveys. Killer whales prey on baleen and toothed whales, dolphins, seals, sharks, fish and cephalopods in Australian waters (Morrice 2004).

Figure 6. Adult female killer whale and young calf on 19 April 2016.

3.3.6 Risso's dolphins *Grampus griseus*

The most interesting sighting during EGAB1 and EGAB2 was the group of Risso's dolphins recorded during EGAB1. BWS has only sighted one other group of Risso's during many years of surveys between the GAB and western Bass Strait. The earlier sighting (February 2012) was only 50 km east of the recent sighting, remarkably close given the scale of aerial survey coverage over the years.

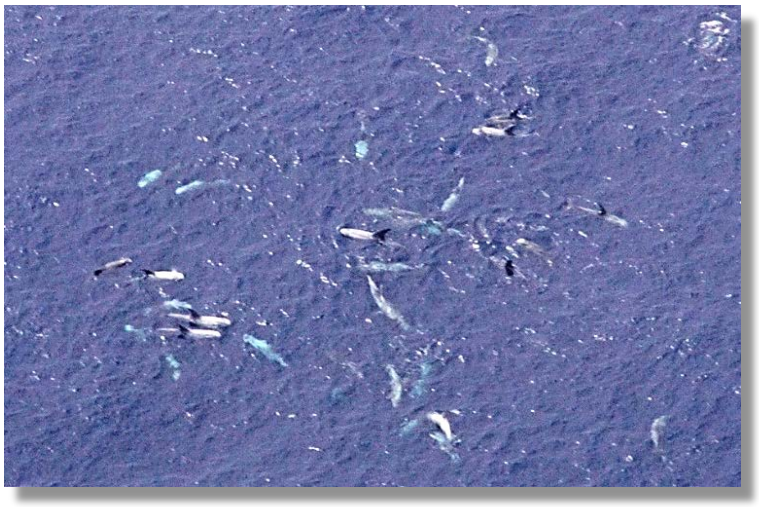


Figure 7. Group of Risso's dolphins on 10 December 2015, showing the pale coloration and large dorsal fins typical of adults.

While Ross (2006) states that Risso's dolphins have been recorded from all States and Territories except the Northern Territory, Jefferson *et al.* (2013) state that they have been recorded only

off Australia's east coast. Little is known of their ecology and nothing of their movements (Ross 2006). Further surveys are required to assess the significance of the GAB to this species.

Group size in the 2012 sighting was 40 and depth was 339 m, compared with the group size of 60 and depth of 458 m during EGAB1. A range of size classes was evident in both sightings, and in both sightings their behaviour was described as 'milling' (apparent random direction of movement) and 'socialising' (frequent interactions between individuals). Such behaviour may be common during daylight. In the Northern Hemisphere Risso's dolphins feed mostly at night, exclusively on squid (Baird 2002).

3.3.7 Other dolphin species

Unidentified dolphins (dolphins sp.) were the most commonly recorded cetacean during the surveys, with 31 sightings (mean group size 29, mean depth 149 m). Group size was half that (58) reported by Gill *et al.* (2015) from 384 sightings at a mean depth of 134 m.

Figure 8. Socially active bottlenose dolphins sighted on 20 April 2016. The surfacing posture and pigmentation of the animal at lower left enabled identification as *Tursiops* sp., probably *T. truncatus.*

The majority of dolphins sighted were most likely short-beaked common dolphins *Delphinus delphis* (e.g. Bilgmann *et al.* 2008, Hamer *et al.* 2008), poorly understood in terms of population demography and movements. Bottlenose dolphins are represented by more than one species in this region (Gill *et al.* 2015). Given the offshore locations of both bottlenose sightings, they are likely to have been common, or offshore bottlenose dolphins *Tursiops truncatus.*

3.3.8 Unidentified whales

Three unidentified whales sighted briefly on 19 April were likely to have been beaked whales. They were approximately 5-6 m long and appeared light grey. Possible candidate species known to occur off southern Australia are: Cuvier's beaked whale *Ziphius cavirostris*; Gray's beaked whale *Mesoplodon grayi*; True's beaked whale *Mesoplodon mirus*; and the strap-toothed

beaked whale *Mesoplodon layardii*. These deep-diving squid eating whales live in remote offshore waters, are cryptic in habit and rarely observed.

Shepherd's beaked whales *Tasmacetus shepherdi*, twice sighted to the west of Kangaroo Island in recent years (IFAW 2013, Gill *et al*. 2015) were ruled out as their very distinctive pigmentation was not apparent during the brief sighting of these three whales.

