WESTERN AUSTRALIAN EXERCISE AREA
BLUE WHALE PROJECT

FINAL SUMMARY REPORT

MILESTONE 6

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FOR

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Abstract

A group of Western Australian researchers has been studying the presence of blue whales, presumed to be primarily pygmy blue whales, *Balaenoptera musculus brevicauda*, in the Perth Canyon area west of Fremantle, WA, from summer 1999-2000 to summer 2003-2004. The Canyon lies within a larger area of importance to the Australian Navy, the Western Australian Exercise Area (WAXA). The Canyon is a steep sided feature at its eastern end which dissects the continental shelf and runs west to reach the abyssal plain. Based on aerial survey and acoustic detections, blue whales arrive in the Canyon as early as November, with the numbers of animals steadily increasing to a peak in the following March – May. From aerial survey line transect analyses, and allowing for 'missed' animals, an average of 30 (95% CI 15 - 58) blue whales are present at the peak season. After May the number of whales drops, so that by late June most animals have left, although a few acoustic detections are made into July. There is evidence that early in the season the animals have arrived from the north while late in the season they depart to the north, although this is not yet conclusive as a general trend. Based on photo-id and satellite tags, individual blue whales may spend from two to four weeks in the Canyon engaged in feeding. They have been observed feeding on krill, with *Euphasia recurva* found streaming from animals' mouths at the surface and detected in faecal samples. Acoustic backscatter observations have revealed blue whales feeding in a yo-yo pattern as deep as 400-500 m during daytime. Behavioural observations show typical feeding behaviour comprises animals circling or zigzagging, with dives of 8.4 minutes (mean), followed by 8-10 blows over a surfacing interval of 3.4 minutes (mean). Concentrations of macro-zooplankton have been observed by acoustic backscatter techniques at the eastern Canyon end specifically near the Canyon rims. During daytime in summer dense 'balls' of krill have been observed and sampled just below the Leeuwin current (generally < 200 m depth) around the head or eastern Canyon end. These 'balls' have dimensions of 80-250 m horizontally and 20-50 m vertically. Dense aggregations of krill and myctophid fish also form below 300 m, in daytime around the eastern Canyon rims, comprising the deep scattering layer (DSL) there. At night these macro-zooplankton migrate upwards to form dense layers from 50-250 m depth. During the day blue whales target the krill 'balls' and the dense DSL layer, respectively above and adjacent to the Canyon rim, whereas at night they target the dense layers in shallower depths over the eastern Canyon rims. Modelling the oceanography of the Canyon has revealed that eddy formation driven by the passage of the southward, surface-flowing, nutrient-poor Leeuwin current, a deeper northward flowing current and their interactions with the bathymetry are major factors controlling the physical dynamics of the Canyon. To sustain feeding blue whales for the summer months implies that nutrient enhancement and / or entrainment occurs over the Canyon. The distribution of blue whales in the Canyon mirrors that of the dense macro-zooplankton layers at its eastern end. Outside the Canyon whales have been detected by acoustic tracking to be in low numbers in deeper waters to the west, to fan out across the wide continental shelf to the south towards Cape Naturaliste and to focus along the shelf break to the north. Satellite tagging has shown one animal heading to 500 km south of Esperance WA to remain in the Southern Ocean convergence zone for two weeks until the tag failed, one animal remaining in the Canyon for two weeks, and two animals heading north at the end of a season. In the wider context blue whales have been detected: off Exmouth (WA) in November, possibly heading south to reach the Canyon in December: in Geographe Bay (WA) over October to December; off Cape Leeuwin (WA) and along the Otway Basin ('Bonney' coast, Vic), over the same period as in the Perth Canyon.

As well as blue whales, sightings in the Canyon have been made of beaked, sperm, minke, Risso's, humpback and southern right whales and large numbers of dolphins. Acoustic detections suggest that true (Antarctic, *B. musculus intermedia*) blue whales over-winter around the Canyon and head south in mid October.

Acknowledgments

The work has been supported by Australian Defence and the Commonwealth Department of Environment and Heritage, and under ethics permits from Murdoch University, UWA and the WA Department of Conservation and Land Management.

Contents

1) Introduction

This document presents summary data and preliminary conclusions from a study of blue whales (*Balaenoptera musculus*), presumed to be primarily the pygmy blue whale (*Balaenoptera musculus brevicauda*), found in the Perth Canyon, the head of which lies 48 km west of Fremantle, Western Australia. The location of the Perth Canyon is shown in Figure 1 and its structure in Figure 2. A three-year work program was funded primarily by the Australian Defence Forces (ADF) over the period Oct-2001 to Oct-2004 while the Commonwealth Department of Environment and Heritage contributed funding for aerial surveys and boat-based operations from the 1999-2000 summer. The ADF-funded field program entailed aerial and vessel-based work over three summer-autumn periods and sea noise recordings made as best as possible year round. The Royal Australian Navy (RAN) utilises the Perth Canyon for training exercises, as part of its Western Australian Exercise Area (WAXA), and has a vested interest in understanding the use of the region by great whales and other fauna.

At the three-year project's inception a number of questions pertaining to the management and use of the Perth Canyon by the RAN were posed. Following this introduction the study findings relevant to these questions are addressed. Summary sections for each of the techniques used in the study then follow. The use of the Canyon by great whales, primarily blue whales, presumed to be pygmy blues (see below), was addressed in a multidisciplinary fashion. Work programs included:

- aerial surveys
- analysis of genetic material
- small boat-based great whale visual observations and sampling
- establishment of a photo-ID catalogue
- satellite tagging
- study of the signals produced by great whales and fish in the Canyon
- studies of physical oceanography, including primary productivity
- studies of the location and biomass of krill

A summary of major field work carried out and sampling undertaken is listed in Table 1.

This document presents summary data and preliminary results. Some of the data for the 2003-2004 season have only just been received or gear is still awaiting recovery. Details of methods and a final analysis and synthesis of results await publication in refereed journals.

Two sub-species of blue whale are believed to use the Canyon. Over the summer-autumn period large numbers of presumed pygmy blue whales are present there, while over the winter-spring period, based on acoustic records, a small number of presumed true (Antarctic) blue whales (*Balaenoptera musculus intermedia*) appear to be present. From here on, this document refers to the presumed blue pygmy blue whale sub-species, unless otherwise indicated.

As in all scientific endeavours, detailed studies always ask as many questions as they solve. This study has been no exception. A listing of questions posed by the study or relevant to great whales which utilise the Western Australian coastline is presented.

The document then presents summaries of data obtained, as appendixes in table format.

Table 1: Summary of work or analysis carried out in the Perth Canyon by the authors since 1999. Abbreviations are: WAM = Western Australian Museum; CWR = Centre for Whale Research; WW = Western Whale; CUT = Curtin University of Technology; JB = John Bannister; CB = Chris Burton; RM = Rob McCauley; CJ = Curt Jenner; MNJ = Micheline-Nicole Jenner; SR = Susan Rennie; NG = Nick Gales; CSK = Chandra Salgado Kent; CP = Charitha Pattiaratchi; CH = Christine Hanson; EA = Environment Australia (now DEH); DEH = Department of Environment and Heritage; AAD = Australian Antarctic Division

Work summary	**when**	**whom**	**Funding source**
Aerial surveys[1] - Canyon only	Late 1999 – May 2000	WAM, WW - JB, CB, MNJ	EA
Small boat surveys (behaviour, photo-ID, genetic samples, acoustic deployments)	Feb-Apr 2000	CWR – CJ, MNJ	EA
Passive acoustics (drifted loggers and 5 week bottomed logger)	Feb-Apr 2000	CUT, CWR – RM, CMNJ	EA
Aerial surveys - Canyon only	Late 2000 – May 2001	WAM, WW - JB, CB, MNJ	EA
Aerial surveys, Canyon & wider	Late 2001 – May 2004	WAM, WW - JB, CB, MNJ	Defence & DEH[2]
Small boat surveys (behaviour, photo-ID, genetic samples,)	Late 2001 – May 2004	CWR - CMNJ	Defence
Satellite tagging (4 tags attached)	2002-2003 summers	CWR, AAD, CJ, MNJ, NG	Defence, AAD
Passive acoustics (11 logger deployments, 9 retrieved, 1 lost, 1 pending recovery)	Late 2001 - current	CUT - RM, CSK	Defence
Oceanographic moorings (vertical temperature logger strings, 11 deployed, 6 recovered, 3 lost, 1 pending)	Late 2001 - current	CUT, UWA – RM, SR, CP	Defence
National Facility vessel -*RV Southern Surveyor* cruises – oceanography, primary productivity, passive acoustics, biomass assessment using echo sounders, physical krill and fish sampling using nets	Aug 2003, Jan-Feb 2004	CUT (seven day cruise SS0204) – RM, SR, CSK CH; UWA (1 day Aug 03) – CP, SR	Defence, UWA, CUT, CSIRO

[1] line transect analyses of aerial survey data from the Canyon, 2000-2004, have been undertaken by Dr Sharon Hedley, Research Fellow, Research Unit for Wildlife Population Assessment, University of St Andrews, Scotland, under contract to WAM

[2] formerly Environment Australia

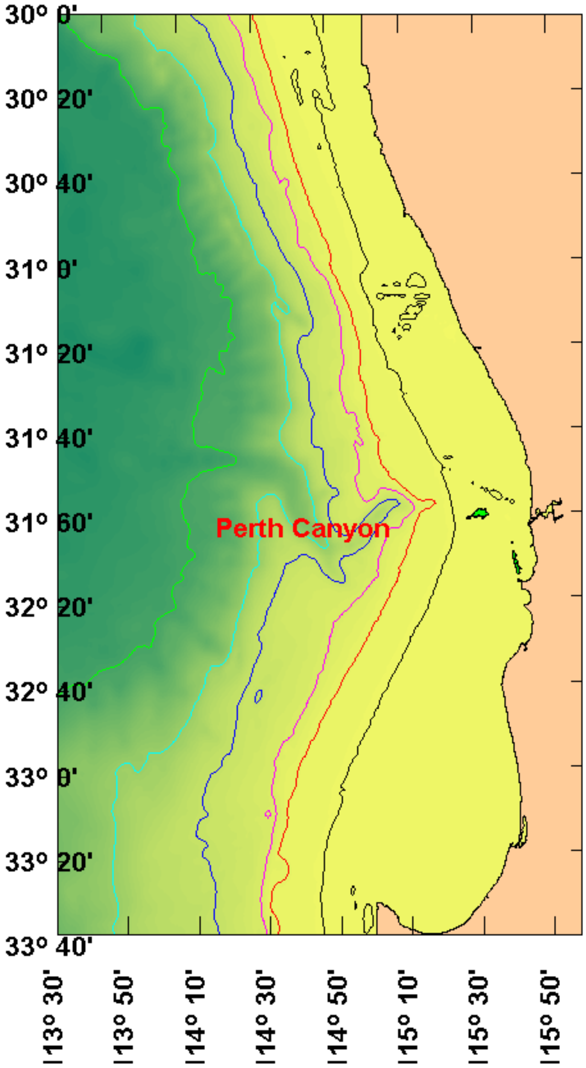

Figure 1: Location of the Perth Canyon, immediately west of Fremantle. Geographe Bay lies at the bottom of the coast shown.

2) Answers to questions posed

The program of work for the WAXA study posed several questions relating to the use of the Perth Canyon by blue whales. The questions were designed to provide information for management of Naval interactions with blue whales. These questions were:

1. *determine the numbers and distribution of blue whales within the WAXA area;*
2. *establish any seasonality in their presence;*
3. *determine movements of blue whales within the WAXA and the wider region - that is, are there temporarily 'resident' animals or is there a continual flow of animals into and out of the region?;*
4. *establish what the animals are doing there, why they aggregate in the Perth Canyon, and if there are simple environmental predictors to indicate their likely presence in the WAXA;*
5. *define blue whale calling habits and behaviour in the WAXA and along the WA coast;*
6. *and as best as possible determine how surface and sub-surface Naval operations may affect these animals.*

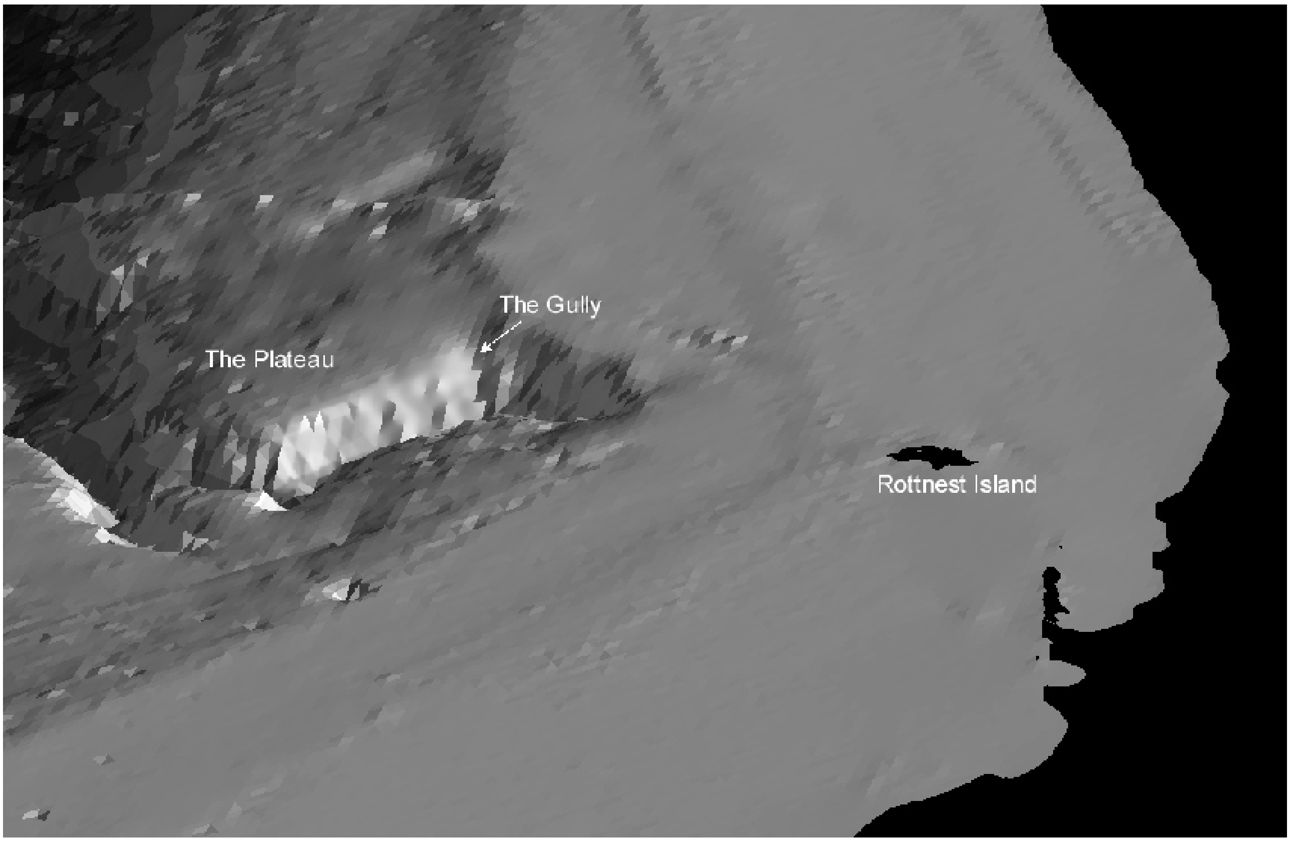

Figure 2: Three dimensional representation of the Perth Canyon showing several features referred to in the text.

It was agreed on the projects inception that question 6 above would not be systematically studied in the program of work carried out over 2001-2004.

In summary the questions have been answered so far, as follows:

2.1) Determine the numbers and distribution of blue whales within the WAXA;

Based on aerial survey results as shown in Table 2, which use line transect analysis and allow for animals 'missed' while diving, the maximum number of pygmy blue whales within the Canyon at any time varied between years from estimates of 4 - 43, with a four-year period estimate of 30 (95% CI 15 – 58, Table 2). The abundance estimates in Table 2 are for the peak season only, i.e. January-May each year. While the point estimates indicate an increase over the period, the overlapping confidence intervals do not support such a conclusion.

The mean encounter rates for blue whales within the Canyon via all visual techniques for the years 2000 – 2004 are listed in Table 3, with these rates plotted on Figure 3 with 95% confidence limits (note the aerial survey data include all flights but are limited to the Canyon only, and are not corrected here for 'missing' animals). The high variability evident precludes making assumptions about any increase in sighting rates and thus populations size, over the data collection period.

Table 2: Estimates of abundance (rounded for clarity) from the line transect analyses ('Abundance') and after correcting for availability bias i.e. diving animals ('Adjusted Abundance'), see section 4.1.2. The total survey area considered for all surveys was 2,909 km^2 and the correction factor used for all surveys was 2.59.

Year	**Abundance (% cv)**	**Adjusted abundance [95% CI]**
2000	5 (26.94)	13 [8 – 23]
2001	10 (48.05)	26 [10 – 68]
2002	2 (72.37)	4 [1 – 17]
2003	16 (16.52)	41 [29 – 57]
2004	17 (16.34)	43 [31 - 60]
2000 - 2004	12 (25.60)	30 [15 58]

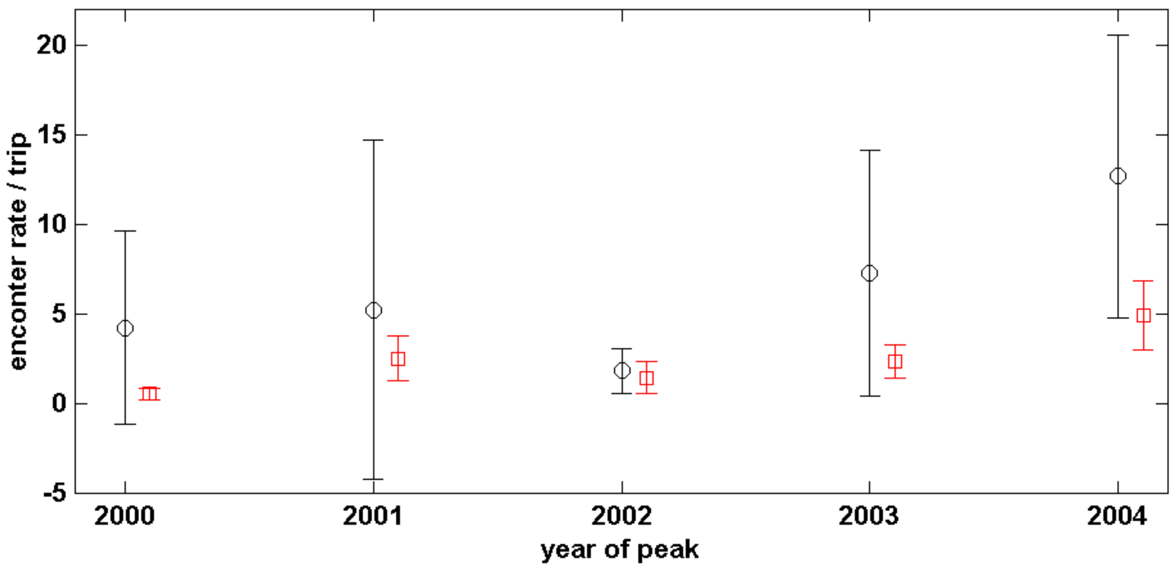

Figure 3: Mean encounter rates of pygmy blue whales in the Perth Canyon for the visual surveys made between 1-Nov and 31-May each season (black circles are aerial surveys, red squares are vessel sightings, error bars are 95% confidence limits).

Table 3: Yearly summaries of visual sightings of blue whales carried out within dates shown. Note that aerial surveys include all flight paths but results are only for whales inside the box defined by 21° 40' (N limit), 32° 20 (S limit), 114° 10 (W limit) and 115° 20 (E limit).

Dates	**flights**	**pods**	**whales**	**Whales / flight**	**surveys**	**Pods**	**whales**	**Whales / survey**
	aerials				**Boat surveys**			
01-Nov-1999 31-May-2000	4	14	17	4.25	33	15	18	0.55
01-Nov-2000 31-May-2001	19	20	21	1.11	30	61	76	2.53
01-Nov-2001 31-May-2002	13	9	11	0.85	35	38	51	1.46
01-Nov-2002 31-May-2003	10	66	73	7.30	30	66	71	2.37
01-Nov-2003 31-May-2004	10	114	127	12.70	28	120	138	4.93

There was overlapping acoustic sampling between 2000 and 2003. Some 2000-2003 overlapping days remain to be worked up and the full 2004 summer data set, which overlaps all the 2003 set and 33 days of the 2000 set, remains to be worked up. On 17 days where the 2000 and 2003 sampling sets overlap there was a 5.43 times greater increase in the number of individuals blue whales calling averaged within a day, in 2003 (discussed further in 4.5.2).

There was clear preferred blue whale habitat within the Canyon, with whales focussed at its eastern end around the slopes. The preferred habitat is shown in Figure 4. Boat-based observations were focused in this region. Blue whales were observed to range wider than the Canyon eastern end, with the locations of singers presented in Figure 5 for 11 days over the period 22-Feb-2003 to 01-Apr-2003, as derived from acoustic tracking. Again the acoustic tracking indicated a preferred habitat at the eastern Canyon end.

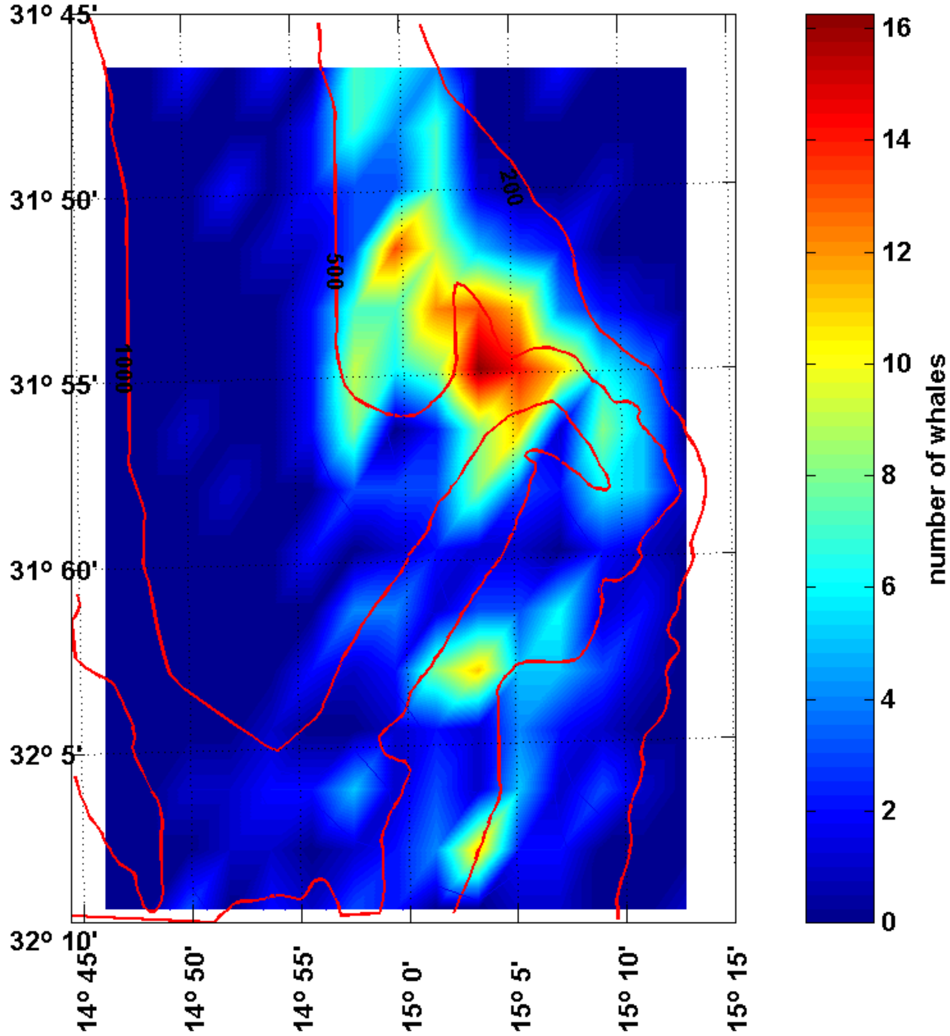

Figure 4: Preferred habitat for pygmy blue whales in the Perth Canyon, as shown by the cumulative numbers of whales sighted by all visual sightings, binned in 3 km squares (aerial and vessel surveys from 1999 on).