4 PAST AERIAL SURVEYS OF THE EGAB BY BWS

BWS first conducted aerial surveys in the EGAB in December 2003. Prior BWS surveys covered the shelf break south as well as west of Kangaroo Island. The months and years within which BWS conducted surveys in this region, and species observed during these surveys, are given in Table 4. Figure 9 (copied from Gill *et al.* 2015), summarises regional aerial survey effort between 2003-2012, using a 25x25 km grid. While the target species for these surveys was the pygmy blue whale, other species were recorded whenever encountered.

High variability in cetacean abundance was found in the EGAB during past seasons (Table 4). Patchy temporal effort makes it difficult to draw significant conclusions from these data.

Blue whales were numerous in December 2003 and December 2005, and at these times the EGAB/KI region appeared to be the primary regional foraging ground for this species, as very few were found simultaneously in the adjacent Bonney Upwelling region (Gill *et al.* 2011). In December 2003, large krill surface swarms were abundant in areas where blue whales were abundant and surface feeding was frequently observed. December 2003 also showed the highest species diversity including both mysticete and odontocete cetaceans (5 species).

The only other months during which blue whales were sighted, in very low numbers, were November and December 2011, while during the remaining six surveys, no blue whales were sighted.

Pilot whales were the most frequently encountered species during these prior surveys (4 times), followed by dolphins (3) and sperm whales (3). Dolphins were numerically the most abundant 'species' encountered overall, followed by pilot whales.

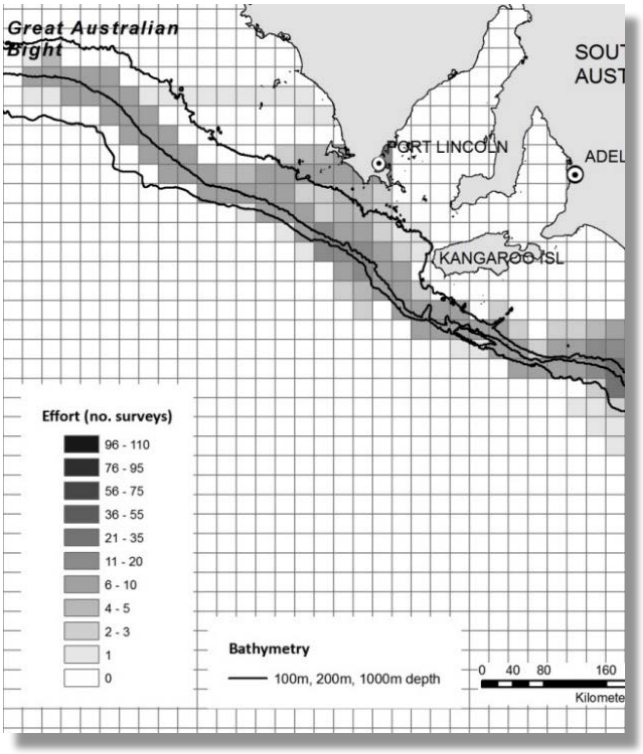
February 2012 was an exceptional month as Risso's dolphins and Shepherd's beaked whales were encountered, both previously unsighted during BWS surveys. At the time this was one of fewer than 10 sightings of free-swimming Shepherd's beaked whales worldwide.

During December 2004, March 2005 and March 2006 there were no sightings of any cetaceans of any kind.

Table 4. Summary of surveys and sightings, all prior BWS blue whale aerial surveys in the EGAB/KI region.

Month and year	N blue whales	Km flown	Blue whale ER*	Other species	Other spp. ER	Other spp. density
2-13 December 2003 (6 surveys)	135	3792	35.6	Minke whale (1) Sperm whales (7) Pilot whales (30) Dolphins (1504)	0.3 1.8 7.9 396.6	0.03 0.16 0.72 36.1
18 April 2004	0	1200	0	Sperm whales (2) Dolphins (74)	1.7 61.7	0.15 5.6
13 December 2004	0	747	0		0	0
29 March 2005	0	246	0		0	0
19 December 2005	33	490	67.3	Pilot whales (65) Dolphins (367)	132.7 748.9	12.1 68.1
29 March 2006	0	872	0	0		
27-28 November 2011	1	1570	0.6	Sperm whales (4)	2.5	0.23
20 December 2011	3	1176	2.6	0		
3-4 February 2012	0	1905	0	Risso's dolphins (40) Pilot whales (30)	21.0 15.7	1.9 1.4
26-27 February 2012	0	1620	0	Shepherd's beaked whales (6)	3.7	0.34
28-29 March 2012	0	1947	0	Pilot whales (565)	290.2	26.4

Figure 9. Distribution of survey effort in the GAB/KI region, prior BWS aerial surveys, December 2003 to March 2012. Cropped version of Figure 1, Gill *et al.* (2015).