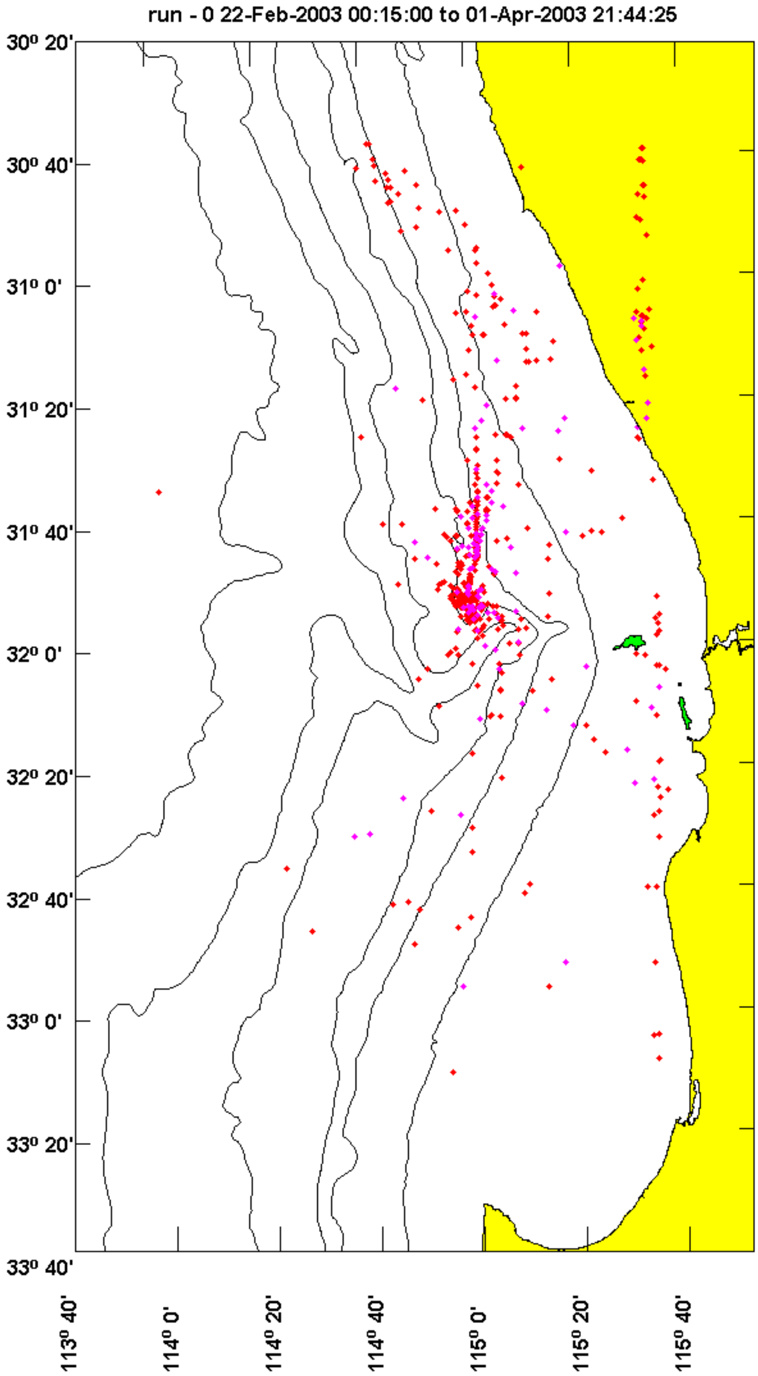

Figure 5: Location of pygmy blue whale singers over 11 days from 22-Feb-2003 to 01-Apr-2003 based on acoustic tracking. Shown is the full analysed data set. Some correlations gave incorrect arrival time differences, resulting in many locations lying over land. For these signals the bearing is likely correct but the range is incorrect.

2.2) Establish any seasonality in the presence of blue whales within the Canyon;

There was a strong seasonal pattern in the presence of blue whales within the Perth Canyon. The lumped boat-based, aerial survey and acoustic detections are shown in Figure 6 (data from multiple years are overlaid or averaged for the passive acoustic detections). From this information, blue whales can be expected to be present in the Canyon between November and late May, with maximum numbers from mid-February to mid-May.

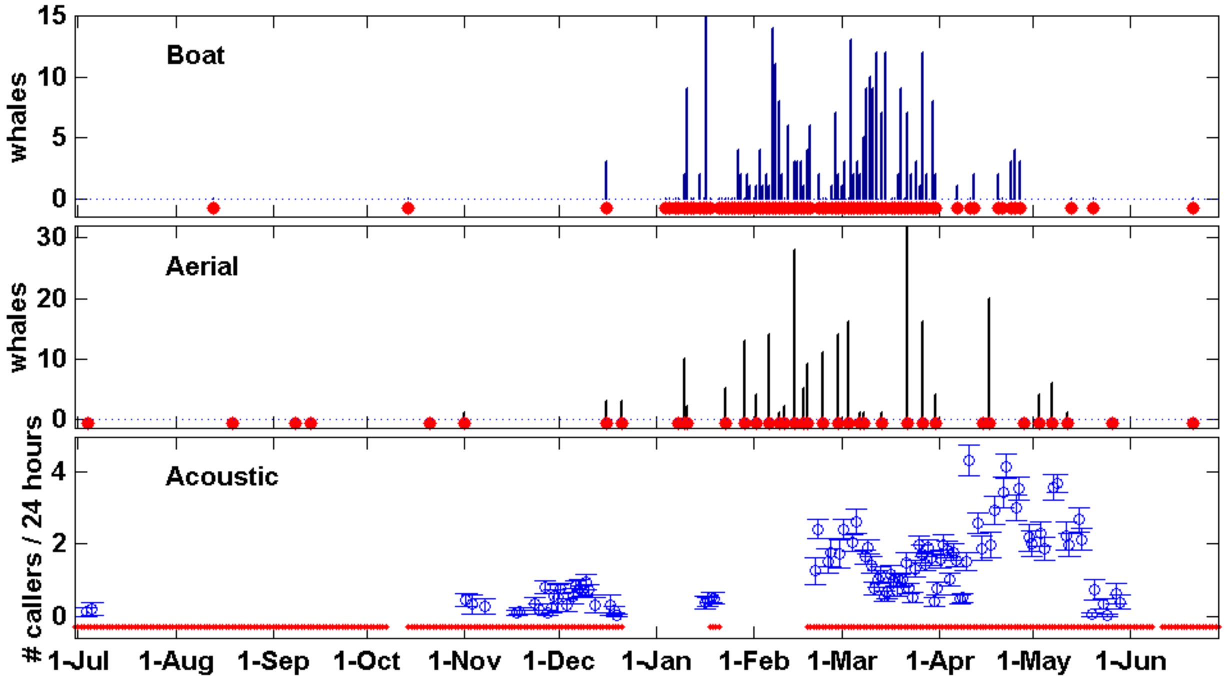

Figure 6: Blue whale sighting data from the Perth Canyon, lumping all data, for the boat-based surveys (top), aerial surveys (middle) and acoustic detections (lower). The red dots / bars indicate when sampling occurred. The visual surveys give counts of whales seen, while the acoustic data are presented as the 24 hour average of the number of different individual blue whales calling within a 90-200 s sample taken every 15 minutes. The acoustic data have 95% error bars shown. The acoustic data is averaged across seasons whereas the visual sightings data are presented for each survey.

2.3) Determine movements of blue whales within the WAXA and wider region

Blue whales were followed within the WAXA during the vessel surveys for periods up to six hours. Their behaviours were catalogued as one of: feeding; milling; migrating; or socialising. The photo-ID catalogue built up from animals sighted in the Canyon (section 4.2.4), revealed that whales were frequently resighted within a season (20 individuals out of a total catalogue size of 165 animals). The mean resight period was 21.3 ± 8.3 days (± 95% CI), indicating that animals stayed within the Canyon for 2-4 weeks on average.

Satellite tags implanted on three whales in the Canyon showed: one animal stayed within the Canyon over an eight day period, spending its time along the Canyon flanks; one animal tagged towards the end of a season zig-zagged north – south as far as Lancelin; a third animal tagged towards the end of a season travelled very rapidly north with the last good fix west of the Abrolhos Islands and a further fix indicating the animal had continued north to approximately Shark Bay.

The acoustic tracking data (Figure 5) indicated that few blue whales were to be found west of the Canyon head, that to the north of the Canyon the animals stayed within a band along the shelf edge, and that to the south they fanned out across the wide continental shelf. The tracking data also showed the Canyon head region as a focal area.

2.4) Establish what blue whales are doing in the Canyon, why they aggregate, and if there are simple environmental predictors to indicate their likely presence in the WAXA;

Blue whales were observed to be feeding in the Perth Canyon. This was based on: observations of krill streaming from the mouths of animals surfacing; consistent defecation by animals (each surface cycle for many animals); identification of krill mouthparts in faecal samples; observations of consistent surface feeding behaviour (dive / surface in large circles, with downtimes of ~ 8.4 minutes and a surface time of ~ 3.4 minutes with 8-10 blows); and acoustic backscatter observations of whales apparently feeding in patches of dense backscatter at depths of 200 - 500 m in the daytime. The dominant krill species identified in the Canyon was *Euphasia recurva* (based on multiple plankton tows). An example of dense patches of backscatter, identified as krill, is shown in Figure 7 (patches at 200-250 m depth were sampled with a plankton net). Pygmy blue whales were feeding to the south (0.5 n mile) and west (1 n mile, in line with the transect) of these patches. An example of a whale caught in the beam of a Simrad EQ60 echosounder, whilst believed to be feeding is shown on Figure 8. This animal was yo-yoing along a dense scattering layer (extracted from Figure 8 by manipulating the gain) between 400 – 480 m depth.

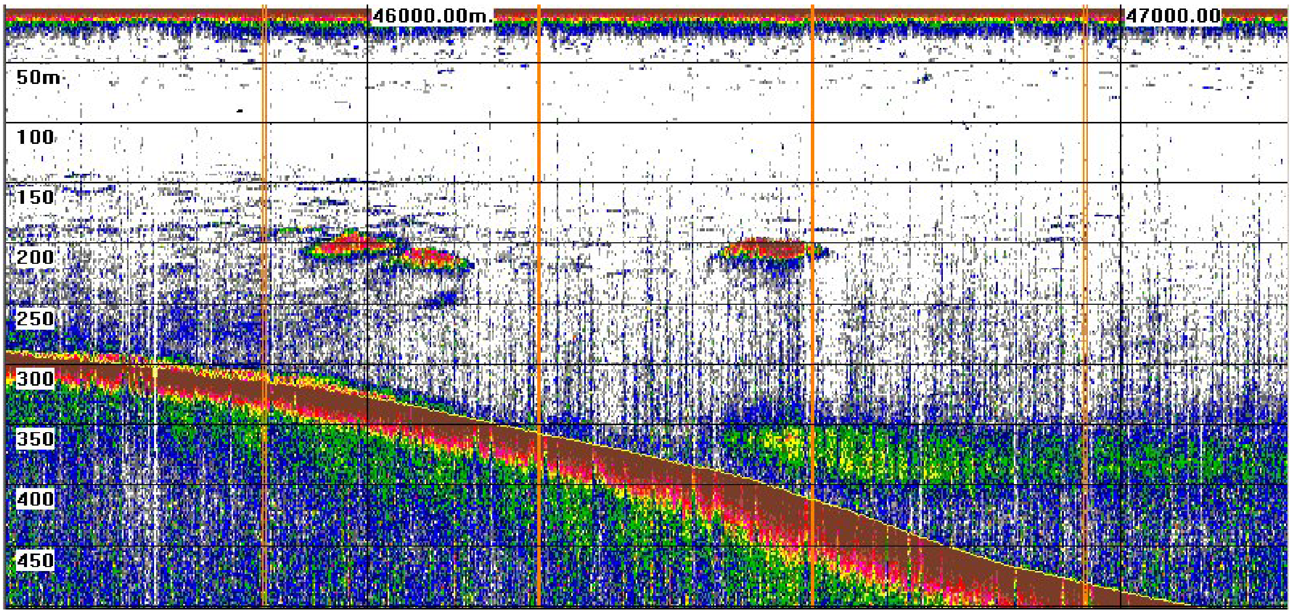

Figure 7: Examples of dense backscatter patches (200-250 m depth), determined to be comprised of krill and a dense deep scattering layer (> 350 m depth, RHS) also believed to be partly comprised of krill.

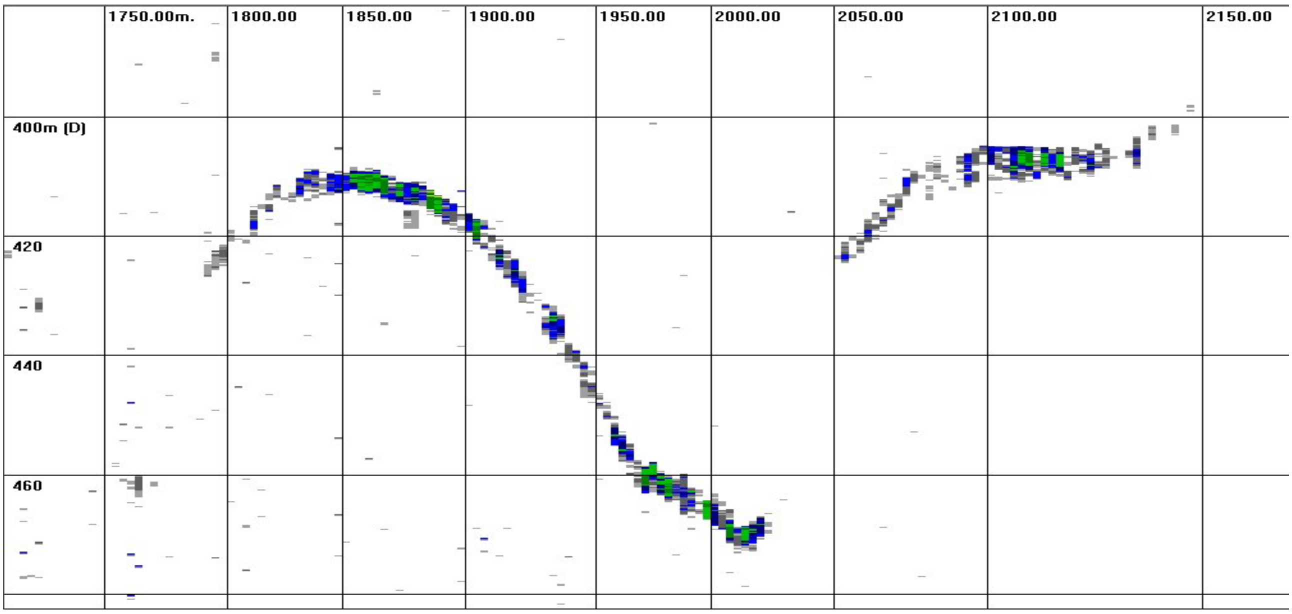

Figure 8: Example of pygmy blue whale caught in the beam of a Simard EQ60 echosounder whilst apparently feeding.

Based on evidence available the Canyon acts as either: 1) a region of enhanced productivity through small scale upwellings which can sustain a relatively high biomass of krill; 2) an "aggregator" for nutrients and therefore able to sustain high productivity; or 3) invokes some combination of each of these mechanisms. The Leeuwin current dominates the surface waters of the Canyon, bringing warm low nutrient water south over the Canyon (thus largely suppressing any upwelling evidence). The Canyon seems to persistently spin up eddies and counter eddies in the Leeuwin current which can remain over the Canyon or drift off. These eddies may be up or downwelling enhancing depending on their direction of spin. The extent of the Leeuwin current can be seen in Figure 7 where it is represented by the clear water with almost no biological targets above 150 m depth. The exact mechanism for nutrient enhancement leading to high productivity and hence the krill in the Canyon is still under active investigation. A seven-day oceanographic cruise into the Canyon in Jan-Feb 2004 (*RV Southern Surveyor*, National Facility vessel cruise) returned a mass of information which is currently being analysed to define the Canyon's: primary productivity; krill biomass; and fine scale oceanographic features. This information, combined with long term data from strings of temperature loggers set about the Canyon, satellite sea surface temperature and chlorophyll images, and modelling of the Canyon oceanography will be used to provide a better understanding of what is driving the Canyon's productivity. Susan Rennie, a PhD candidate, currently has a high resolution oceanographic model of the Canyon working, and is now investigating the system response to different forcing patterns.

2.5) Define blue whale calling habits and behaviour in the WAXA and along the WA coast

In summer-autumn the Perth Canyon is dominated by a three part call produced by pygmy blue whales ('common' call). This call sequence is very distinct. Calling rates of up to eight individuals vocalising at a given point in time have been recorded. The call sequence has most energy concentrated in a band around 15-30 Hz although harmonics extend up to 80 Hz. The call source levels are high, sufficient such that in deep water or along the shelf edge the call may transmit into many hundreds of km. Calling from within the Canyon was around twice as prolific in the hours of darkness compared with daylight, with post-dusk and pre-dawn favoured calling periods. This call sequence is being used to obtain relative abundance estimates of pygmy blue whales (ie. Figure 6) and has been used for tracking singers and so elucidating behaviour and movement patterns.

Pygmy blue whales are known to produce several signal types. A signal type believed produced by true blue whales (base on similarities to other identified true blue signals, and the exceptional frequency stability throughout the call) have been heard in the Canyon, mostly through June-Sep. Only one or two true-blue callers have been detected at any given time, indicating that the number of singing animals in the Canyon is low. A signal type widely heard by Navy submariners and known as the bioduck is common in the Canyon during late July-Dec. The seasonal timing of the bioduck is similar to other great whales which migrate up from Antarctic waters. Humpback whales feature though recordings in winter-spring.

The calling behaviour of blue whales is currently being investigated from recordings off Cape Leeuwin, the Perth Canyon and Exmouth. The data available includes grids of hydrophones suitable for obtaining positions or bearings (at ranges greater than the tracking range) in the Perth Canyon and off Cape Leeuwin. The calling behaviour of other great whale species and fish are also being investigated.

3) Potential publications

A tentative list of publications is given. There will be considerably more than indicated.

Bannister, J.L. Burton, C.L.K. and Hendley, S.M. (in prep). Abundance and distribution of blue whales in the Perth Canyon area from aerial surveys, 1999-2004.

Matthews, D., Macleod, R. McCauley, R.D. (2004) Bio-Duck activity in the Perth Canyon. An Automatic Detection Algorithm. Proceedings, Australian Acoustic Society, November, Queensland

McCauley. R.D. Salgado Kent, C., Burton, C.L.K., Jenner C.K., John L. Bannister J.L., Cato, D.H., (in prep) A description of blue whale (Balaenoptera musculus) calls and calling habits from the Perth Canyon, Western Australia

McCauley. R.D. Salgado Kent, C., Jenner C.K., John L. Bannister J.L., Cato, D.H., Burton, C.L.K., (in prep) Movement of blue whales along the Western Australian coast based on acoustic tracking

McCauley. R.D., Cato, D.H. (in prep) Temperate Australian marine fish choruses.

McCauley. R.D., Bannister J.L., Jenner C.K., Burton, C.L.K., Salgado Kent, C. (in prep) Blue whales in the Perth Canyon, Western Australia

Rennie, S., McCauley R.D., Pattiaratchi, C. (in prep) Analysis of temperature logger data from the Perth Canyon, in the Leeuwin Current, 2002-2004.

Rennie, S., Pattiaratchi, C., McCauley R.D.(in prep) Application of ROMS (Regional Oceanographic Modelling System) to south-western Western Australia: The Leeuwin Current and Perth Canyon.

Rennie, S., Pattiaratchi, C., McCauley R.D.(in prep) Oceanographic features leading to high productivity in the Perth Canyon

4) Preliminary summaries of results / analyses

4.1) Aerial Surveys

Western Whale (Chris Burton) & Western Australian Museum (John Bannister)

4.1.1) Operational results

Three separate aerial survey formats were employed over the five years of the project to determine the distribution and abundance of blue whales. The initial and focal area in the study was directly over the Perth Canyon (Figure 9). Subsequent 'extended areas' were designed to assess the wider distribution of blue whales in the WAXA, but to include the Perth Canyon. The 'southern extended area' incorporated three parallel transects from Moore River south to Cape Naturaliste, 250 km from Perth, and ran for two years from December 2001 until February 2003 (Figure 10 left). A 'northern extended area' involved three similar parallel transects from Lancelin south to Mandurah during 2004 (Figure 10, right).

A total of 54 flights was conducted, of which 37 were flown in the Perth Canyon survey area, 11 in the southern extended area and six in the northern extended area. Of the total 279 blue whale sightings recorded, 217 (78%) were within the Perth Canyon area, 12 (4%) in the southern extended area and 50 (18%) in the northern extended area. The location of all blue whale pods sighted from the aerial surveys to date is shown in Figure 11.

Species diversity recorded from the aerial surveys was moderate with seven other species and many unidentified sightings recorded. Dolphins were by far the most abundant cetacean recorded in all areas, being consistently high within the Canyon. Great whale species recorded were blue, humpback, minke, sperm and southern right whales. Large numbers of dolphins were observed widely distributed throughout the southern extended survey area. A clear migratory corridor for the southward movement of humpback whales within the continental shelf boundary was apparent. Humpback whales were recorded in moderate numbers, mainly in spring from 1999 to 2002 when flights were conducted at that time.

The number of blue whale sightings in the Canyon area was larger in 2003 and 2004 than in the previous three years, although the relative number of flights remained constant. Seasonal abundance of blue whales also remained consistent with most blue whale sightings occurring in summer, with peak months being February and March, and the peak period overall being January-March.

The spatial distribution of blue whales was also consistent from year to year, with the main concentration of blue whales observed on the northern plateau of the Canyon, and a further concentration on the southern rim. This apparent separation is believed to represent the sub-surface distribution of prey.