5 CETACEAN HABITAT IN THE EGAB

The EGAB presents a diversity of cetacean habitat from the broad gently sloping shelf to the steeper upper slope, and the complex bathymetry of its canyon systems. Enriched water from shelf-break upwelling south of Kangaroo Island accumulates along the shelf edge and is advected into the 'Kangaroo Island pool', feeding secondary upwelling inshore to the west of Eyre Peninsula, making this one of most productive marine regions around Australia (McClatchie *et al.* 2006, Ward *et al.* 2006).

These surveys have confirmed that the outer shelf and upper slope region of the GAB are likely foraging habitat for a diversity of cetacean species. Gill *et al.* (2011, 2015) have previously found a diversity of species in this region including pygmy blue whales, a minke whale, sperm whales, pilot whales, Risso's dolphins, Shepherd's beaked whales and 'dolphins sp.' The 2015-16 surveys have added fin and killer whales to the list of species recorded by BWS in the EGAB, although both were sighted previously in the Bonney Upwelling. Both species are rarely sighted off southern Australia. We were able to identify both common and bottlenose dolphins during the current surveys, also previously known to occur in the region.

During survey EGAB3 numerous dolphins, as well as the only krill surface swarms sighted during the EGAB surveys, were sighted in the previously unsurveyed (at least by BWS) upwelling zone west of Eyre Peninsula, underlining its potential as a cetacean aggregation area. Further surveys should be considered for this area throughout a future upwelling season.

Distribution of species generally conformed to what is known of their ecology, and to results of past surveys in the region. Sperm whales were found in deeper, steeper terrain on the upper slope than other species. Pilot whales, killer whales, Risso's dolphins and 'like' beaked whales were also on the upper slope, but in shallower depths and gentler slopes than sperm whales. These findings were consistent with Gill *et al.* (2015). Risso's dolphins occur from tropical to temperate regions, but our GAB sightings are consistent with a preference elsewhere for shelf and slope waters in temperate regions (Jefferson *et al.* 2013).

Species such as sperm and pilot whales, and common dolphins, appear to be widespread along Australia's southern shelves, yet little has been published about their ecology and nothing about their movements. Whether they are seasonal or year-round occupants of the EGAB is not known, nor is their genetic relationship to animals seen in other aggregation areas off Victoria, Tasmania or Western Australia.

6 POSSIBLE ENVIRONMENTAL INFLUENCES ON SURVEY RESULTS

The results shown in Tables 2 and 3 indicate striking temporal differences in species diversity and abundance between surveys. The December and January-February (EGAB1 and EGAB2) surveys were alike in their low species diversity and low numbers of sightings overall. In contrast, the April survey (EGAB3) showed both higher species diversity and abundance, and a wider distribution of sightings.

This upwelling system demonstrates clear seasonality in upwelling intensity and primary productivity (Ward *et* al. 2006, Nieblas *et al.* 2009, Gill *et al.* 2011). Peak upwelling intensity tends to occur in February and peak primary production in February-March, although considerable variability has been noted between seasons (i.e. years) in both timing and intensity (Nieblas *et al.* 2009, Gill *et al.* 2011). This is highly likely to influence variability in cetacean sightings between seasons (e.g. compare 2003-04 and 2004-05, Table 4).

Figure 9 shows 5-day mean upwelling intensity index (UII) for the 2015-16 upwelling season. Values for this season are compared with a combined mean from the 13 previous seasons. After a strong downwelling event in late November-early December 2015, there were two strong upwelling events in December, with survey EGAB1 taking place during the first of these events. This was followed by a period of sustained upwelling from the end of December until mid-February, with EGAB2 taking place during this period. After a brief period of negative windstress, strong upwelling resumed between 10-30 March. Survey EGAB3 took place in the subsequent period of downwelling.