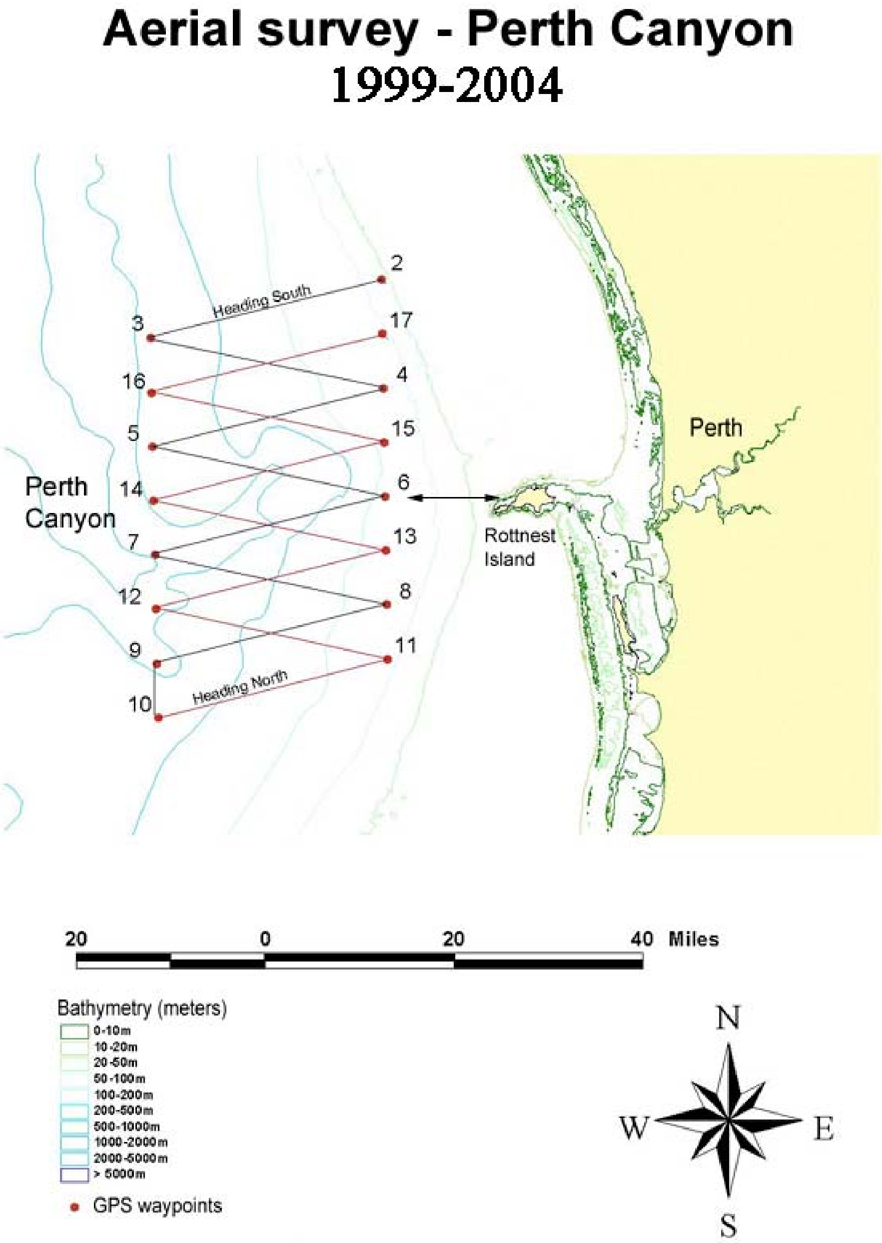

Figure 9: Aerial survey transects for the Perth Canyon area.

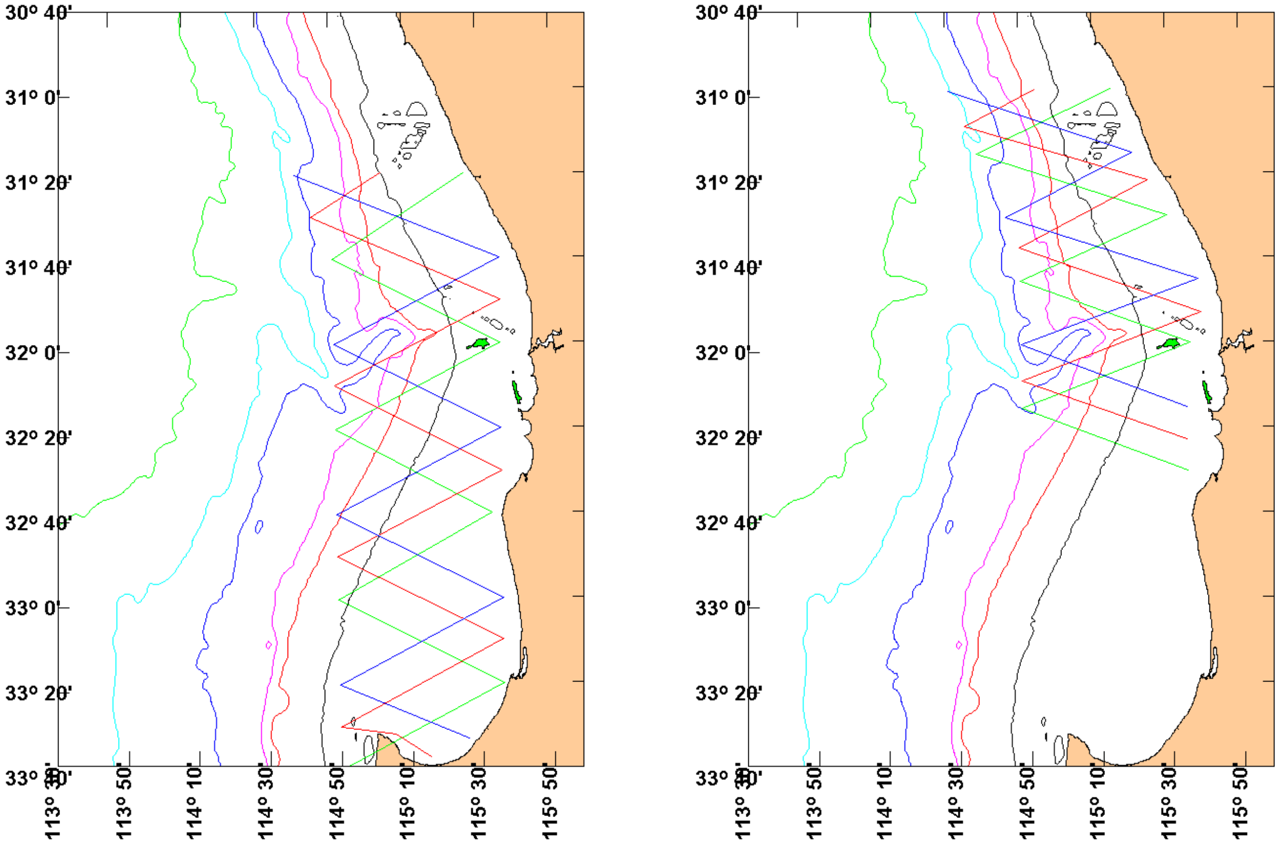

Figure 10: (left) Aerial survey transects for the southern and (right) northern extended areas.

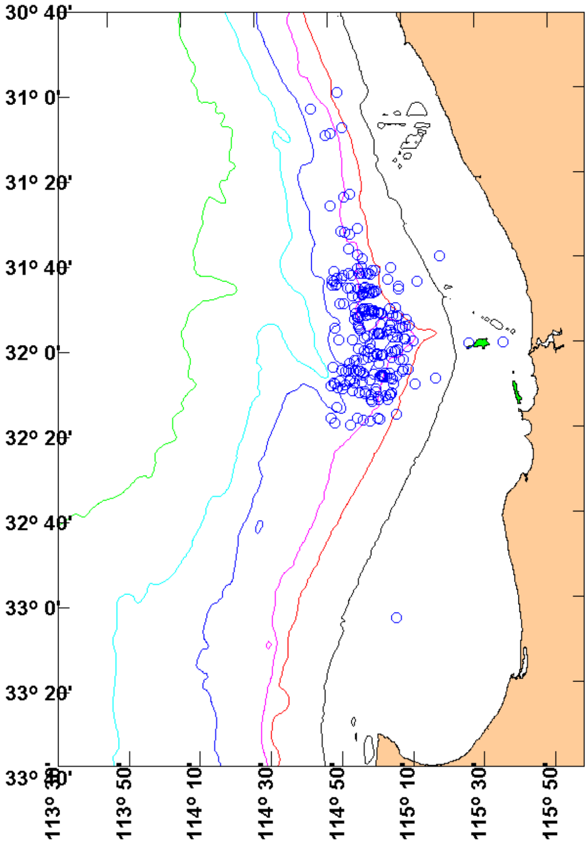

Figure 11: Location of all blue whales sighted on the aerial surveys (blue circles).

In the 'southern extended area', with flights conducted from Dec 2001 to Feb 2003, the number of blue whale sightings remained relatively low (12). Of the 11 flights, seven were evenly spread through the season in 2002, with but only one in the summer of 2001 and three during the summer of 2003. All blue whale sightings occurred in summer with peak months being February and March and over 80% were observed in the deeper waters to the north of the Perth Canyon. This was anticipated as a third of the total transects were designed to pass over the presumed high concentration area of the Canyon. Only one blue whale was sighted south of the Canyon, on the western edge of Geographe Bay, a surprisingly low result given the large number sighted in the Bay (over 120 sightings) during a project undertaken from Oct to Dec 2003, using aerial, vessel and land based methods.

The transect design for the northern extended area was essentially identical to that of the southern area, but with legs moved north to Lancelin, and with a third of the transects passing over the Canyon region. A high number of blue whales was observed compared with the southern survey area with sightings made between January and April 2004. A further presumed feeding aggregation area was apparent off Lancelin, including a number of sightings made in transit to the northern starting waypoints. Individual whales in this area were observed moving in all directions, as in the Canyon feeding area.

4.1.2. Line transect analysis

St Andrews University Scotland (Sharon Hedley), WAM (John Bannister), WW (Chris Burton), CWR (Curt and Micheline Jenner).

Data were available from the 33 completed flights over the Canyon area, involving 216 sightings in 193 pods 'on effort' (i.e excluding those seen outside the search area), over a total of 10,000 nautical miles. As already indicated, the data were clumped, with most sightings over the five year period in January –March.

The aim of the analysis was to obtain a 'best estimate' of blue whale abundance at the peak season, i.e. of the number present at any one time (= 'population' size) during the period Jan-March. Line transect theory requires calculation of a 'half effective strip width' surveyed from the plane, the mean school size of the animals sighted, and the 'encounter rate' (number sighted / 100 km along the flight path). The density (number of animals / km^2) can then be calculated, from which an abundance figure for the total area (of which the effective strip width is a sample) can be obtained. It is then necessary to account for the proportion of animals not seen, i.e. underwater when the plane passed overhead. The latter involves calculation of the time (t) during which an animal at the surface is available to be seen, as well as knowledge of the species' average surfacing (s) and diving (d) times, to give the probability (P) of an animal being seen at the surface. P is then obtained from

$$P = \frac{s + t}{s + d}$$

Values obtained for the above, for the peak season Jan-March 2000-2004, were:

- effective strip half-width: 2.42 km (4.84)

- mean school size, by year: 2000 = 1.17 (9.63);
    - 2001 = 1.06 (5.26); 2002 = 1.00; 2003 = 1.12 (4.71); 2004 = 1.15 (3.66)

- encounter rate (number/100km): 2000 = 0.739 (24.16);
    - 2001 = 1.562 (47.24); 2002 = 0.262 (72.03);
    - 2003 = 2.340 (14.20); 2004 = 2.509 (14.46)

- density (number/ km2): 2000 = 0.179 (26.94);
    - 2001 = 0.341 (48.05); 2002 = 0.054 (72.73);
    - 2003 = 0.540 (16.52); 2004 = 0.570 (16.34)

- estimated abundance: 2000 = 5 [3, 9]; 2001 = 10 [4, 26];
    - 2002 = 2 [0, 6]; 2003 = 16 [11, 22]; 2004 = 17 (12, 23)

The % Coefficient of Variation (CV) is given in curved brackets, and the 95% Confidence Interval (CI) in square brackets.

To obtain an abundance figure corrected for diving animals, *t* was calculated from data obtained on the surveys as 1.350 minutes, while *s* and *d* (obtained by CWR during boat-based operations in the same area) were 3.304 (1.502) and MDT 8.751 (3.916) minutes respectively, giving *P* as 0.306, i.e. a correction factor of 2.59. The unadjusted and adjusted abundance estimates were given in Table 2. Overall for the 5-year period the unadjusted and adjusted figures were 11.579 and 30 [95% CI 15, 58].

An alternative method of allowing for diving animals, involving ‘cue-counting’ (where all cues, including blows) are included in the analysis, has yet to be carried out.

4.2) Vessel sightings - Pygmy Blue Whales 2000-2004

Centre for Whale Research (WA) Inc. Curt & Micheline-Nicole Jenner

4.2.1) General

Vessel surveys were conducted at the eastern end of the Perth Canyon between January and May each year from 2000 to 2004. 425 individual blue whale sightings in 356 pods were made over a total of 11,423.4 nautical miles during 1,365.5 hours on the water. General statistics for vessel surveys are listed in Table 4. A variety of data types was collected, including photo-id, biopsy, behaviour, faecal samples, satellite tag tracks, GPS ‘follows’, CTD casts, acoustic recordings, echo sounder profiles, SST measurements and general climatic information. Other mega fauna sighted are listed in Table 5.

Table 4: Summary of vessel surveys between 2000 and 2004.

Year	Blue Whales Sighted	Photo-id		Genetic Samples	Satellite Tags		Survey Miles	Survey Hours
		New	Unique		Attempts	Successful		
2000	18	14	11	9	0	0	2257.3	241.5
2001	78	45	28	22	0	0	2119.6	248.5
2002	48	13	11	5	5	2	2253.7	275.3
2003	73	39	29	1	5	2	2117.7	269.7
2004	208	110	73	30	2	0	2675.1	330.5
Totals	**425**	**221**	**152**	**67**	**12**	**4**	**11423.4**	**1365.5**

Table 5: Other mega fauna sighted in study area, January-May, 2000-2004.

Common Name	Scientific Name
Spinner Dolphin	*Stenella longirostris*
Bottlenose Dolphin	*Tursiops truncatus*
Striped Dolphin	*Stenella coeruleoalba*
Risso's Dolphin	*Grampus griseus*
Sperm Whale	*Physeter macrocephalus*
Short Finned Pilot Whale	*Globicephala macrorhynchus*
Unidentified Balaenoterid	?
Unidentified Ziphiid	?
Unidentified Delphinid	?
Australian Sea Lion	*Neophoca cinerea*
Ocean Sunfish	*Mola mola*
Manta Ray	*Manta birostris*
Leatherback Turtle	*Dermochelys coriacea*

4.2.2) Sightings Locations

The spatial data contributed to the project by the vessel surveys can be regarded as “fine scale”, as compared to the aerial survey spatial data which is of broader scale. Therefore the discussion below should be regarded as being specific to the head of the canyon only and is not necessarily transferable to the wider region covered by the aerial surveys.

In general, whale sightings were more frequent on the slopes of the Canyon walls and the plateau areas to the north and south of the Canyon rather than in the centre of the canyon (Figure 12). More specifically, pods were sighted an average of 7.7 km (95% CI $\pm$ 0 .5 km, n = 356) from the centre line of the Canyon over the five years. This corresponded to an average depth of 600 m (95% CI $\pm$ 28m, n = 356) although the “preferred depth” included the 300 to 600 m depth bins, with the 400 to 500 m range being the most populated (Figure 13). The steep depth contours characterize the canyon walls, a small gully, and a plateau area to the north of the Canyon where large numbers of whales where encountered (Figure 14). The Gully runs from SSE to NNW, rising up from the centre of the Canyon, and forms the eastern side of the Plateau. The Plateau is a 440 – 480 m deep sub-sea area of slowly shelving, but basically flat, terrain covering approximately 43 km^2 on the northern side of the Canyon, and was the location chosen to moor the acoustic data loggers (Figure 2).

Vessel surveys were concentrated around the Gully and the Plateau after the first two seasons when it became apparent that these were preferred habitats. Approximately one third (121/356) of the pods sighted between 2000 and 2004 were found in those two regions.

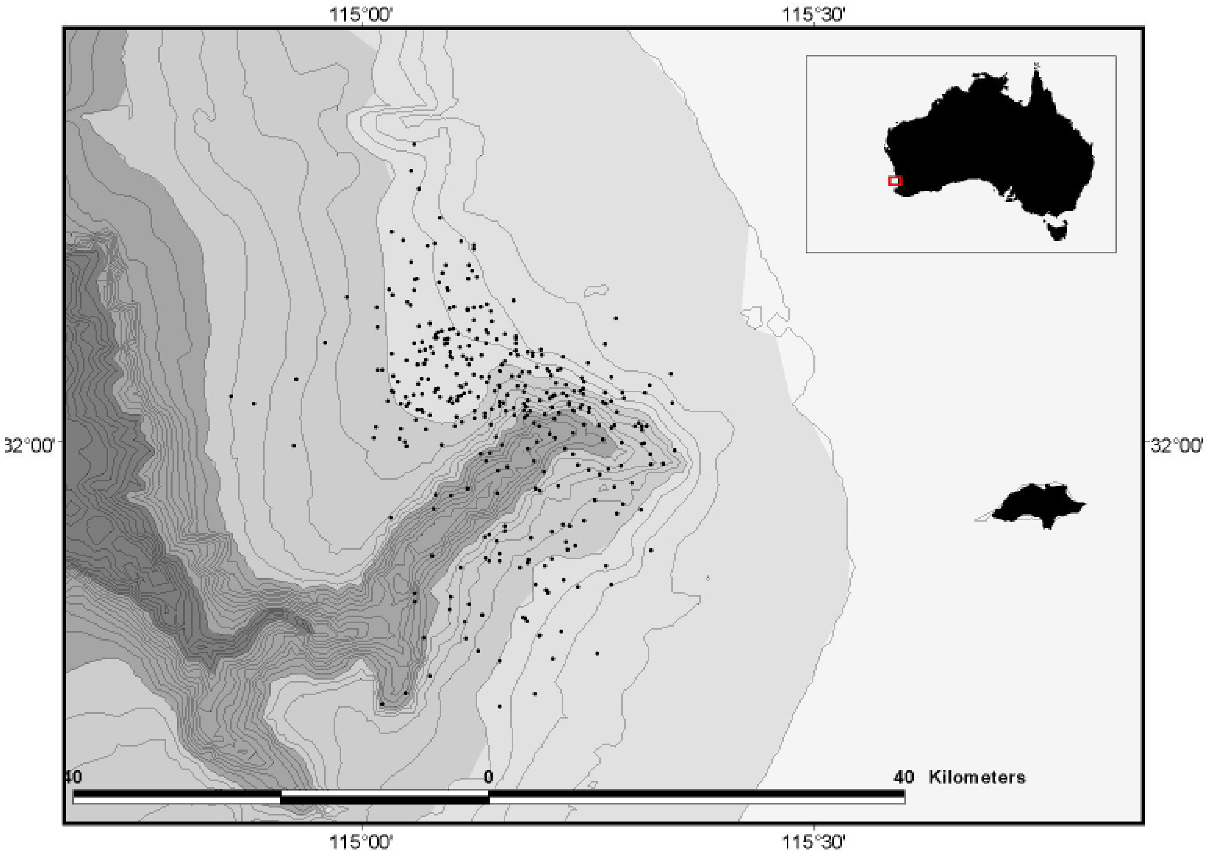

Figure 12: Spatial distribution of blue whale pods over the Perth Canyon from 2000 to 2004. Mean range from the centre line of the canyon is 7.7km.

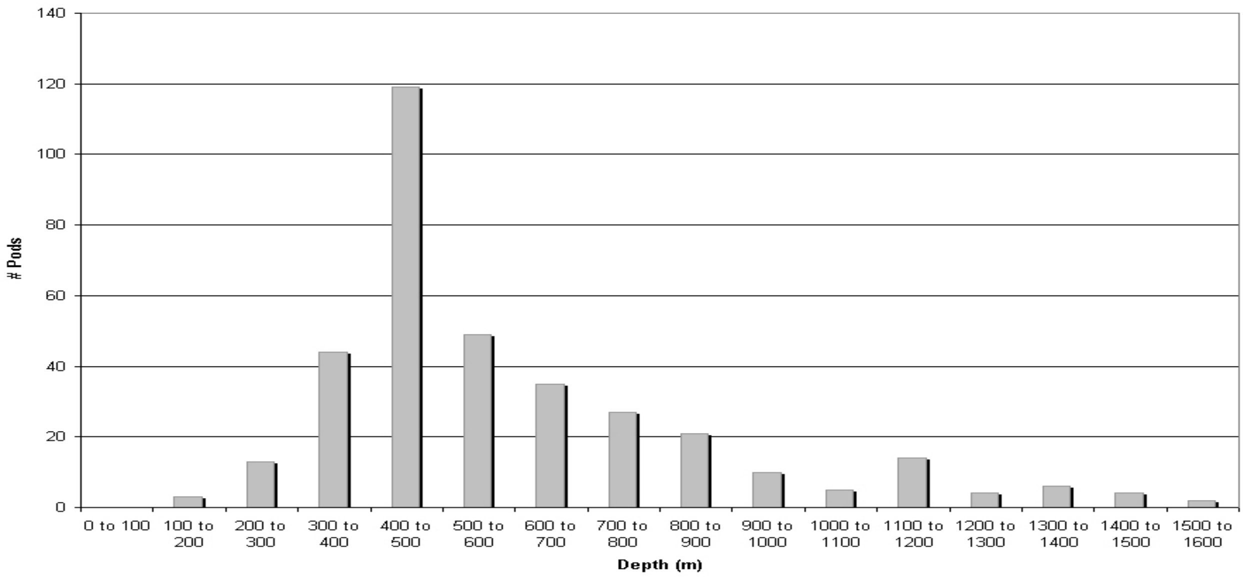

Figure 13: Blue whale pod sightings in relation to 100m depth bins (2000 to 2004).