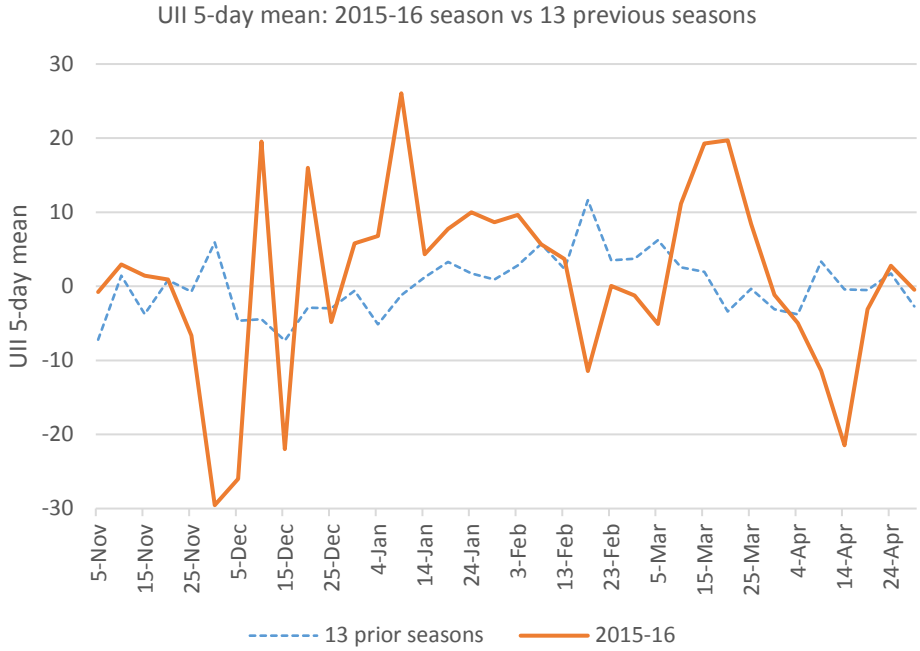


Figure 9. Five-day mean upwelling intensity index (UII) derived from 1500 h daily wind data from Cape Nelson, Victoria (using methods of Van Ruth *et al.* 2010). The 2015-16 season is compared with the mean from the 13 previous seasons. Positive values = upwelling-favourable windstress; negative values = downwelling-favourable windstress.

Comparison with the 13 previous seasons showed that this was a relatively strong upwelling season, despite a very weak start in November, with upwelling events spread across much of the season. Presumably this sustained upwelling resulted in significant nutrient input into the EGAB. The low numbers of cetaceans observed during EGAB1 and EGAB2 are consistent with low levels of primary production typically observed early in upwelling seasons (e.g. Nieblas *et al.* 2009, Gill *et al.* 2011). The increased diversity and abundance recorded during EGAB3 are consistent with the hypothesis that primary and secondary production, and cetacean abundance in upwelling systems, usually approach their maxima several months after the onset of an upwelling season (e.g. Croll *et al.* 2005).

Evidence for enhanced productivity late in the upwelling season was provided by the MODIS AQUA chl-*a* data. Figure 10 shows mean monthly composite data for the sampling area. Mean chl-*a* levels were relatively low from November 2015 to February 2016, which appeared low given sustained upwelling early in the month (Figure 9).

Mean chl-*a* levels peaked during the sustained upwelling of March (highest individual value 19.1 mg m^{-3}), then remained relatively high during April (highest individual value 9.0 mg m^{-3}). Enhanced levels of primary production evident during March and April were likely available to higher trophic levels, ultimately including the cetaceans observed during our surveys.

These results are exploratory only. Sightings and environmental data presented in this report could be integrated with other published data (e.g. Gill *et al.* 2011, 2015) to further model the distribution and occurrence of cetaceans in the GAB.

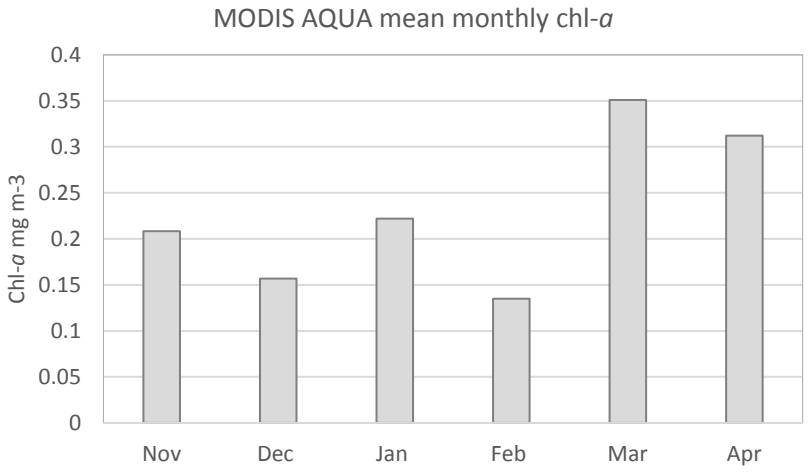


Figure 10. Mean monthly composite MODIS AQUA chl-*a* data for the 2015-16 upwelling season.

7 INTEGRATION OF AERIAL SURVEY DATA WITH IMOS ACOUSTIC LOGGER DATA

An original objective of the aerial survey program was to compare sightings data with acoustic data recorded from the IMOS sea noise logger deployed at the shelf break west of Kangaroo Island. The logger was deployed in December 2014 and retrieved for data download and re-battery in November 2015 (McCauley 2016). Unfortunately no aerial surveys were flown during the 2014-15 summer to enable comparison of data. The logger was re-deployed in December 2015 and will not be retrieved again until December 2016. Hence no acoustic data is available yet for comparison with the 2015-16 aerial survey data.

8 ACKNOWLEDGEMENTS

Thanks to observers Dr Andrew Levings, Vincent Antony and Dr Maria Garcia for their hard work in the air. Thanks also to pilot Andrew Merwood and the operations staff at GAMair for fitting in with our unpredictable schedule.

The Great Australian Bight Research Program is a collaboration between BP, CSIRO, the South Australian Research and Development Institute (SARDI), the University of Adelaide, and Flinders University. The Program aims to provide a whole-of-system understanding of the environmental, economic and social values of the region; providing an information source for all to use.

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APPENDIX A. ALL CETACEAN SIGHTINGS

Date	Local time	Species	No.	Apparent behaviour	Dec lat	Dec long	Depth m	Slope m/km	Notes
09-Dec-15	10:44	dolphins	5	not recorded	-37.865	140.092	86	0.2	
09-Dec-15	10:55	dolphins	10	feeding	-37.625	139.757	80	0.2	
09-Dec-15	11:32	dolphins	20	not recorded	-37.050	138.403	103	0.7	near many krill swarms
09-Dec-15	11:48	dolphins	50	not recorded	-36.981	137.746	160	3.2	moving fast in tight groups
09-Dec-15	12:07	dolphins	30	not recorded	-36.659	137.077	126	0.1	moving fast in tight groups
09-Dec-15	12:08	dolphins	50	not recorded	-36.644	137.041	154	1.8	moving fast in tight groups; many albatrosses
10-Dec-15	9:20	dolphins	100	fast travel east	-34.936	135.415	88	0.1	
10-Dec-15	9:50	sperm whale	1	defaecated	-35.199	134.317	756	4.5	large male likely foraging & re-oxygenating
10-Dec-15	11:39	Risso's dolphins	60	milling, socialising	-33.450	130.804	458	1.3	obvious social inter-actions, calves in group
31-Jan-16	9:49	dolphins	200	not recorded	-37.348	139.215	196	2.1	big scattered school
31-Jan-16	10:32	dolphins	40	not recorded	-36.756	137.276	122	1.1	
31-Jan-16	10:39	dolphins	50	fast travel	-36.601	136.960	126	0.1	
31-Jan-16	11:09	dolphins	5	not recorded	-36.355	136.200	142	0.2	
31-Jan-16	11:13	like sperm	1	dived	-36.401	135.999	1371	10.9	large whale with forward-angled blow
01-Feb-16	9:50	dolphins	10	milling	-34.983	135.511	92	0.2	
02-Feb-16	13:11	blue whale	1	feeding	-37.410	139.655	59	0.1	adult whale; lunge fed near front; no krill visible
02-Feb-16	13:39	dolphins	8	travel	-38.154	140.409	123	0.1	
02-Feb-16	13:46	dolphins	30	milling	-38.247	140.703	118	0.5	
18-Apr-16	10:01	dolphins	50	feeding	-36.599	137.068	110	0.1	
18-Apr-16	10:08	blue whale	1	diving	-38.284	140.811	97	0.5	no krill sighted this area
18-Apr-16	10:19	blue whale	1	feeding	-38.153	140.570	62	0.1	surface lunge feeding on small scattered krill
18-Apr-16	12:09	dolphins	10	milling	-36.537	136.302	628	10.6	likely common dolphins; gannets & albies this area
18-Apr-16	12:10	dolphins	3	surfaced	-36.514	136.238	652	13.5	like commons
18-Apr-16	12:50	dolphins	3	surfaced	-35.766	135.479	303	4.1	like commons