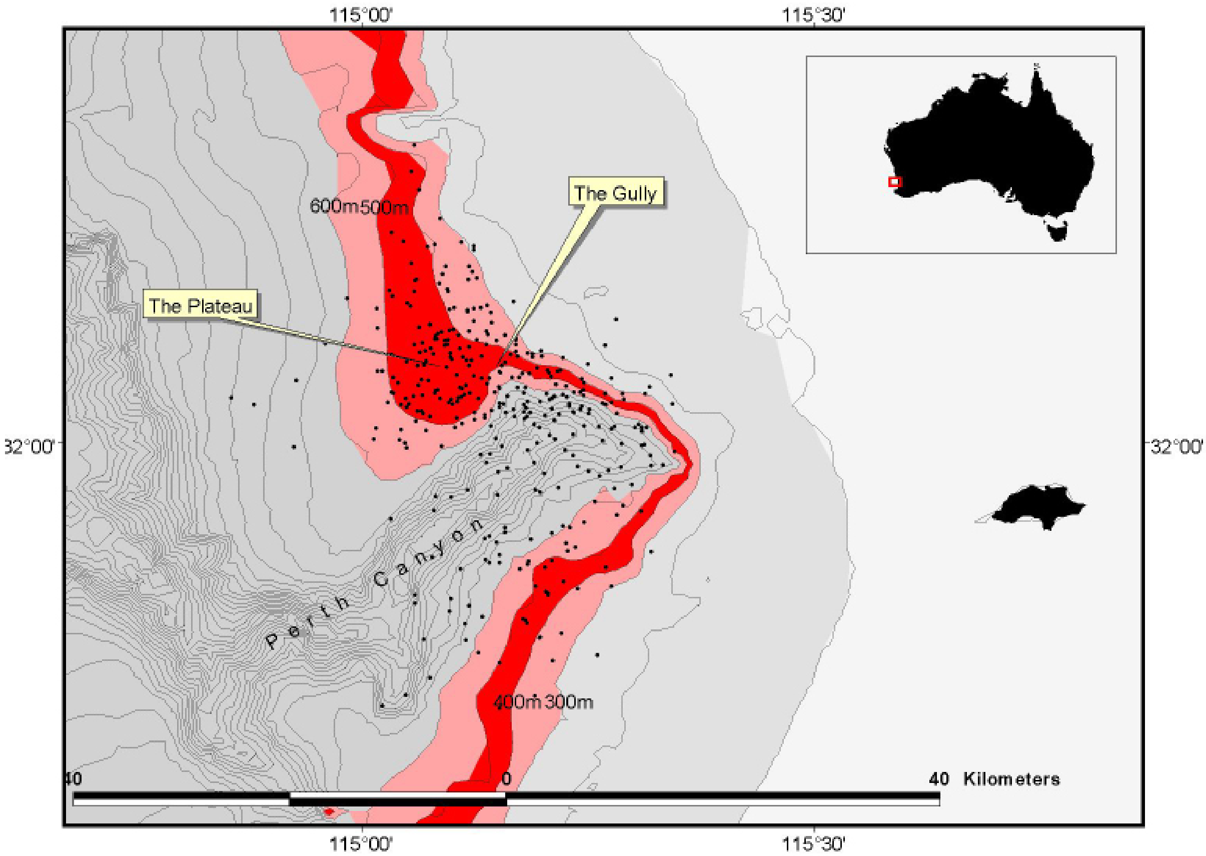

Figure 14: Distribution of blue whales over the Perth Canyon in relation to the Gully and Plateau regions. Red shaded area = 400 – 500m depths.

4.2.3) Whale Behaviour

The behaviour of most blue whales sighted over the Canyon was consistent with feeding at depth, although some migratory and competitive behaviour was also observed. Whales were assumed to be feeding at depth if their swimming pattern was circular or zigzagging, if they had long (> 7 min) downtimes followed by 8-10 surfacings to blow, if they defecated, or if krill was found in their tail beat ‘footprints’. Whales were assumed to be migrating or changing feeding areas if their swimming pattern was relatively straight and if their downtimes were six minutes or less. Competitive behaviour was characterised by high speed (>15 knot) linear or circular ‘chases’ involving two or more whales with frequent porpoising (Figure 15). Medium speed chases were observed on several occasions often with the lead animal defecating in the path of the following whale.

A deep scattering layer, presumed to be partly of krill, was observed on the vessel’s sounder on each day of the surveys in water depths greater than 300 m. Echo-sounder follows of blue whales showed the whales ‘yo-yoing’ through dense portions of the deep scattering layer. One species of krill (*Euphausia recurva)* has been identified from live specimens dip-netted from whale footprints and this species has also been identified in faecal samples.

Down time and surface interval data were collected in order to establish ‘normal’ patterns for these behaviours and also to provide a constant for use in calculating abundance estimates from the aerial surveys (see section 4.1.2). The average down time was 8.4 min (n=552). The average surface interval was 3.4 min (n=766) after an average of 9 blows (n=634).

Figure 15: A photo sequence of a blue whale surface charging at 18 knots while “chasing” another whale (sequence runs top-left, bottom-left, top-right, bottom-right).

4.2.4) Photo-Id

A total of 216 whales was photo-identified over the five year study period. The number of re-sights is shown in Table 6. In total 51 whales were seen more than once.

Table 6: Total numbers of photo-id resights from 2000 – 2004.

	2000	2001	2002	2003	2004
2000	0	3	0	0	3
2001	-	5	1	3	10
2002	-	-	0	2	1
2003	-	-	-	3	4
2004	-	-	-	-	16
TOTAL	**0**	**8**	**1**	**8**	**34**

Residency periods within a season indicate the importance of the area for feeding. Inter-season (between year) resight periods can indicate the length of migratory journeys or a variation in use of the area by different age or sex classes of the population. The information is therefore most powerful with long term data sets, i.e., 10+ years.

Inter-season Resights

Over the five year period, one whale (# 8) was identified in each of four seasons, one (# 4) over three seasons and 11 over two seasons (Table 7). An animal for which a lateral body image was obtained in Geographe Bay by Doug Coughran, Department of Conservation and Land Management, in 1996, was identified in the Canyon in the two seasons 2001 and 2004 (# 13).

Table 7: Inter-season resights from 2000 - 2004.

Resight ID#	2000	2001	2002	2003	2004
1	●	●			
4		●		●	●
6		●			●
8		●	●	●	●
9		●		●	
10			●	●	
12				●	●
13		1996 - ●			●
18	●				●
19	●				●
20		●			●
25		●			●
26		●			●

The highest number of inter-season resights in the database thus far is 10, between the years 2001 and 2004 (Table 7). While this might be taken to indicate a three-year migratory cycle, the number of resights is so far too few to allow a firm conclusion on inter-season visitation time.

Interestingly, two cows photographed in the Canyon, both accompanied by calves, were resighted. The first (resight # 10, sighting ID 91 & 84) was sighted in February, 2002 migrating northwards with a calf and then resighted in late March, 2003 with another adult (not the grown calf), milling over the plateau. On the second sighting the whale was successfully satellite tagged (Tag 40620) and a note was made that the whale looked very large, possibly pregnant.

The second cow was resighted 29 days apart (11-Jan and 9-Feb) in 2004, on each occasion accompanied by its calf, in almost the same location (< 15 km away). The cow appeared to be deep diving while the calf (length ~ 10 m) remained circling at the surface on the first sighting. On the second sighting the pair was approached by a third whale which stayed with it for the duration of the follow (91 min).

Intra–season Resights

There have been higher numbers of resights within seasons than between. This suggests that the Perth Canyon is a destination for blue whales and not simply a location on their migratory path. The longest intra-season resight period was 63 days. Whale # 19 (identified as a male by biopsy in 2000, see section 4.3) was photographed first on January 11, 2004, milling west of the Plateau, and then again on March 14, 2004 milling near the Gully. Its behaviour in both cases was consistent with deep-water feeding.

The relatively high number (16) of intra-season resights in 2004 (Table 8) coincided with the highest number of whales seen in the Canyon by the boat-based surveys in one season. The average intra-season resight period was 21.3 days (± 8.3, 95% CI, n=16) suggesting that individual whales may use the Canyon for feeding purposes from two to four weeks.

4.2.5) Satellite Tags

Development of a satellite tagging system has proceeded rapidly over the five-year study period. Nick Gales (Australian Antarctic Division) has been collaborating with CWR to develop a blubber-implantable tag and delivery system for both humpback whales and blue whales since 2000. The first trials on blue whales took place in 2002, when two of five tags were successfully deployed.

The first successful tag (# 3606a) was deployed on March 12, 2002 and transmitted data for eight days (Figure 16). It seems likely that transmissions occurred while the whale was milling at the surface over a food source; the locations were over the slopes of the Canyon.

The second successful tag (# 3606b) was deployed in December 2002 in Geographe Bay on a cow of a cow / calf pair (Figure 17). The tag was initially thought to have failed because no data were transmitted for 43 days. Apparently the salt water activation switch must have been covered by the whale's blubber, preventing it from operating until the natural rejection process had ejected the tag slightly. The first transmission location was 950 km from where the tag was deployed (minimum distance travelled assuming the most direct route) in an area of the Southern Convergence where there was whaling in the 1960's. Assuming the animals was a pygmy blue whale, this may represent the southern migratory limit of the population seen off the Perth Canyon between January and May each year. Alternatively it may have been a true blue whale heading south for summer.

Table 8: Summary of intra-season photo-id resights from 2000-2004.

Resight ID#	January	February	March	April
1 (2001)		●●		
2 (2001)		●●		
3 (2001)		●	●	
4 (2004)				●●
5 (2003)			●●●	
6 (2001)			●●	
7 (2001)			●●	
11 (2003)			●	●
14 (2004)	●	●●		
16 (2004)	●	●		
17 (2004)	●	●		
19 (2004)	●		●	
21 (2004)			●●	
22 (2004)		●	●	
23 (2004)		●	●	
24 (2004)			●	●
26 (2004)			●	●
27(2004)			●	●
28 (2004)			●	●
29 (2004)			●●	●
30 (2004)			●	●

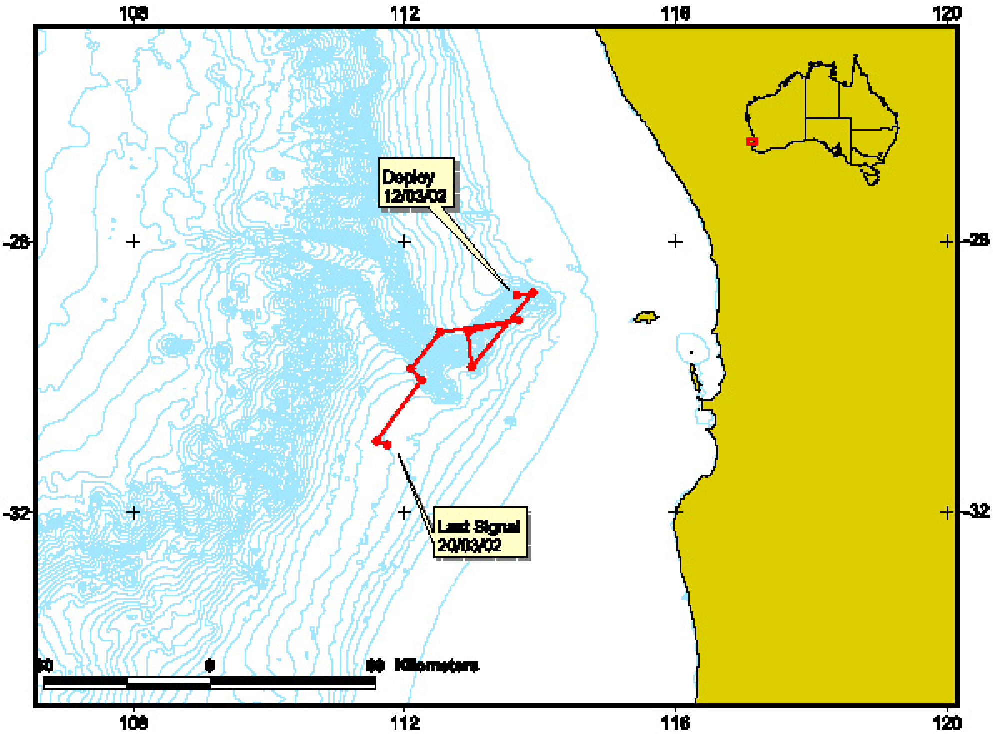

Figure 16: Track of satellite tagged blue whale 3606a, 2002 (note scales are incorrectly labelled).

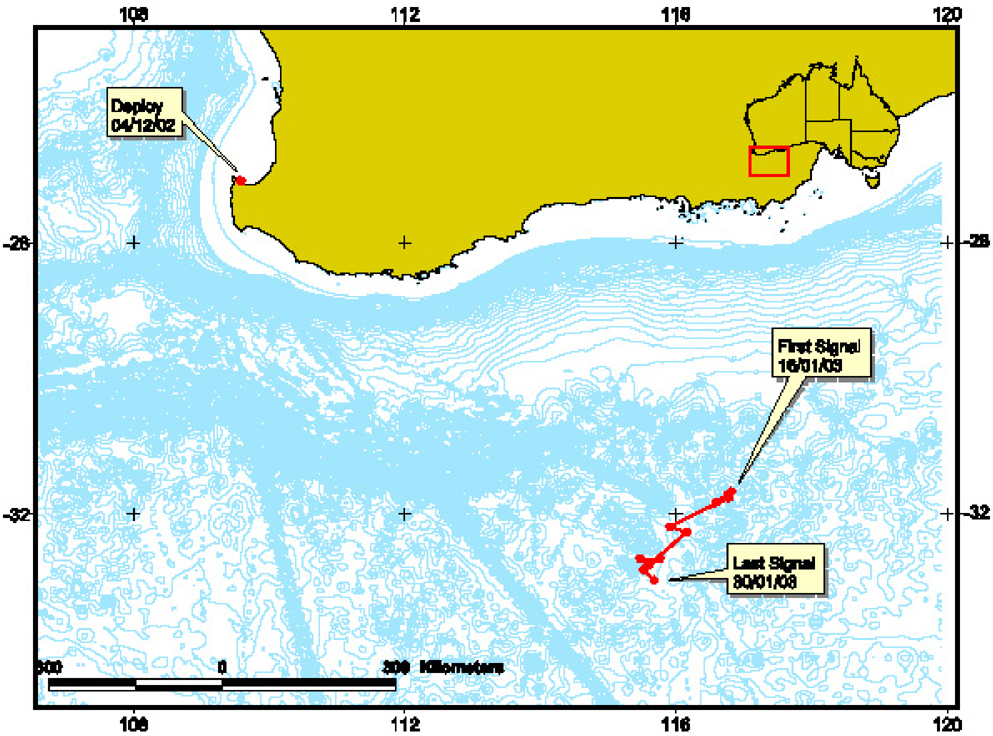

Figure 17: Track of satellite tagged blue whale 3606b, 2002 (note scales are incorrectly labelled).

The third successful tag (# 40618) was deployed on 27-Mar-2004, and transmitted for 16 days while the whale zig-zagged over the Canyon region and an area 125 km to the north (Figure 18).

The fourth tag (# 40620), deployed on 27-Mar-2004 on a very large individual, was later identified by photo-id as the cow of a cow / calf pair sighted one year earlier. Unlike Tag # 40618, this whale did not remain in the Perth Canyon area but instead began to move north along the coast, covering a distance of 425 km in seven days while the tag transmitted (Figure 19).

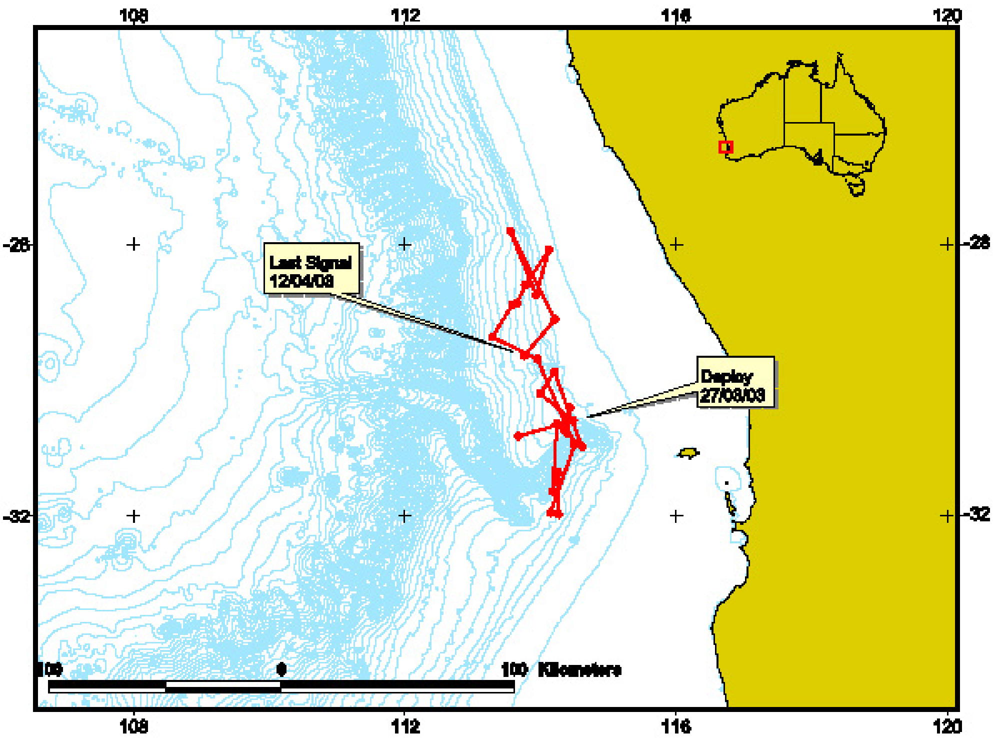

Figure 18: Track of satellite tagged blue whale 40618, 2003 (note that scales are incorrectly labelled).

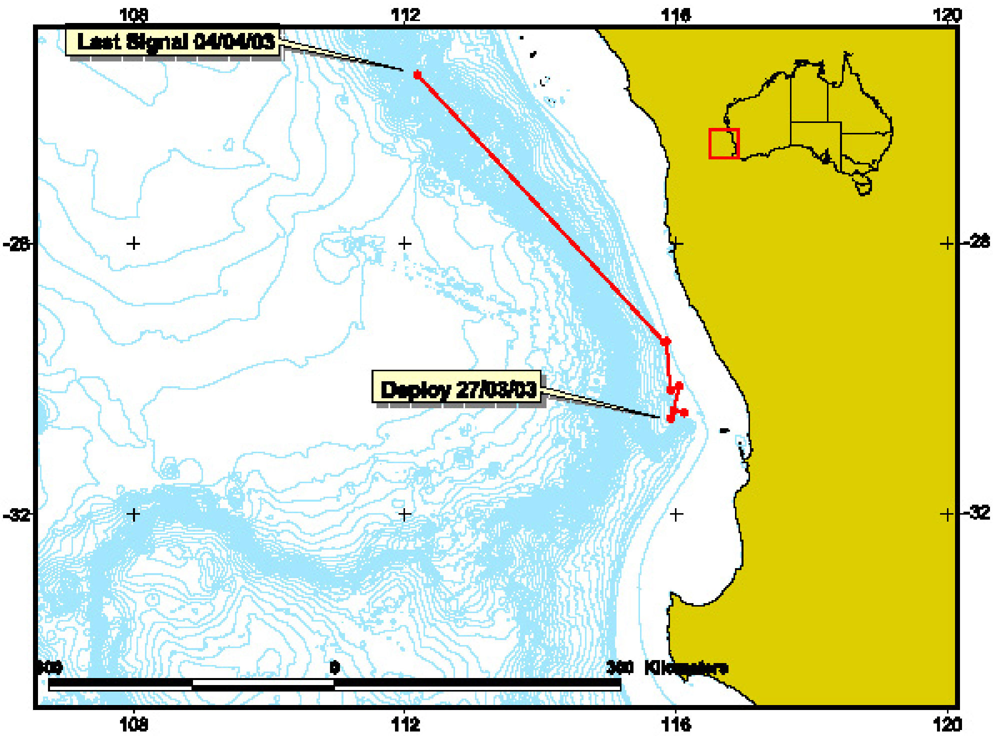

Figure 19: Track of satellite tagged blue whale 40620, 2003 (note that scales are incorrectly labelled).

4.3) Genetics

In the course of boat-based studies, biopsy samples of skin and blubber were obtained for genetic studies. Samples were obtained by crossbow, under permit obtained by WAM from Murdoch University Animal Ethics Committee. They were sent for analysis to the La Jolla, California, Laboratory of the US National Marine Fisheries Service which, *inter alia*, is conducting a worldwide study of blue whale, including pygmy blue whale, populations. The results were to include information on genotype and sex, and if possible, on subspecies.

Of 13 samples available from 2000 and 2001, two were found to be of the same animal, a female, sampled on consecutive days in February 2000. Of the remainder, one could not be sexed, and of the remaining 10, seven were male and three were female. Thus in the sample as a whole there was a preponderance of males (7:4).

Of six samples from 2002, the analysis failed on one, and all the remainder were male.

A further 31 samples, mainly from 2004, are now being analysed.

In addition to samples obtained by biopsy, a larger number of additional sloughed skin samples was forwarded to the La Jolla Laboratory. They were obtained relatively easily during the boat-based operations by dip net from whales' 'footprints'. However, they have not been analysed as, in contrast to humpback whales where such samples have proved useful, results from blue whales have only been obtained, and then with considerable effort, from 40-60% of blue whale sloughed skin samples analysed. The blue whale sloughed skin analysis also invokes a greater potential for false results through allelic dropout (non-amplification of genes).

Genetic sampling has not yet been able to distinguish individual pygmy blue whales genetically from true (Antarctic) blue whales. Differences have been observed between individuals of true and pygmy blues from the Indian Ocean and the South Pacific, but so far these have not been shown to be markedly different from differences apparent between populations of pygmy blues, e.g. from the western Indian Ocean, off Madagascar, and the eastern South Pacific, off Chile. In spite of a high level of statistical differentiation, no diagnostic differences have yet been found to enable confident identification to subspecies of any particular genetic sample of unknown provenance (LeDuc et al 2003).

4.4) Passive acoustics

A total of 12 moored sea noise loggers have been set in the Canyon since 2000, 11 of these under Defence funding since early 2002. Additionally a number of drifted logger deployments have been made, including three 36 hour deployments made on the *Southern Surveyor* cruise in 2004. Deployments are summarised in Table 14 (Appendixes). One moored logger has been lost, the mooring line was snapped by a tug and we have been unable to recover it. This logger will have corroded through by now. One mooring had its riser cut at 250 m depth but was successfully grappled (mooring 13), while a third mooring also had its riser cut and is awaiting recovery (mooring 14 - we are confident of its location and the lay of the ground rope). The mooring design has been difficult and confounded by:

- the need to isolate as best as possible the mooring line from the sea noise logger to reduce noise
- the need for a vertical riser to instrument with temperature loggers
- the inability of initially purchased SonaDyne type 7182 acoustic release's to meet their stated specifications (divide by three would be a better estimate)
- the mooring depth (430 – 490 m)

- strong currents down to 250 m depth associated with the Leeuwin current (surface currents consistently at 2 kn and peaking at 3 kn were experience in the first half of 2002)
- a large amount of submarine traffic in exercises over the Perth Canyon and thus a high risk of risers being cut

We replaced the SonarDyne acoustic releases with EdgeTech CART models in late 2003 and so solved the problem of the units not being able to release when under load. The final mooring design settled on, which allowed for a riser but kept the floatation low in case the riser was cut, is shown on Figure 20. Note that the bights in the ground line are exaggerated in this figure. This mooring design used a long gound line with a 200 mm dia buoy set in the middle of each rope length (220 / 350 m). This ground line decoupled the riser from the mooring, acted as a mooring line when the acoustic release was released, and offered a target for grappling if all else failed.

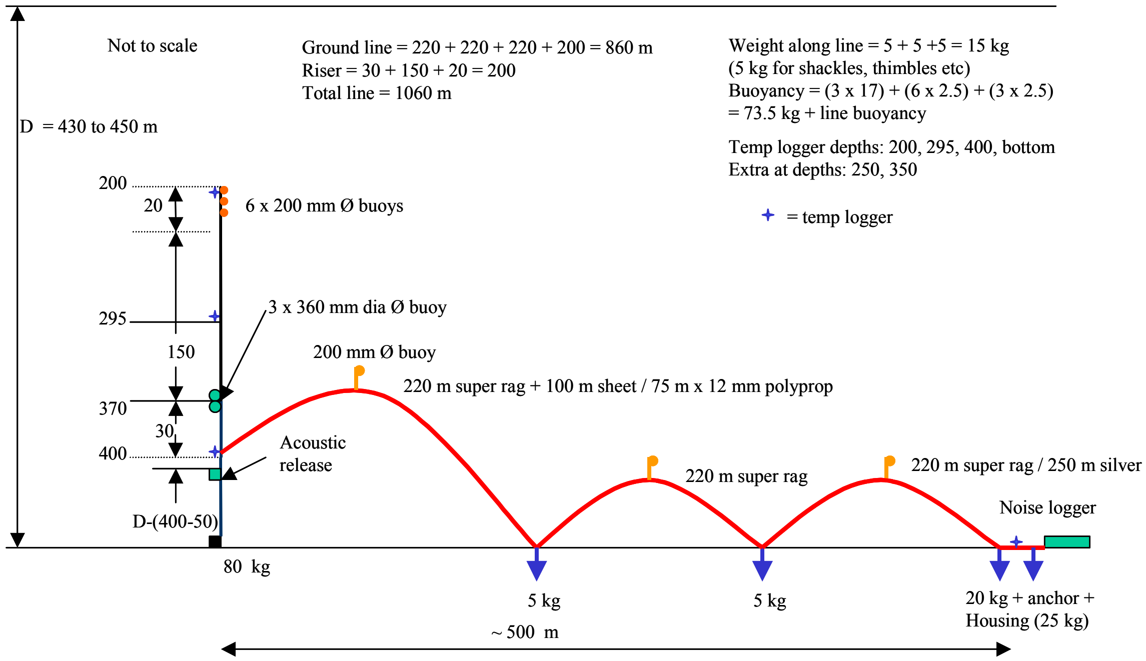

Figure 20: The final mooring configuration used in the Perth Canyon. By keeping the main floatation low on the riser the risk of the riser being cut was lowered. The bights shown in the ground line are exaggerated, these were pulled low on deployment.

The time periods of moorings recovered and successful data logging are shown in Figure 21 (the red represents data collected, blue the logger in the water). The set numbers used in acoustic analysis are shown in Figure 21. A notable failure of the logger hardware occurred on the first deployment, when software supplied by the main processor chip manufacturer (Persistor) immediately before the deployment, seized the operating system of each logger. Instead of three months of data we managed three days. This failure was exacerbated by failure of the acoustic releases to operate and a year of very strong Leeuwin currents. Mooring 8, which was lost, was set to operate over May to Aug 2002, while mooring 14, which is still awaiting recovery, should have run over Oct-2003 to Jan-2004.

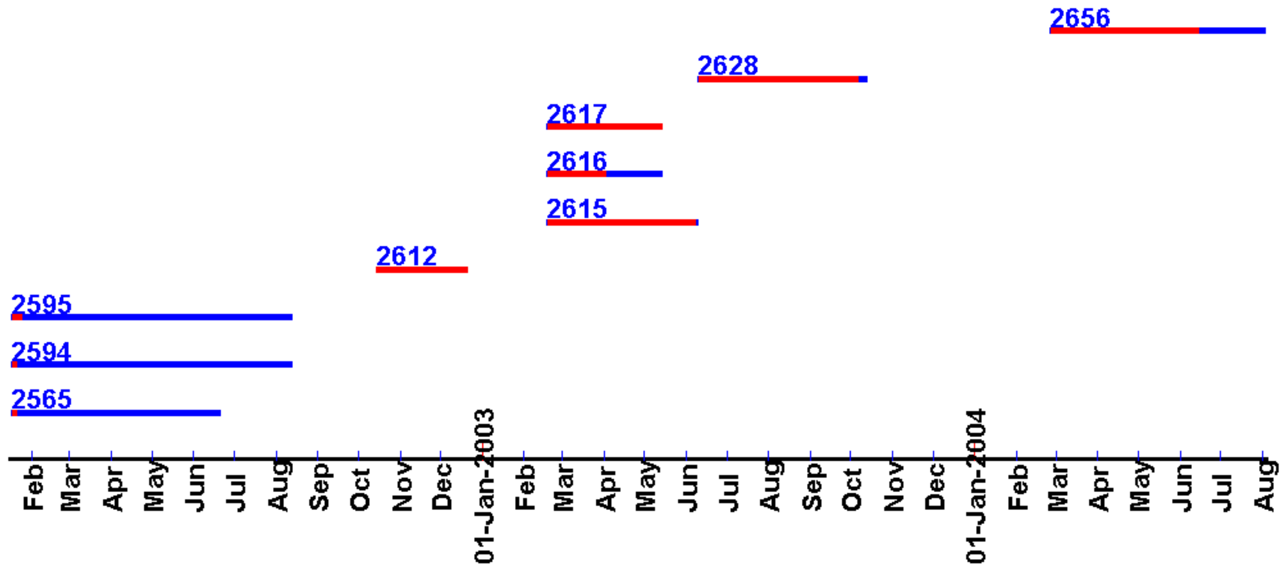

Figure 21: Time frame of acoustic logger deployments. The blue bars represent time in the water, the red bars represent successful data collection.

4.4.1) Call types recorded

A large variety of biological and physical call types have been recorded from the Perth Canyon. A listing of common signal types and a brief summary of their structure is given in Table 9 for physical or man-made sources and Table 10 for biological signals. This list is not complete nor concise, there were many other signals types recorded, often with considerable variability.

Table 9: Major physical signal types recorded from the Perth Canyon

Designation	**description**	**Notes**
Explosions	Impulses with many multipaths	rare
Surface gunfire	Impulses with few multipaths	Uncommon
Earthquakes / land slips	Increase in low frequency (< 50 Hz) energy over 10's s	Uncommon
Vessel noise	Very varied, often with strong tones	Passing ships show classic interference patterns
Air gun signals	Low frequency (10-100 Hz) pulses repeated @ ~ 10 s intervals, pulses can be many s long	Common background noise at some times, usually near ambient levels, sources from Abrolhos northwards

Table 10: Major biological signal types recorded from the Perth Canyon

Designation	**description**	**Notes**
Pygmy blue whale call	3 parts- I a 19 Hz tone for 21 s followed by 21 Hz tone for a further 22 s, Five to ten s later II a long frequency upsweep, beginning near 20 Hz and increasing to 26 Hz over 23 s. Approximately 23 s later, III a 20 s, 19 Hz tone, all components with harmonics, type I & III often with a secondary 64 Hz pulse tone, sequence repeated with 70-170 s between end of one call and start of next	Very common in summer, several variants noted in late 2002 and 2003, several of these believed associated with certain individuals
‘true’ blue whale	Single tone at 23.5 Hz, 3 – 12 s long	Not positively ID’d but resembles Antarctic blue call in structure
‘bio’ duck	Series of pulse trains with maximum energy between 100-200 Hz, very variable length, at least 3 variants, one of lower frequency (50-100 Hz)	Source unknown, has distinct seasonal pattern in calling which suggests an animal migrating up from Antarctica, possibly Antarctic minke?
Short down-sweeps - ‘fin’ / ‘blue’ whale	Frequency down-sweeps between ~ 90 - 25 Hz lasting a few to 5 s, several common types with variable frequency composition and length	Resemble ‘fin’ whale calls from literature but one call directly attributed to a blue whale (not clear wether a true or pygmy blue)
Humpback song	Very varied, 20 Hz-2500 Hz, described elsewhere	Recorded but not intensively studied here
Fish choruses	Distinct signals not yet discerned, chorus is an increase in noise level over 19:30 – 23:00 each night over 1.8 –3.2 kHz	Very regular, always evening chorus (timing varied within evening) often pre dawn chorus, max level / evening fluctuates – parallels behaviour of other fish choruses
‘clicks’	Generally low frequency (most energy 10-40 Hz), short (10’s to 100’s ms)	Unknown source, some are probably mooring related noise but others are real, possible whale feeding associated noise?
‘social’ sounds	A variety of short (mostly < 10 s) sounds < 100 Hz of mixed structure	Sounds uncommon, variety of types, nature of signals suggest large great whale sources

Examples of blue whale signal types are shown to illustrate the variety of sources from blue whales which were encountered in the Canyon records. The examples shown are:

- Figure 22 – ‘common’ form of the pygmy blue whale call
- Figure 23 – A variant of the ‘common’ pygmy blue whale call (seen as the first two components in Figure 23, which were repeated as a ‘call’, but which were variants of the ‘common’ type III component, one of which can be seen over 70-180 s in Figure 23). Several variants were found in late 2002 and early 2003 (the late 2003 records are still to be recovered and analysis of the 2004 records is pending).
- Figure 24 – An example of unknown signals of biological origin overlying pygmy blue whale and air gun signals. It may have been possible that multiple sources were responsible separately for the pulsed signals centred about 500 Hz (these were comprised of a distinct series of pulses which gradually increased in pulse separation over the 7-8 s of the ‘call’), and the short frequency down-sweeps between 50-150 Hz, which closely resemble signals recorded from a blue whale off Cape Naturaliste and shown on Figure 25.

- Figure 25 – In December 2003 Chris Burton recorded these sounds at ~ 100-200 m from a 'large blue whale' adjacent Cape Naturaliste in approximately 20 m water depth. Chris noted the water above the whale 'boiled' coincident with the signal coming through on the hydrophone. To 'boil' the signal negative peak-pressures at the surface must have been greater than the difference between atmospheric and the water vapour pressure. At 19º C the water vapour pressure is 2.206 x 10^3 Pa. This would put at least some part of the signal waveform with a peak negative signal pressure of > 220 dB re 1 µPa (this would be the minium peak negative pressure, it may have been higher). Assuming the signal was a pure tone (it wasn't), then this would put the mean squared pressure, at the surface at > 217 dB re 1 µPa (again it could have been higher). Alternatively, the measured peak signal pressure (+ve and –ve) of the signal over 1-4 s shown on Figure 25 was approximately seven dB higher than the mean squared pressure averaged over the full signal. This would put the signal level at the water surface at > 213 dB re 1 µPa mean squared pressure. The influence of the bottom will have been substantial in determining the signal structure at the sea surface (at the frequency of most energy in the signal of ~ 65 Hz, the wavelength is longer than the water depth) and will bias the signal level estimate. But, assuming a worst case scenario of complete addition of a reflected signal, then the source level estimate would only drop by three dB. Hence a conservative estimate would put the source level of this signal in excess of 210 dB re 1 µPa mean squared pressure (a minimum estimate), which is extremely high.
- Figure 26 – Shown on the left panels, short, pure tone signals recorded from the Perth Canyon, mostly over winter / spring in 2003 and believed to be from Antarctic blue whales. These signals varied in length from 3 to 12 s and were always very sharp tones centred approximately within one Hz of 23.2 Hz. A comparison of these signals with Antarctic blue whale calls is shown on the right hand side panels of Figure 26. This signal was recorded off Cape Leeuwin and is identical to those described by Sirovic et al (2003) for true blue whales recorded off Antarctica.

The call types shown over Figure 22 to Figure 26 illustrate that a variety of calls existed within a species complex. Further variants of the 'common' pygmy blue whale call as shown on Figure 22 included:

- calls missing altogether the type I component (5-60 s on Figure 22)
- the type I component split for a few s at about two thirds of its normal length
- the call comprising a modified type III component only, often in sets of two

There was evidence, from the consistency in timing and change in the level of signals through time, that many of the variants in the common pygmy blue whale call observed, were consistently due to individual animals. Thus it may be that different animals vary their call structure, or the variants were due to juvenile animals in the process of learning the final common call structure. There was also a large variation in measured intervals between the end of one common pygmy blue whale call and the start of the next, ranging over 75 s (Perth Canyon) to 170 s (Cape Leeuwin). On top of these signals and those shown, there were also a number of signals which we believed were social calls produced by pygmy blue whales. This diversity of call types makes interpreting the patterns in call behaviour, timing and location, difficult. Currently, we believe:

- the pygmy blue complex of calls is relatively distinct, although more diverse than initially considered, with one 'common' call structure and several variants of this;

- the tonal signal shown on the left panel of Figure 26 are structurally very similar to the call produced by true or Antarctic blue whales, and given the lack of other potential sources which could make this call then it is highly likely that it is a true blue whale call;
- The down sweep shown on Figure 25 was recorded from a large blue whale. It was not known wether this was a true or pygmy blue whale. This type of call was relatively commonly recorded through several summer periods in the Canyon. Similar, although not identical, down-sweeps have been recorded from north-western Pacific blue whales (Stafford et al 2001). Hence it could be that the call was from a pygmy blue whale, or vagrant true blue whale/s which spent the summer in temperate rather than Antarctic waters. There is genetic evidence that true blue whales may over-summer in temperate waters and conversely that pygmy blue whales may over-summer in Antarctic waters (LeDuc et al, in press).

Similar variations of call structure were noted in the bioduck call, with three variants of this.

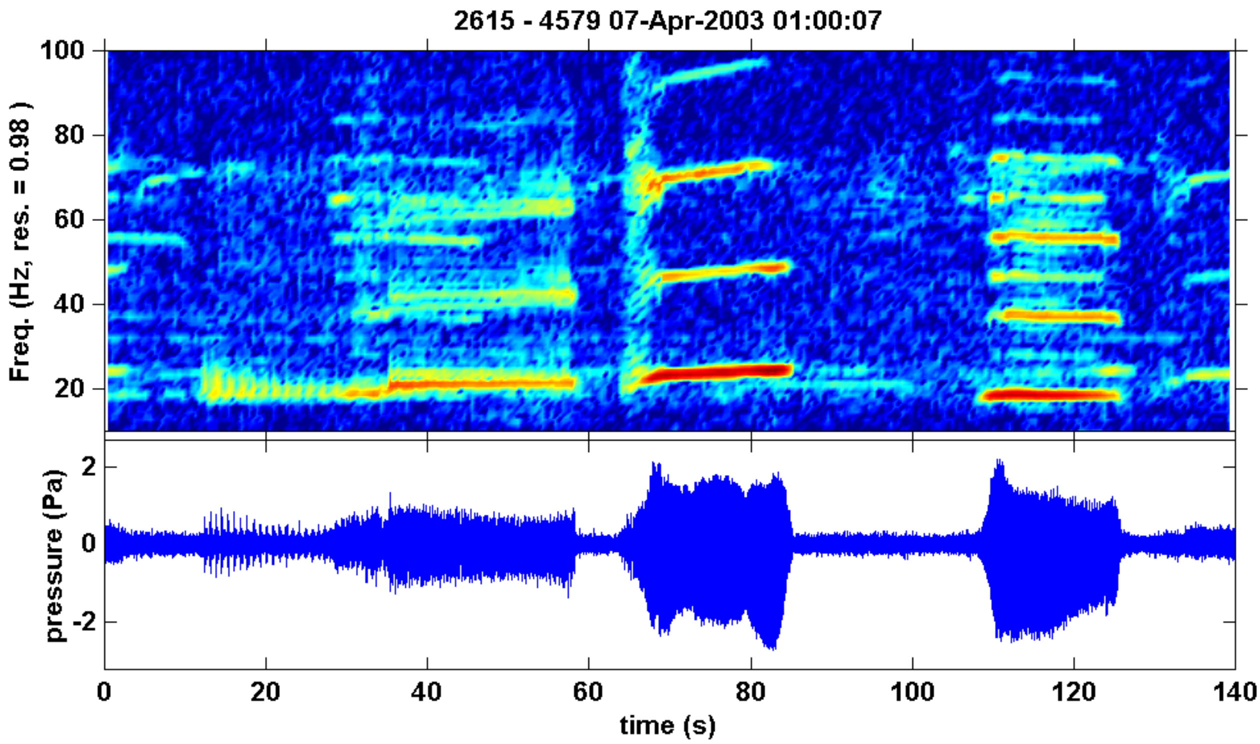

Figure 22: Common structure of a pygmy blue whale call. The call stretched over 114 s and reached up to 116 dB re uPa (mean squared pressure) at its peak frequency of 23 Hz

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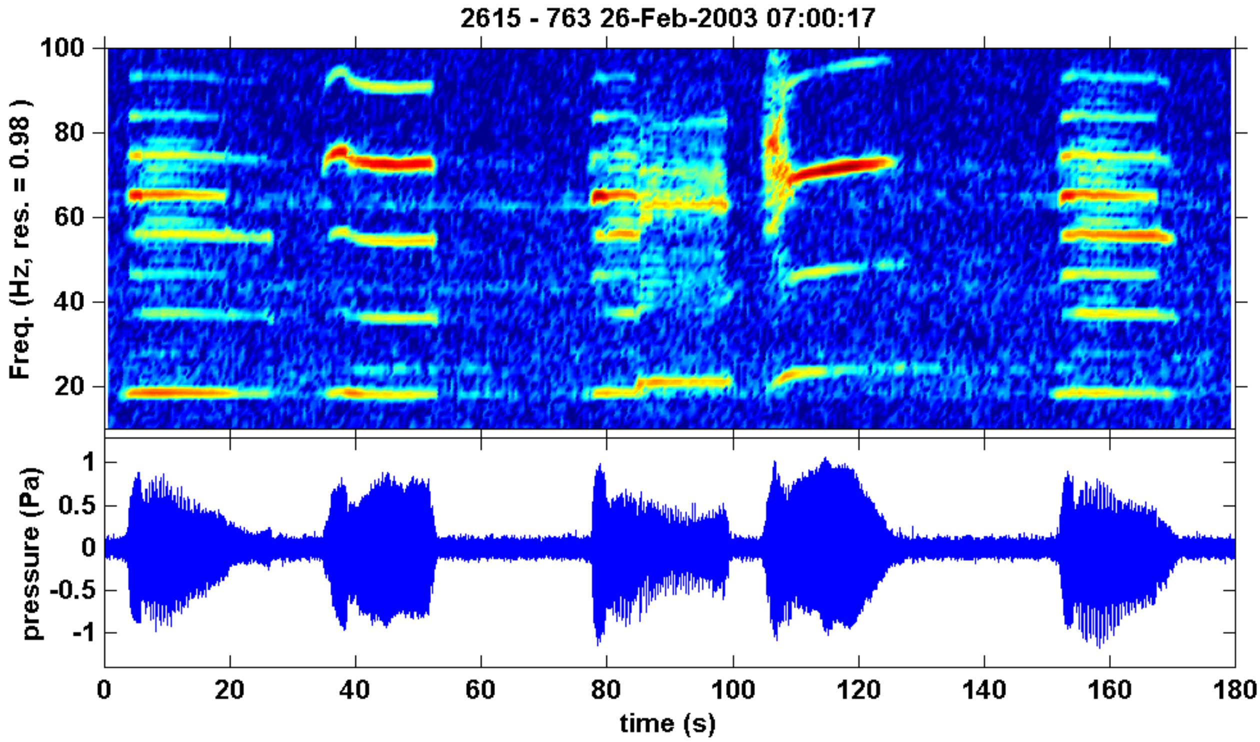


Figure 23: Two sets of pygmy blue whale calls with an aberrant form shown in the first 55s, with a leading type II component then a modified type II component. The second call (75-180 s) has a modified initial period in the type I component.

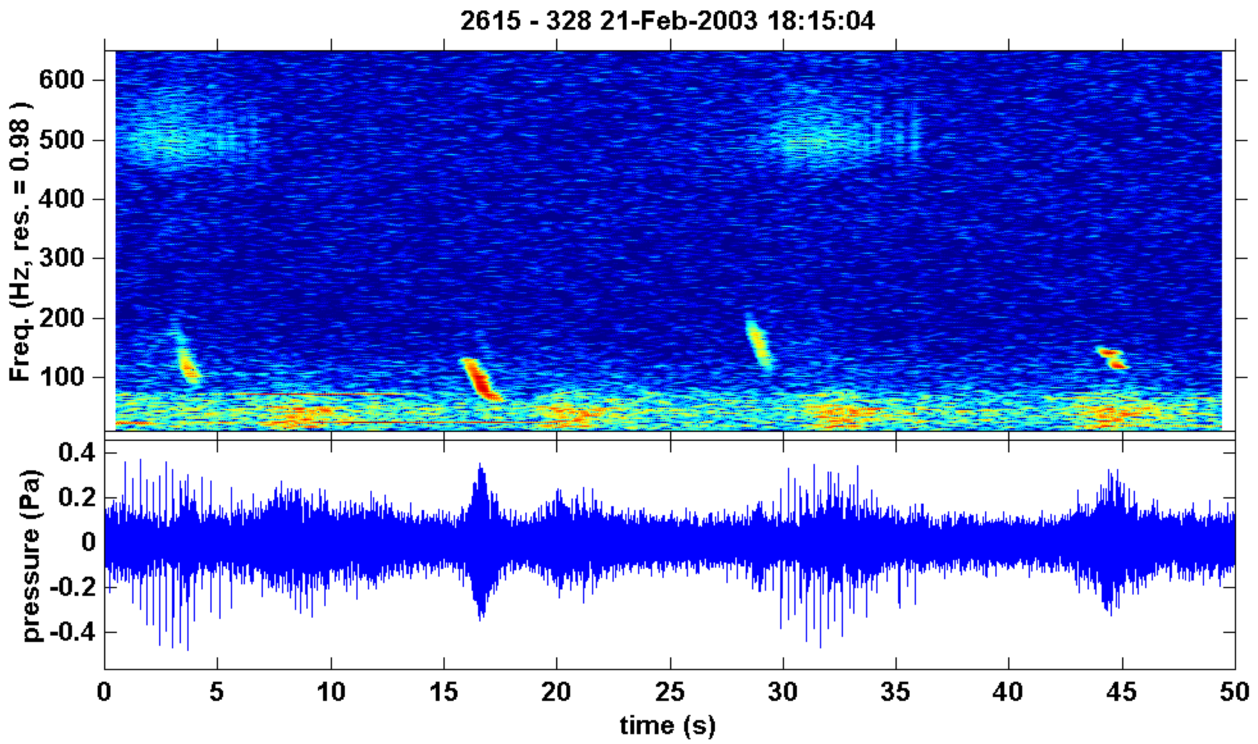


Figure 24: Unknown signals of biological origin (pulsed signals at 500 Hz and downsweeps over 50-150 Hz), overlying pygmy blue whale and distant air gun signals .