18-Apr-16	13:03	pilot whales	300	fast travel	-35.607	135.216	240	3.8	very active group moving fast to west; some calves
19-Apr-16	10:22	dolphins	2	surfaced	-34.953	135.443	91	0.0	
19-Apr-16	10:39	pilot whales	40	slow travel	-35.383	134.754	167	1.0	
19-Apr-16	10:42	fin whale	1	slow travel offshore	-35.399	134.750	225	4.3	blew 3-4 times, dived 3 min then resurfaced. No krill. Near groups of pilots
19-Apr-16	10:45	pilot whales	30	milling	-35.399	134.731	334	5.6	socially active, at least 4 calves present
19-Apr-16	10:49	pilot whales	20	active	-35.414	134.743	430	6.7	near fin whale and other pilot groups
Date	Time	Species	Number	Apparent behaviour	Dec lat	Dec long	1296	4.4	Notes
19-Apr-16	10:58	sperm whales	2	blowing	-35.285	134.433	1265	3.8	two large whales near each other
19-Apr-16	11:00	sperm whale	1	blowing; dived	-35.277	134.387	942	2.9	blew several times then fluke up dive
19-Apr-16	11:07	pilot whales	50	milling	-35.145	134.174	844	3.4	milling
19-Apr-16	11:09	pilot whales	40	milling	-35.130	134.158	783	3.0	milling
19-Apr-16	11:11	pilot whales	40	milling	-35.104	134.093	966	2.0	milling
19-Apr-16	11:13	pilot whales	40	slow travel	-35.136	134.073	494	2.5	not recorded
19-Apr-16	11:22	killer whales	10	fast travel	-34.982	133.786	461	3.0	no adult males seen; at least one mother-calf pair
19-Apr-16	11:36	unidentified whales	3	dived	-34.901	133.461	428	2.0	larger than pilots - grey – like beaked whales?
19-Apr-16	12:02	pilot whales	6	fast travel	-34.405	132.772	364	1.1	
19-Apr-16	13:01	pilot whales	30	travel	-33.454	130.983	129	0.1	at least one calf present
19-Apr-16	13:46	bottlenose dolphins	25	tight group	-33.682	132.308	129	0.1	pale grey with dorsal cape
19-Apr-16	14:05	dolphins	30	tight group	-34.331	132.956	127	0.1	
19-Apr-16	14:06	dolphins	100	scattered	-34.348	132.979	132	0.3	
19-Apr-16	14:41	dolphins	1	not recorded	-35.107	134.514	41	0.5	
20-Apr-16	10:22	dolphins	2	surfaced	-34.680	135.133	76	0.2	
20-Apr-16	10:34	common dolphins	3	fast travel	-34.460	134.985	82	0.0	hourglass pattern of *Delphinus* on breaching animal
20-Apr-16	10:45	dolphins	3	not recorded	-34.251	134.963	78	0.0	
20-Apr-16	10:45	dolphins	50	not recorded	-34.233	134.930	75	0.1	
20-Apr-16	11:22	dolphins	2	not recorded	-33.588	134.299	71	0.1	

20-Apr-16	11:24	dolphins	6	not recorded	-33.597	134.225	84	0.1	
20-Apr-16	11:44	dolphins	15	not recorded	-33.923	133.814	93	0.0	
20-Apr-16	12:02	dolphins	4	not recorded	-34.407	134.026	96	0.0	
20-Apr-16	12:06	dolphins	5	not recorded	-34.491	134.221	172	0.9	
20-Apr-16	14:03	pilot whales	50	slow travel	-37.359	139.232	117	0.5	tightly grouped; several calves
20-Apr-16	14:07	bottlenose dolphins	500	very active; socialising	-37.420	139.362	65	0.3	milling, breaching and otherwise very active; many calves present
20-Apr-16	14:29	dolphins	3	not recorded	-38.015	140.365	79	0.3	
20-Apr-16	14:30	blue whale	1	feeding likely	-38.052	140.377	124	0.3	dived near krill swarms
20-Apr-16	14:51	blue whale	1	feeding likely	-38.402	141.204	86	0.2	surfaced near small krill swarms
20-Apr-16	14:55	blue whale	1	feeding likely	-38.423	141.312	86	0.2	surfaced near small krill swarms


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