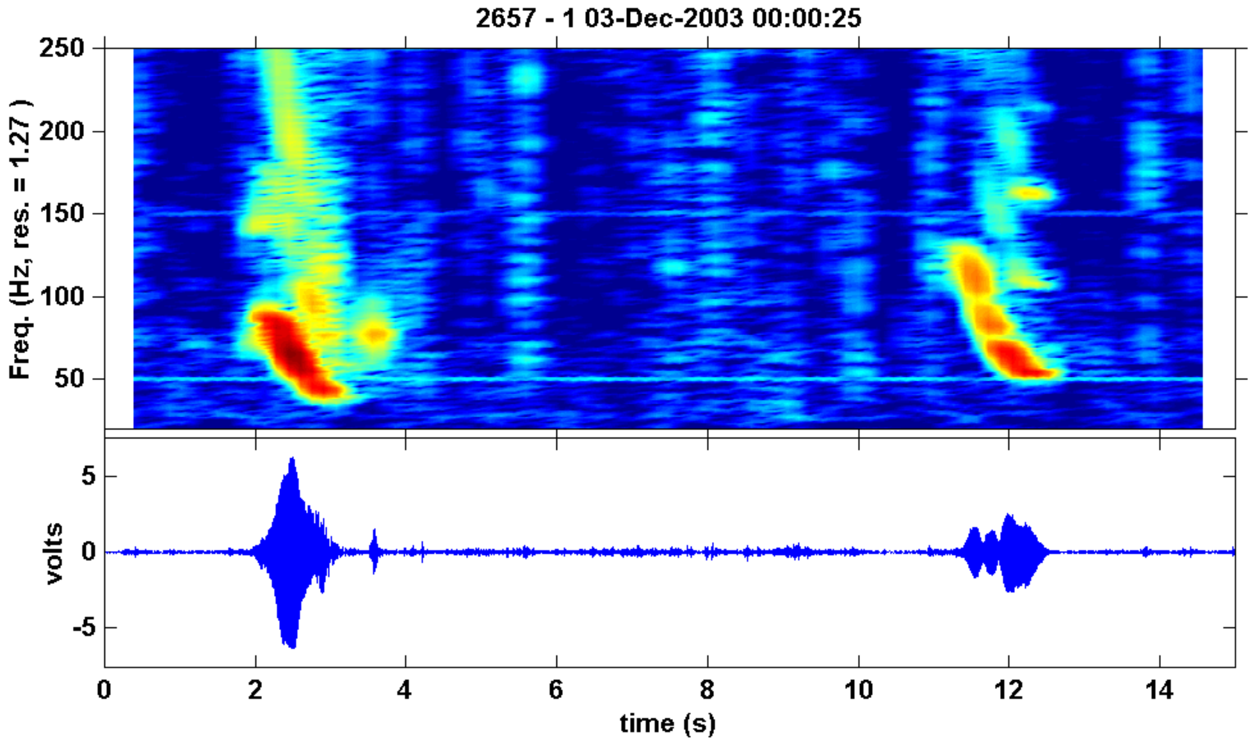


Figure 25: Spectrogram of calls recorded from 'large blue whale' in shallow water off Cape Naturaliste in late 2003 by Chris Burton.

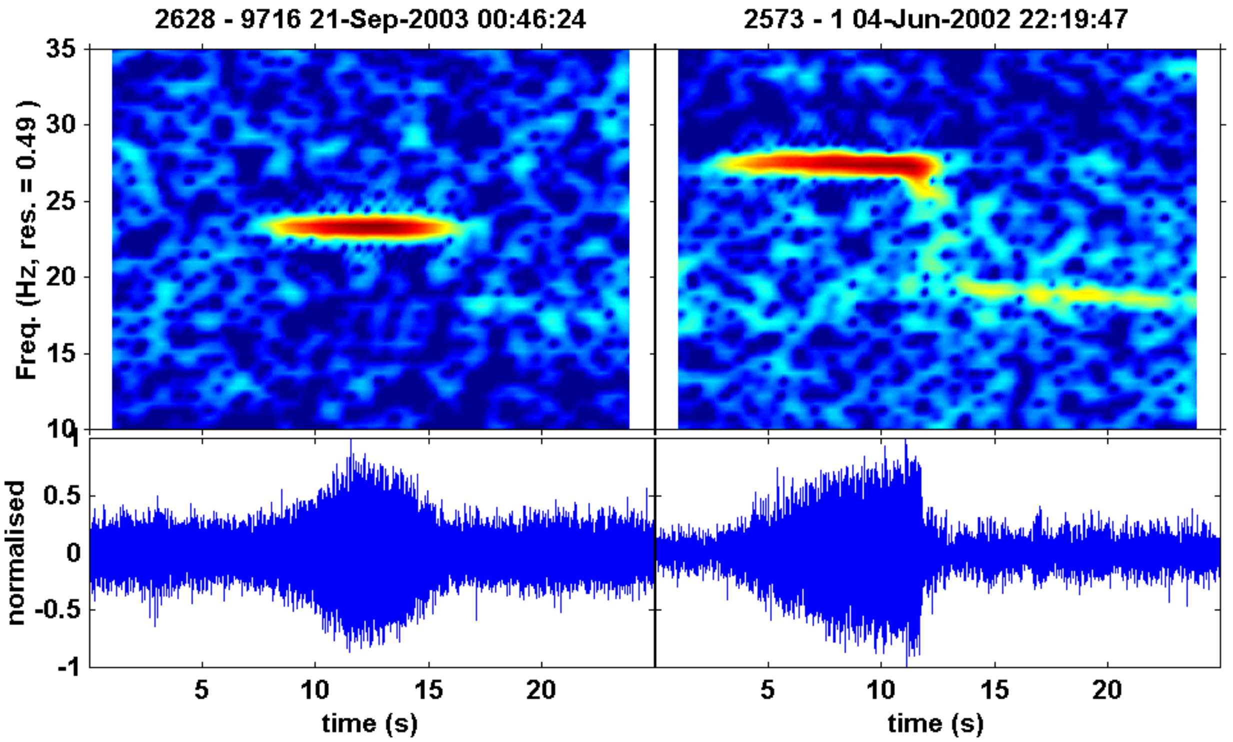


Figure 26: (left panels) Believed blue whale, possibly true blue, from the Perth Canyon. (right panels) Antarctic blue whale call as measured off Cape Leeuwin. The plot scales are identical, with 5 s time ticks.

4.4.2) Presence and abundance of great whales in Perth Canyon from passive acoustics

The use of the sea noise loggers allows the presence / absence of different signal types, and thus whale species, to be followed in time. Using all the data available from the Canyon, then the presence of several whale species is shown on Figure 27, using a season split from 1-Jul to 30-Jun the following year.

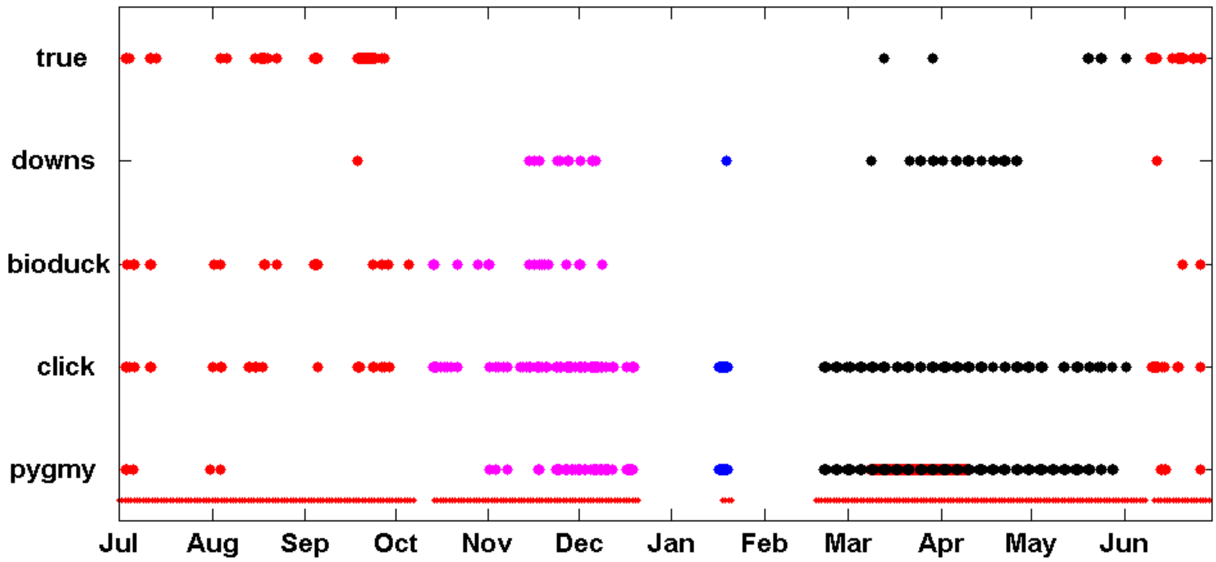


Figure 27: Presence or absence of various call types from the Perth Canyon (all data lumped). The lower scale represents sample days analysed.

Humpbacks have not been included in this analysis to date. Figure 27 highlights the seasonal patterns in whale presence for the species shown. In summary, trends for sources other than pygmy blue whales were:

- **True blue calls** (Figure 26, left panel) – within a calendar year true blue whales began to be detected in small numbers in May, but only became common in June. They persisted over winter and into early Oct (note that the winter data set 2628, has been thoroughly checked through Jun and mid Sep on but not through Jul to mid-Sep, an automatic detection routine has many winter hits but these have not been manually checked to rule out vessel tones). This is consistent with a winter migration north from Antarctica to spend the summer along the Australian coast. Such a pattern suggests that by late Oct most animals have headed south. This timing coincides well with the observations of Chris Burton and Steve Mitchell (whale watch operator out of Busselton) of 'blue' whales consistently seen each Oct-Dec in Geographe Bay (Figure 1) heading south around Cape Naturaliste. This opens the question as to wether these Cape Naturaliste animals are mostly true blue whales, whom have over-wintered along the WA coast and are heading south to Antarctica, as opposed to early season south travelling pygmy blue whales which are largely not detected passing through the Perth Canyon (Figure 27). This would not rule out some of the southerly travelling animals off Cape Naturaliste being pygmy blue whales though.
- **Down-sweeps** (Figure 24 and Figure 25) – The timing of these calls coincides with the presence of pygmy blue whales in the Perth Canyon, suggesting the source is also a pygmy blue whale. But the observation of Chris Burton of this call type produced by a very large blue whale seen off Cape Naturaliste in Dec, confuses this. Possible explanations are: either true and pygmy blue whales produce the call type; vagrant true blue whales remain in the Canyon over summer; at least some pygmy blue whales head south around Cape Naturaliste over Oct-

Dec; or a similar call is produced by other species in the Canyon (ie. fin whales) which we have not correctly differentiated from the blue whale form. All of these scenarios are possible and without further work we cannot currently say which is correct.

- **Bioduck –** In a calendar year**,** did not appear until mid winter, then persisted in high numbers of detections per day until the end of Oct, and then persisted with sporadic low detection rates into early Dec whence it was not heard again until the following winter. The timing is consistent with an animal which migrated up and back to Antarctica with a possible source the Antarctic form of the minke whale.
- **Clicks -** These were a confusing set of signal, mostly comprised of short (<< 1 s), low frequency (most energy in the 10-30 Hz range) impulses. Some of these signals were possibly due to mooring noise (lines tugging on the sea noise loggers) whereas others were real as evidenced by their simultaneous recordings on three spatially separated loggers, their often consistency between impulses and the presence of discernible bounce paths (discussed in milestone report 4, Sep-2003, from this project). The source level of real clicks was estimated to be low, since they were rarely recorded on three spatially separated loggers simultaneously. There was a weak daily pattern to their occurrence, with slightly more clicks produced immediately after sunrise and sunset. Currently we can only speculate on their source and function.

The pattern for pygmy blue whales was for seasonal detections to begin in Nov, then for detection rates to increase steadily and peak over Feb to May, then decline and to largely end in Jun, although some calls occasionally appeared over early winter. The mean detection rate of individual calling animals, averaged in 24 hour blocks beginning at 00:00 hours, is shown on Figure 28 for all available data lumped (top) and for each data set separately (bottom). Shown are the number of individual calling pygmy blue whales within a sample (taken every 15 minutes), averaged each day, with the 95% confidence limits.

The 2003 summer had the peak number of calling animals occurring around early April. Of note on Figure 28 is that where overlap occurred between years (17 comparative days currently analysed for 2000 and 2003 summers out of 33 possible days) then the 2003 summer had rates of calling individuals 5.421 ± 2.24 times higher than in the 2000 summer, which was statistically significant. This was determined for counts of individual callers per sample averaged over a 24 hour period for the same year-day in 2000 and 2003. In 2000 a 'sample' was a 90 s segment every 10 minutes, in 2003 it was a 200 s sample every 15 minutes. A typical blue whale call stretches over 120 s repeated every 75-85 s in the Canyon, hence the 90 s samples made in 2000 should have discerned all singers calling at that time. Even directly correcting the 2003 sample counts by 90/200, which is overly conservative, still gave a statistically greater call rate in 2003 compared with 2000, indicating a higher visitation rate in 2003.

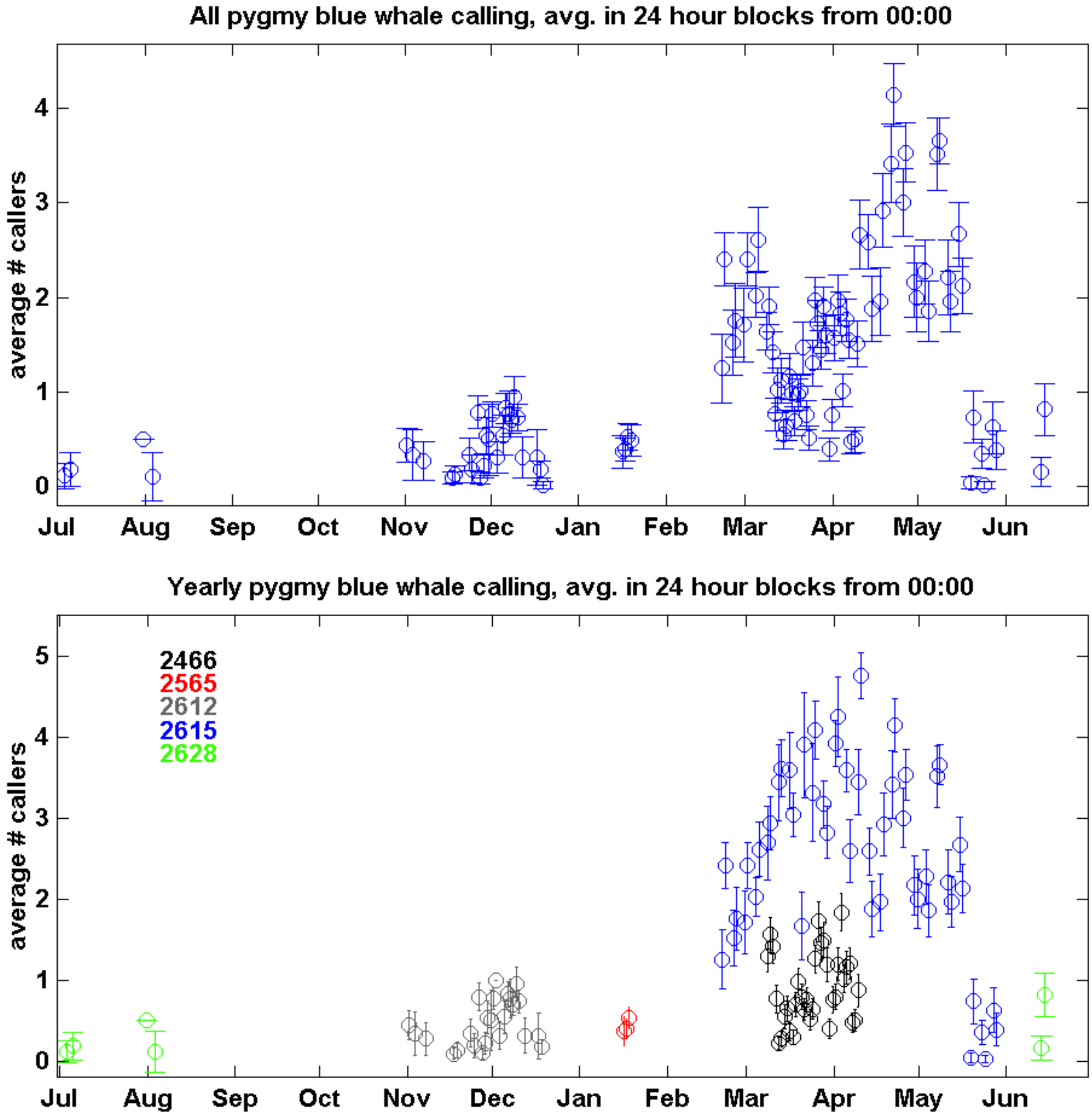


Figure 28: **(Top)** Mean number of individual calling pygmy blue whales, averaged per 24 hour period, from the Perth Canyon, using all available data lumped together. **(bottom)** Mean number of individual calling pygmy blue whales, averaged per 24 hour period, from the Perth Canyon, split for each data set.

It is intended to correlate the acoustic call rates with the visual surveys counts in an effort to benchmark call rates so they give a direct index of whale numbers in the Canyon. There are many pitfalls to this, including:

- the fact that pygmy blue whale calls will transmit into the Canyon loggers from a long range (see Figure 5 for tracked whales for example), possibly into the hundreds of km;
- variable levels of background noise which will change detection rates for faint detections
- daily patterns in calling behaviour (largely overcome by using 24 hour averages)
- differences in counts of calling individuals between different sample lengths (ie 90 s in 2003 vs 200 s in 2002 onwards)
- different behaviour of individual whales

- seasonal differences in the class structure of the pygmy blue whale population within the Canyon

McCauley et al (2001) took into account several of these factors for the 33 day Perth Canyon 2000 data set and deduced that calling rates were < 29% of the number of pygmy blue whales in the Canyon at any given time. It is intended to take this analysis further with the much larger data set in hand, although this analysis is still pending.

4.4.3) Tracking of great whales in and about Perth Canyon using passive acoustics

A grid of three loggers in an approximate five km triangle was deployed on two occasions to track whales (see Figure 21 for timeframes). On the first occasion the grid only ran for three days, although it gave useful results, while on the second occasion it ran for 43 days with three loggers functioning and a further 42 days with two loggers functioning (the second hard disk was incorrectly plugged in on the third logger). Neither of these deployments had consistent time synchronisation sources and relied on external events to synchronise the clocks. In late 2003 a set of three EdgeTech CART acoustic releases and a deck unit was purchased for use on the tracking grid. One of these acoustic releases was modified to ping at 7.5 kHz, every 20 s for 30 minutes with a source level of 192 dB re 1μPa. It was intended for this release to be suspended at 50 m off the bottom on one mooring and for it to ping over 21:45 – 22:15 hours each evening. The sea noise loggers were to be set to sample at 22:00 at 22 kHz for 65 s to capture three pings, which could then be used to synchronise the logger clocks once per day. The tracking grid was readied and sent to sea on three occasions (Oct-2003, Feb-2004 and Aug-2004), but on each occasion the logger from a previous deployment either failed to rise or could not be grappled. Hence the respective deployment of the tracking grid was delayed until either the mooring was re-designed (Oct-2003 & Feb-2004 trips) or the extra boat time involved in grappling had used the money allocated (~$3 k per trip) for the next recovery (Aug-2004 trip). Thus we now have an excellent tracking grid capability which we have yet to deploy.

The results we have in-hand are only partly analysed. A great deal of effort has had to be put into synchronising the three logger clocks, as discussed in the previous milestone report (Milestone 4, Sep-2003). We have also spent some time building separate algorithms for the tracking, to account for the many ‘dead’ spots inherent in a three logger tracking grid. Hence further analysis beyond that shown on Figure 5, is pending.

4.4.4) Analysis of fish choruses recorded in the Perth Canyon

In addition to great whales, regular fish choruses were evident in the Canyon each evening. The initiation of the evening chorus varied between 19:00-21:00, with choruses rapidly reaching their maximum level then continuing for a few hours. On many occasions choruses also occurred pre-dawn. Choruses were centred over the frequency band of 1.2-3 kHz. An example of ten days of sea noise in the 2 kHz 1/3 octave showing the rise in level each evening due to these choruses is shown on Figure 29 and on Figure 30 for a single evening.

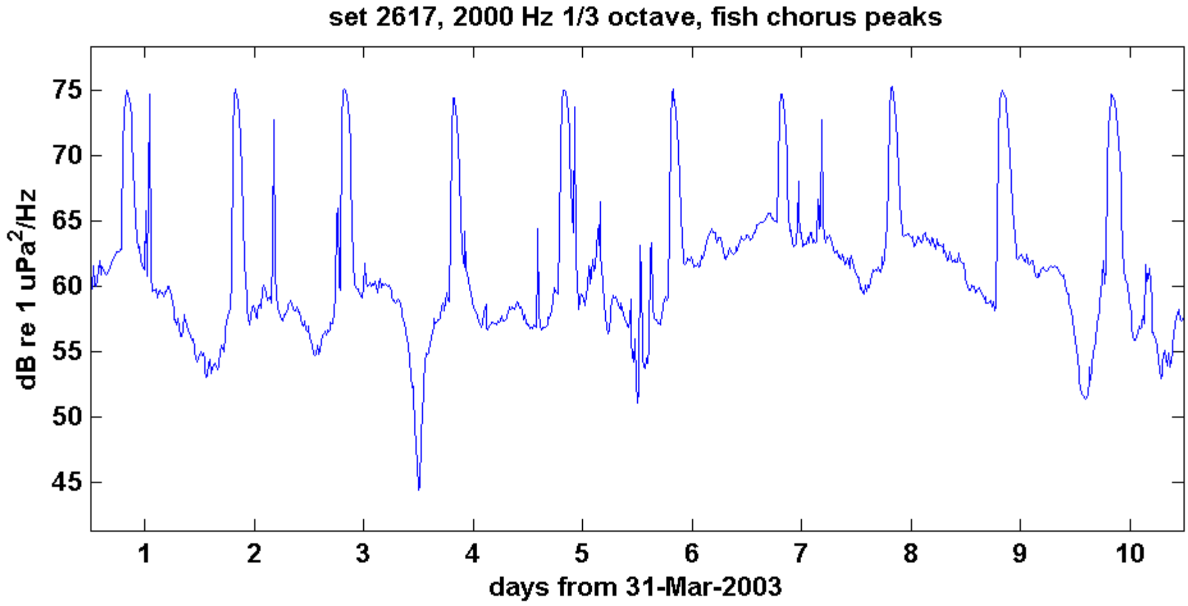


Figure 29: Regular rise in sea noise produced by fish choruses, as evident by the 2 kHz 1/3 octave recorded from the Perth Canyon. The spikes each evening are from fish choruses.

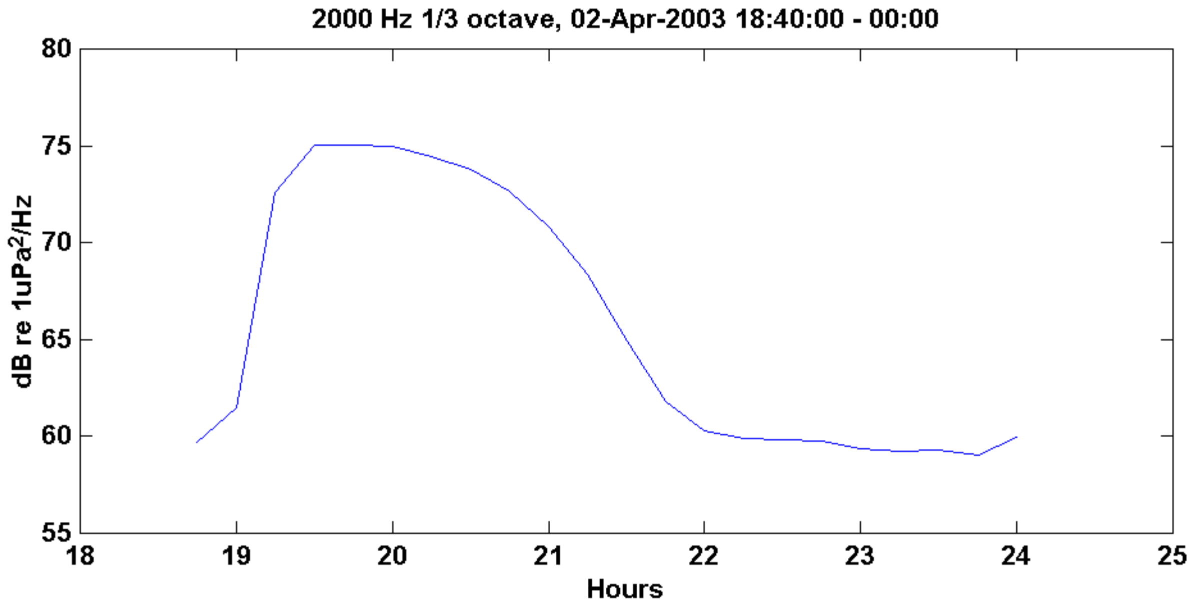


Figure 30: Rise in level of the 2 kHz 1/3 octave through a single evening.

During the 2004 Southern Surveyor trip six net tows were made with an Engel pelagic fish trawl (60 m spread, 10 m opening) in an effort to catch chorus sources. In all six tows, fish of the family Myctophidae dominated catches. These were comprised of primarily two species of ~ 80-100 mm length, probably *Neoscopelus sp*. and *Diapus* sp. The Engel net was not designed to catch Myctophidae, the mesh size in leading panels was far too large, never-less they were the main component of Engel catches from depths below 50 m (a few surface pelagic fish were also caught). There were no fish captured of any description other than the Myctophidae which were capable of producing the choruses heard. This evidence, the finding of similar chorus from nocturnally active zooplanktivorous fish in tropical waters (McCauley, 2001), plus early anatomical studies suggest that the choruses heard around the Canyon were produced by fish of the family Myctophidae. The Myctophidae caught had been feeding on krill. An image of a *Neoscopelus* sp. with its stomach opened and containing krill is shown on Figure 31.

These fish choruses raise some interesting questions about the foraging strategies of pygmy blue whales. To forage successfully the whales need to find and target regions with dense aggregations of krill. The Myctophidae fish also need to target dense aggregations of macro-zooplankton, including krill, to forage on. The two sources act at different scales, there are comparatively large numbers of fish foraging over small foraging ranges, while there are much fewer whales acting over ocean basin scales. If the Myctophidae fishes produce the evening choruses heard, and target krill, as indicated by their gut contents, then it may be that their distribution and thus chorus levels, would reflect the distribution of krill. Since the fish choruses are spatially diffuse over large scales, then they can transmit for very long ranges as the loss of sound on moving away from the fish chorus is comparatively low at approximately cylindrical spreading, until the dimensions of the chorus are reached. For example McCauley and Cato (2000) report picking up evening choruses into the tens of km from active choruses in comparatively shallow waters (< 50 m depth) in the Great Barrier Reef lagoon. Thus the Myctophidae evening choruses may act as acoustic 'beacons' on the scales of many tens of km, indicating potential rich regions of macro-zooplankton and thus potential krill aggregations.

Figure 31: Image of Myctophidae, believed *Neoscopelus* sp., collected from an Engel tow during SS0202 cruise into the Canyon. Several krill were evident in its gut.

To test this three drifts of sea noise loggers were made over five evenings across the Canyon during the SS0204 cruise in early 2004 to measure spatial patterns in choruses. The location of the drifts and the loggers during the choruses each evening is shown on Figure 32 while the measured choruses through the five evenings are shown on Figure 33. Because of deployment / recovery schedules or the proximity of the *Southern Surveyor*, some sections of the chorus on two evenings was not useable. There was a slight difference in level for the recording made over the canyon gulley, or the greatest distance from the Canyon rim, where the densest aggregations of macro-zooplankton (including Myctophidae fishes) was found (see section 4.4.4). However this difference was too small to be statistically meaningful, and indicated that sampling across a larger spatial scale is required to show if the fish choruses do show large scale spatial patterns which may reflect the local macro-zooplankton aggregations.

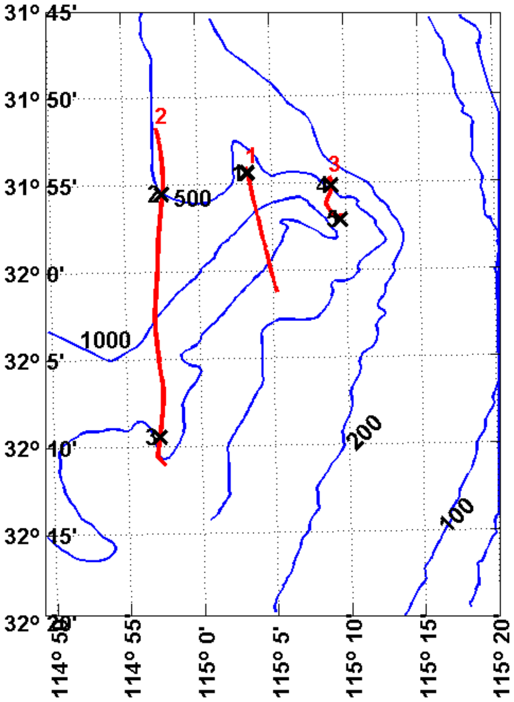


Figure 32: Location of the three drifts of sea noise loggers during the SS0204 cruise. The location of the sea noise loggers at 22:30 each evening are shown by the crosses.

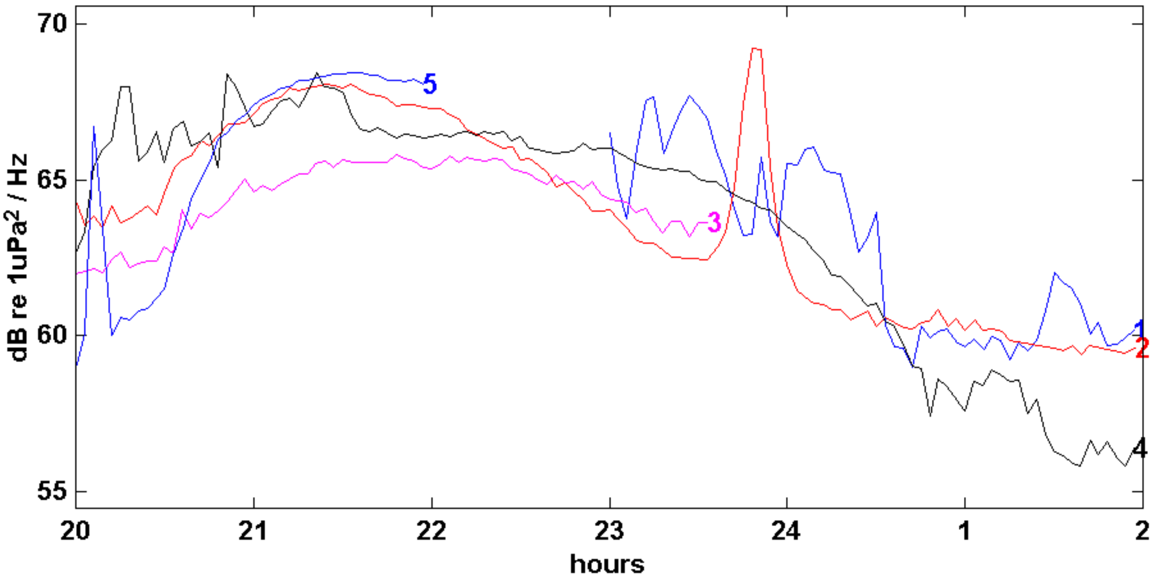


Figure 33: Measured 2520 Hz 1/3 octaves through time over each evening of the fish choruses from the SS024 cruise. Numbers on each line represent the locations shown by the crosses on Figure 32.

4.4.5) Analysis of pygmy blue whale movements in the wider spatial context

Long term sets of sea noise samples have now been collected from the Otway Basin, Cape Leeuwin, Perth Canyon, Exmouth, and NW of Broome. All except the Broome data set have been checked for pygmy blue whales, although a perusal of stacked spectra (seven day batches) and likely looking batches has not yet revealed any pygmy blue whale calls in this data set. The presence of pygmy blue whales as indicated by the mean 24 hour average of the number of distinct callers (all except Cape Leeuwin which is the 24 hour mean of the number of detections/hour), is shown on Figure 34 and the locations of data collections sites on Figure 35.

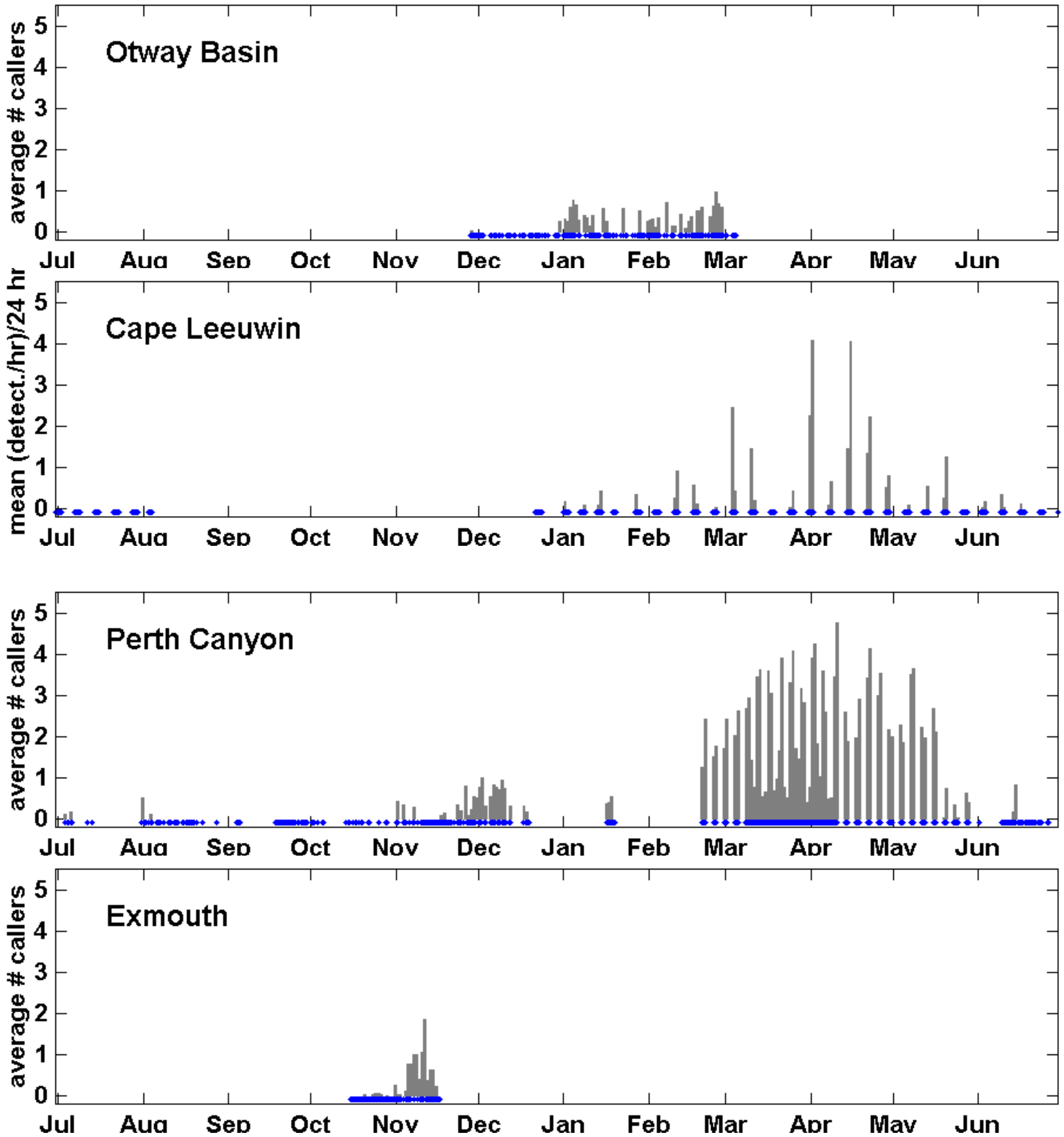


Figure 34: Counts of pygmy blue whale individual callers averaged over a 24 hour period from the Otway Basin, Cape Leeuwin, Perth Canyon and Exmouth. The under lying dots represent sampling days.

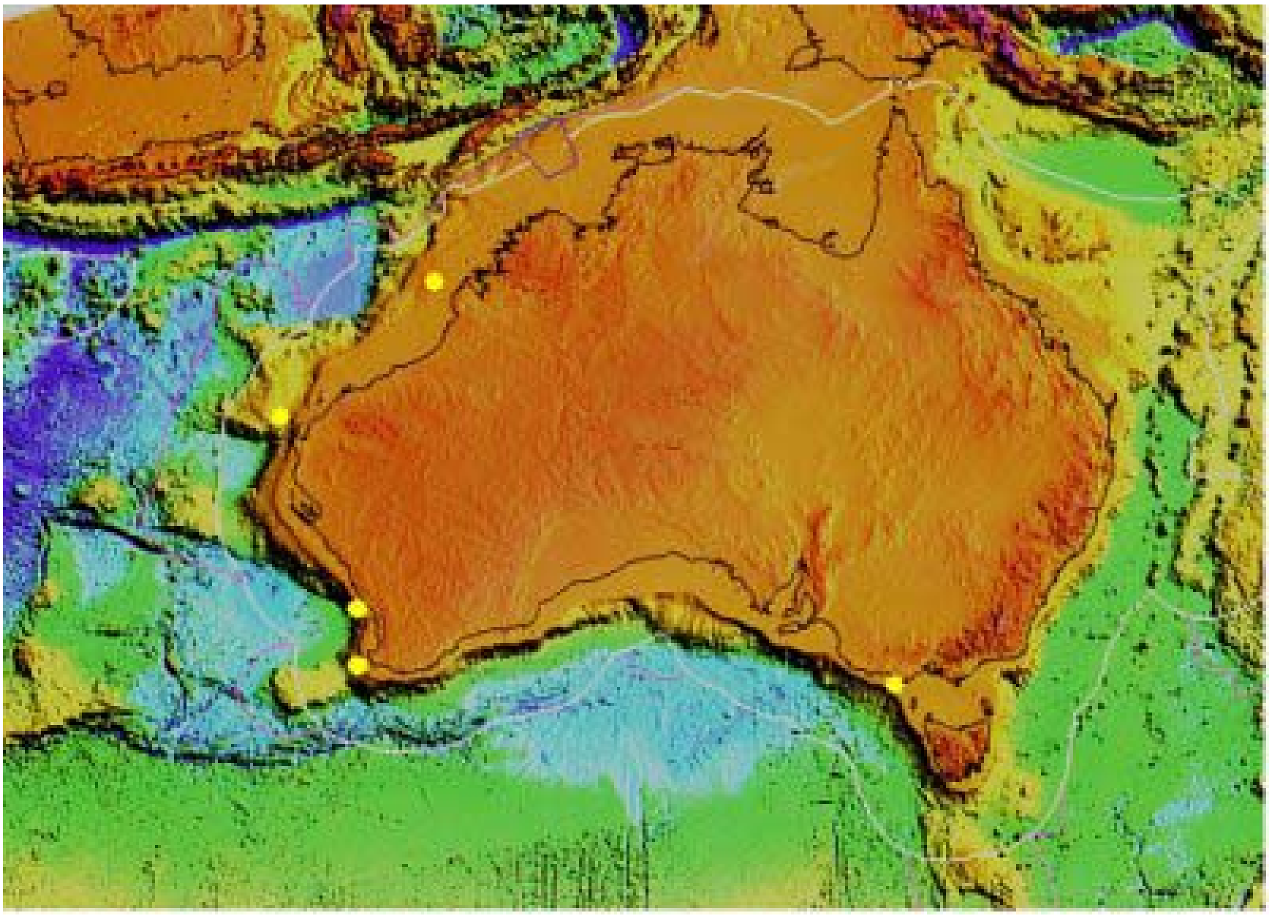


Figure 35: Location of sites from which long term sea noise data sets are available (image of Australia from GeoScience Australia).

The east Australian pattern of pygmy blue whale presence is similar to that of the west coast as can be seen on Figure 34 and from aerial survey data collected by the Deakin University blue whale group (P. Gill pers. Comm.). Where the animals which visit the Otway Basin region arrive from is not known. Pygmy blue whales are known to occur along the Queensland coast.

Along the west coast there is some evidence of an influx of animals from the north early in the ‘season’ (Nov) as indicated by the pulse of animals moving past Exmouth in early Nov. In this recording set animals were found to be moving past the logger as evidenced by a steady increase in received signal level, a plateau in level then a steady decrease for individual animals. Calling animals seemed to move past in a stream with individuals separated by approximately 1.5 days. It was not possible to determine their direction of travel. The available information on the timing of animals moving past Exmouth and arriving off the Perth Canyon fits in with a southerly migration down the west coast. The Perth Canyon and Cape Leeuwin data sets have similar trends in peak visitation times, with maximum animals present in Mar to May. Where these animals have originated from is not known. It is possible for us to determine the direction of travel for animals moving past the Cape Leeuwin hydrophones and during the northern tail of the 2003 Perth Canyon season. This will give further clues on the movements of animals.

4.5) Krill and macro zooplankton sampling

Pygmy blue whales were observed to be consistently feeding on krill in the Perth Canyon. The presence, abundance and distribution of krill were believed to be major factors in determining the numbers of whales whom used the Canyon, their visitation time and the fine scale patterns of where they were found. Hence effort was put into sampling krill directly using plankton nets and in obtaining backscatter estimates of krill location and biomass using echo sounder techniques. The predominant species of krill so far identified from the Canyon is *Euphausia recurva*, although other species have been found in lower numbers. Specimens were collected up to 30 mm in total length, although a typical size was more of the order of 10-15 mm. Images of krill collected from the Canyon are shown on Figure 36.

Figure 36: Images of *Euphausia recurva* collected by plankton net from the Perth Canyon (courtesy of Chris Van Etten). Typical krill ranged from 10-15 mm total length.

It was intended for a PhD student based at Curtin to undertake the krill and macro-zooplankton work. The student began the project and collected material, but withdrew in mid 2004. A considerable amount of material has been collected. A survey of the spatial extent of krill and macro-zooplankton has been carried out on this data set, but further analysis, including biomass estimates, biological interpretation of physical samples collected and the linking of macro-zooplankton with productivity and oceanography, is pending.

Echo sounder data was collected from: a Simrad EQ60 (38 / 200 kHz transducers): Simrad ES60 (70, 120 and 200 kHz transducers); Simrad EA500 (12 kHz), and Simrad EK500 (38 kHz). The EQ60 was mounted on vessels used to deploy and retrieve acoustic moorings and occasionally on the whale watch vessel *WhaleSong*. The ES60 was used on the WA Fisheries vessel RV *Naturaliste* in the Canyon, and the EA500, EK500 and ES60 were mounted on the CSIRO National Facility vessel RV *Southern Surveyor*, which visited the canyon over three periods, in August 2003, and during two cruises in January-February 2004. The *RV Southern Surveyor* ran a dedicated cruise into the Perth Canyon over seven days from 29-Jan-2004 to 4-Feb-2004 (referred to as SS0204 here). Most of the data presented here is taken from this cruise. Physical sampling of krill and macro-zooplankton was made using an EZ or bongo plankton net during RV *Southern Surveyor* and the bongo net only on an RV *Naturaliste* cruises. The EZ net had ten electronically controlled multiple opening nets.

The echo sounder data highlighted a number of features of the macro zooplankton in the Canyon. These were:

- a strong deep scattering layer between 300-500 m depth and extending deeper in parts of the Canyon
- the expected post–dusk and pre-dawn vertical migrations of this scattering layer upwards and downwards respectively
- the tendency for zooplankton aggregations to form just underneath the Leeuwin current
- in summer, the formation of dense 'balls' of krill underneath the Leeuwin current (200-300 m depth) along the Canyon rims at its eastern end, during daytime
- the dispersion of these 'balls' at night time and the formation of large moderately dense patches between the surface and 300 m depth at night time, again over the rims of the Canyon at its eastern end.

To illustrate the spatial patterns of macro-zooplankton around the Canyon the 12 kHz EA500 S_v data (S_v = volume backscattering, which is proportional to the number of scatterers / m^3 and their target strength at that frequency), collected from the RV *Southern Surveyor* over 29-Jan to 04-Feb, was extracted and analysed. Although 12 kHz is not an optimal frequency for obtaining returns off small krill, it did consistently return patches which were verified as krill, either by passing the EZ plankton net through them or from comparison with higher frequency data. The advantage of using the 12 kHz records was that they sampled the full water column, whereas the 70, 120 and 200 kHz sounders were limited in range to < 500 m depth by the hardware sampling regime used. The 120 and 200 kHz sounders were further compromised in that due to higher absorption they have an effective range of < 300 m water depth. The RV *Southern Surveyor* 38 kHz records were noisier than the 12 kHz, hence the 12 kHz records have been used to highlight the spatial trends.

An example of the difference in day-night structure of the macro-zooplankton S_v values from the EA500 records run over the transect down the Canyon slope are shown on Figure 37. The location of where these two runs were made is shown on Figure 38. The daytime records were made over 15:17:29 – 16:30:00 and the night time sections over 22:18:12 – 23:26:46. The presence of 'balls' of krill in the daytime just below 200 m depth can be seen. The EZ plankton net was run through these patches confirming that they were comprised of krill. During night time the deep scattering layer had moved upwards and formed moderately dense patches between 65 and 210 m depth (note that due to noise generated by wave action and the vessel, the top 50 m has been excluded from each plot on Figure 37).

The dense 'balls' seen in Figure 37 were consistent along the Canyon rim. They had typical horizontal scales of from 80-250 m and vertical scales of around 20-50 m.

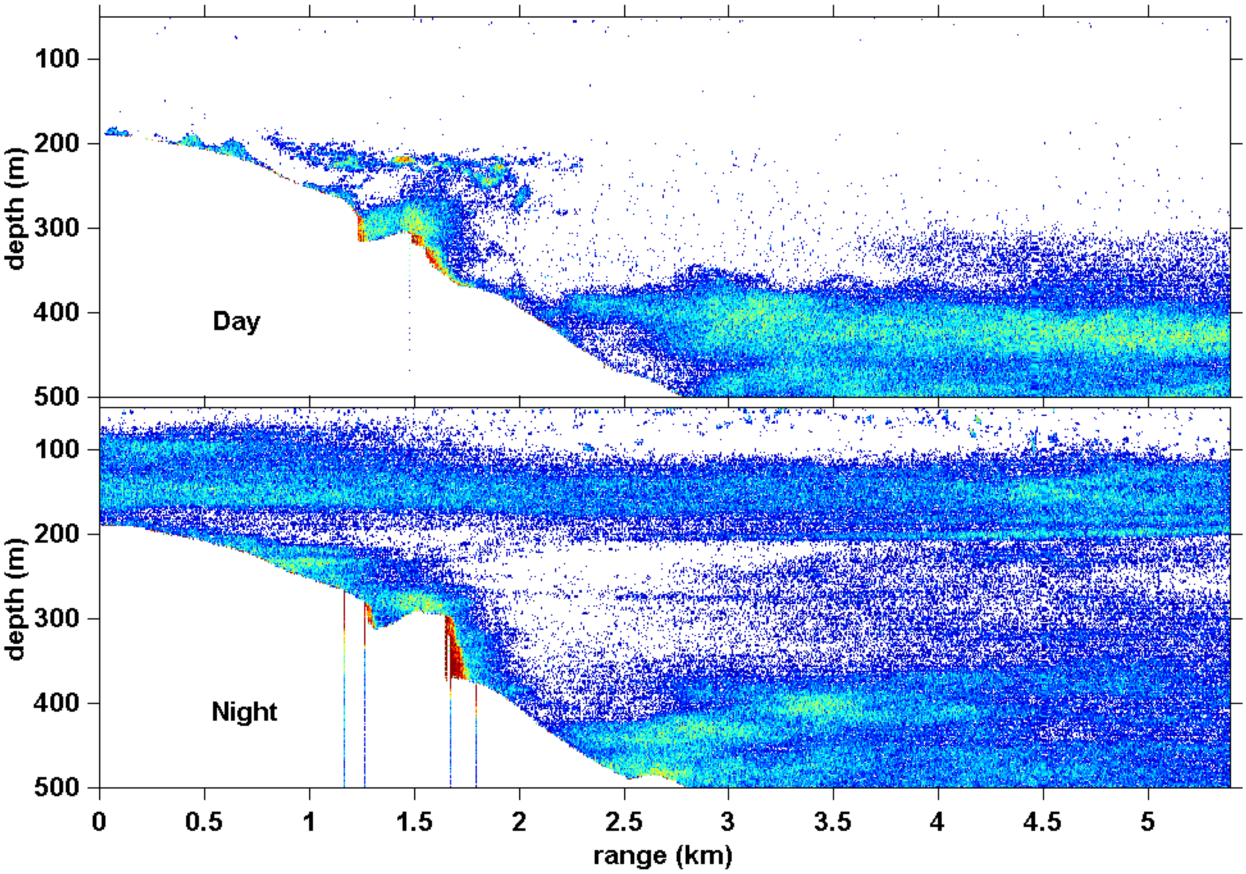


Figure 37: Volume backsattering (*Sv*) at 12 kHz taken on the 03-Feb-2004 in the day and night over the same transects, showing: daytime patches of krill at base of Leeuwin current around 200 m depth in the daytime and dispersion of macro-zooplankton into shallow waters at night time. The range, depth and colour scales of the two images are identical. The *Sv* values for each pass have been 'straightened' or mapped onto a linear track.

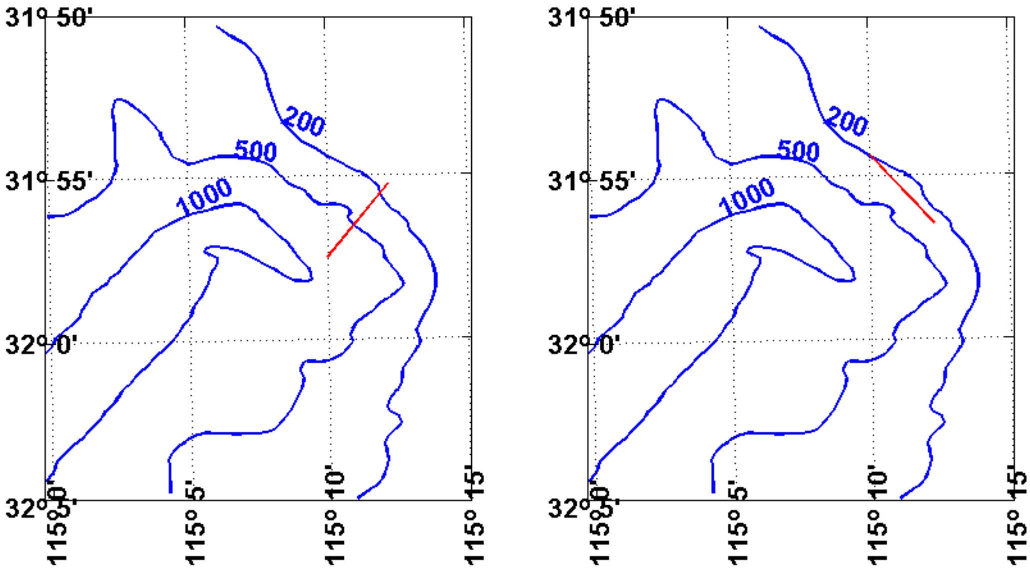


Figure 38: **(left)** Track down the Canyon slope over which the day-night echo sounder runs shown on Figure 37 were made**. (right)** track to NW along which the patches shown on Figure 39 were seen.

A further example of the ‘balls’ of krill which formed along the Canyon rim in daytime is shown on Figure 39, with its track shown on Figure 38 (right). Some interference from the vessels fishing echo sounder can be seen on Figure 39 as the near vertical lines. Several dense balls can be seen just below 200 m depth, with one shallow patch near the end of the run.

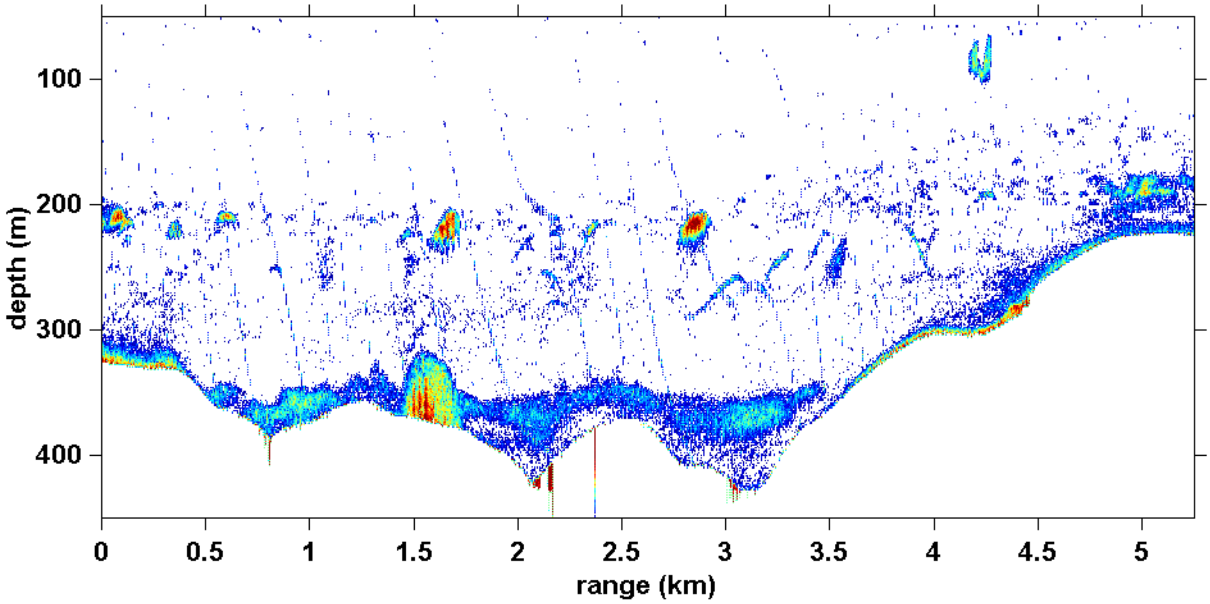


Figure 39: Further example of daytime krill ‘balls’ seen along the canyon edge. Note the vertically oriented lines are interference from the fishing echosounder.

The *Southern Surveyor* Fishing Master commented that the hemispherical patch near the bottom, 1.5 km into the run, resembled squid balls he had seen while deep sea fishing in New Zealand waters. The Engel, pelagic fish trawl was towed over the section shown on Figure 39 from ~ 2 km along the track, at approximately 6-30 m off the bottom, with only Myctophidae fish caught.

To interpret the spatial patterns of macro-zooplankton, all the 12 kHz data collected by the *Southern Surveyor* on the 29 & 30-Jan and the 2 & 3-Feb was assembled and split into day and night time data sets, from which the ‘mean’ volume backscattering (S_v) value was calculated at each spatial point in two depth strata. Data was not used from the 31-Jan and 01-Feb due to rough weather biasing the data. Day and night were taken as 30 minutes either side of the civil twighlight time for the appropriate day (calculated for 32^o S 115^o E in WST) to allow for the vertical migration travel time. Thus day was dawn plus 30 minutes to dusk minus 30 minutes, while night was dusk plus 30 minutes to dawn minus 30 minutes. Depth strata used were 50-380 m and 380–600 m, which encapsulated the day-night differences in the deep scattering layer. The echo sounder records showed targets below 600 m depth but at this depth it became questionable wether the targets were real or noise only, plus any macro-zooplanton at these depths would be beyond the normal diving range of pygmy blue whales. One pygmy blue whale was observed feeding at almost 500 m depth on a 38 kHz sounder record taken from *WhaleSong*. The mean S_v value over the appropriate depth range, was calculated at each spatial point only for values > -ve 100 dB. This removed the extremely small values which would bias the calculation of mean values. Spatial points at which no S_v values in the depth vector exceeded this threshold were set to -ve100 dB. The resulting 2D sets of values (x, y, S_v in a defined depth bracket) were then used to grid a regular spaced spatial array. The resulting grid of values for daytime in the 380-600 m depth range is shown on Figure 40, along with the location of whales sighted from visual surveys over the 28 Jan to 04 Feb, and vessel tracks from which the daytime mean S_v values were obtained. It can be seen that the densest aggregations of macro-zooplankton occurred along the base of the Canyon rims and along its axis, and that the whale locations corresponded well with the dense macro-zooplankton regions. The trend for dense layers of macro-zooplankton to form along the edge of the 400-500 m contour during daytime, as seen on Figure 37 and Figure 40 was consistent over the 2-3 Feb.

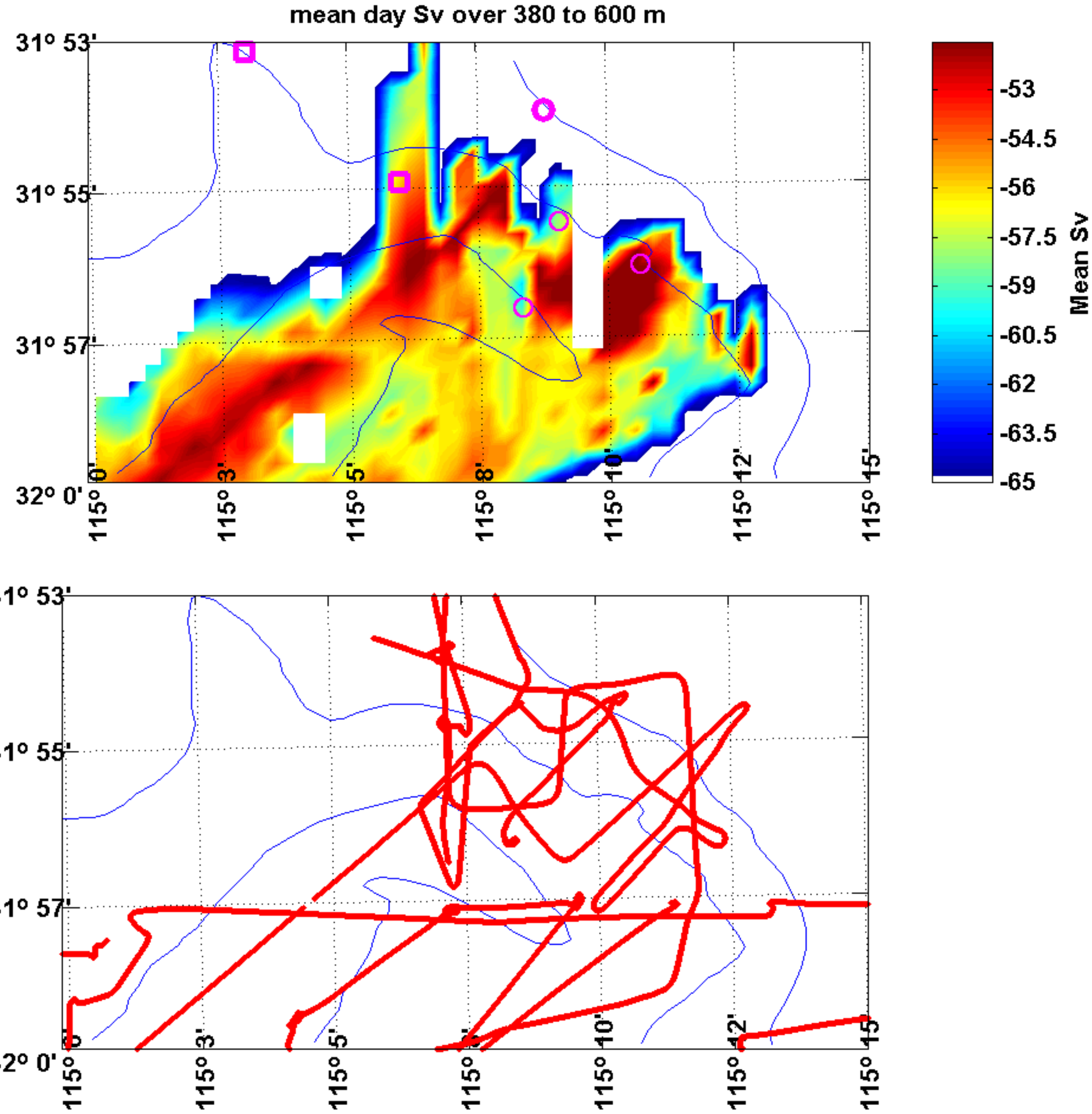


Figure 40**: (top)** Gridded mean daytime Sv, or volume backsattering strength over the depth range 380-600 m, taken with the EA500 12 kHz sounder from the RV Southern Surveyor in the Perth Canyon, over 29-Jan-04 to 03-Feb-04. Daytime was taken as 30 minutes after or before of local, civil twilight time. Note that calculated values below the minimum Sv shown (-65 dB) were not shown on the plot**.** The circles represent pygmy blue whale sightings made from the small vessel and the squares from an aerial survey, over the period 28-Jan to 04-Feb. The line thickness represents the number of whales sighted. **(bottom)** The daytime vessel tracks from which the grid was made.

The calculated mean S_v value for the shallow daytime depth strata (50-380 m) was too sparse to grid effectively (the 'balls' as seen on Figure 37 and Figure 39 were too small to effectively interpolate between). This indicated that during the daytime, although some dense 'balls' of krill were present along the Canyon rim, the densest (by biomass) region accessible to the whales for feeding would have been along the deeper margins of the Canyon rim (380-500 m depth), as can be seen on Figure 40 and Figure 37 (top).

The plot of mean S_v for the night time situation in the shallow depth strata (50-380 m depths), after the macro-zooplankton had migrated high into the water column, is shown on Figure 41. Of a night there was a clear concentration of shallow macro-zooplankton along the Canyon rim. Note that these dense night time patches never extended far into regions with a water depth of < 200 m.

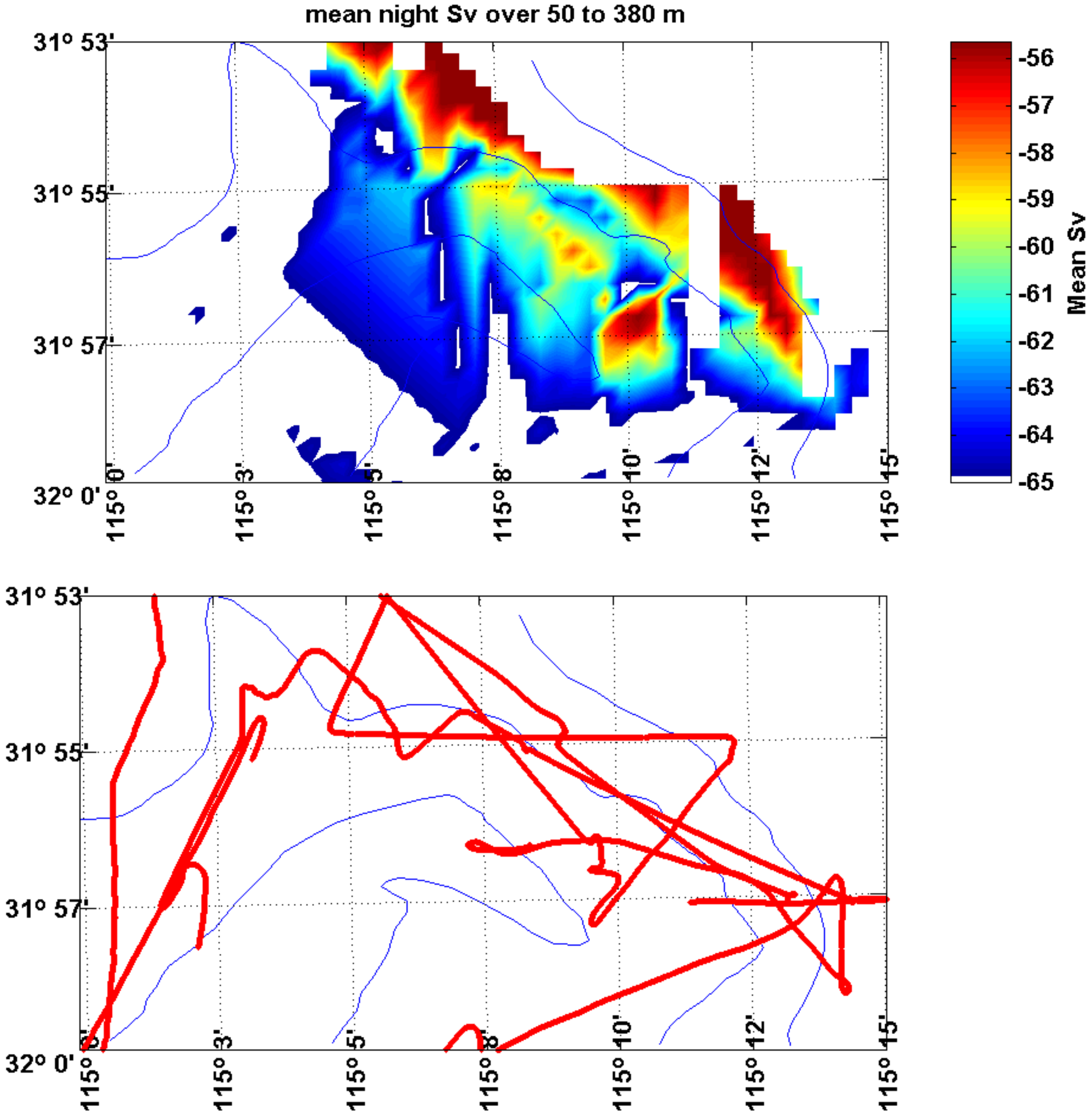


Figure 41: **(top)** Gridded mean night Sv, or volume backsattering strength made over 50-380 m depth, taken with the EA500 12 kHz sounder from the RV Southern Surveyor in the Perth Canyon, over 29-Jan-04 to 03-Feb-04. Night was taken as 30 minutes after or before of local, civil twilight time. Note that calculated values below the minimum Sv shown (-65 dB) were not shown on the plot**. (bottom)** The nightime vessel tracks from which the grid was made.

Thus for the period intensively sampled, the 29-Jan to 04-Feb, there were distinct spatial patterns in the distribution of macro-zooplankton, which during the daytime correlated with sightings of pygmy blue whales. There were distinct differences between the vertical day and night time macro-zooplankton structure. This implied that whale feeding strategies may differ, with in the daytime whales targeting either small shallow balls of krill (100's of m scale) just below the Leeuwin current or the deep scattering layer at 400-500 m depth, while at night time they could target the large (km scale) dense patches which formed from 50-300 m depth along the Canyon rims.

The spatial patterns shown for the macro-zooplankton distribution reflect those at the sampling time. At other times during a season different spatial patterns may occur, in response to different oceanographic forcing factors. We have seen differences in the fine scale locations of foraging whales between years, thus it is probable that different patterns in the optimum locations of macro-zooplankton do occur from that described. We have also yet to link the spatial patterns described here to the concurrently sampled oceanography and productivity measurements made during the SS0204 cruise.

4.6) Oceanography of the Perth Canyon

A detailed study of the circulation of the Perth Canyon oceanography is being carried out by a PhD student, Susan Rennie. This work is expected to be completed in 2005. Susan has collected an enormous amount of information on the Canyon's physical properties, including:

- sets of data from vertical strings of temperature logger set around the Canyon rims for protracted periods
- two cruises of the RV *Southern Surveyor* through the Canyon, including a dedicated cruise in Jan-Feb 2004 where 12 hour per day for six days was set aside for physical oceanographic measurements
- a detailed oceanographic numerical model of Canyon circulation which will be used to assess the Canyon's response to different wind forcing.

The study has resulted in very complex data sets. Some of the techniques used on the *Southern Surveyor* involved exotic hardware (lowered ADCP for example, to give full water column 3D current profiles). The modelling in fine detail of a submarine Canyon has not been done previously. Most Canyon models used very simplified bathymetry profiles and this model also has an unusual poleward flowing, eastern boundary surface current (Leeuwin).

Susan has prepared the following short summary of some aspects of the program. This data analysis is currently in progress.

4.6.1) Temperature loggers

The temperature logger data set covers parts of 2002-2004 and is listed in Table 11. Of six moored strings of loggers, one was at the head of the canyon (mooring 2) and the other five were on a 500 m plateau on the north rim of the canyon (Figure 42).

A summary plot showing seasonal patterns of temperature shifts from the temperature logger strings is shown on Figure 43. The temperature logger strings indicate the existence of a mixed layer and thermocline, which influences the temperature loggers at 100 m and above. The greatest variations were seen where loggers were in the thermocline, and for a fixed depth could theoretically change by up to 6-8 °C in one day (thermocline gradients were 0.1-0.2 °C m^{-1}, so water could rise up to 80 m in one day.) The greatest recorded change over 24 hours was 5 °C. The least variation seen in the loggers was for the bottom or in the shallow well-mixed layer. Bottom loggers only showed small, slow changes in temperature, but conformed in these trends with the shallower loggers.

Frequently periodic variations appeared in the data, at different depths but not often right through the water column. Some, with a period of one day, were induced by a sea breeze. Others, which had a period closer to 0.9 or 0.8, were probably related to the inertial period at that latitude.

There were occasional, brief (<1-2 d days) intrusions of cool water. These extended right through the water column and usually lasted for one day. The cause hasn't been identified and does not directly correlate with wind or weather events.

Table 11: Details of temperature logger data sets.

#	Latitude Longitude	Start Time	End Time	Approx. logger depth (m)	Bottom depth (m)	Interval (min)
2	31° 58.206' S 115° 12.601' E	16/1/2002 17:50	13/6/2002 09:20	75, 300, 370, 485	500	30
5	31° 54.262' S 115° 01.659' E	18/1/2002 14:30	21/7/2002 09:00	50, 100, 200, 300, 450	450	30
9	31° 53.879' S 115° 00.227' E	14/10/2002 09:40	20/12/2002 12:30	50, 100, 200, 300, 400, 450	450	15
10	31° 54.142' S 115° 00.932' E	18/2/2003 12:00	10/6/2003 11:00	40, 90, 190, 190, 330, 440	440	30
13	31° 52.464' S 114° 59.362' E	10/6/2003 8:40	29/9/2003 16:00 17/8/2003 15:30*	*250, 300, 350	452	20
15	31° 50.752 S 114° 59.899 E	26/2/2004 17:00	3/8/2004 12:50	186, 356, 426	426	30

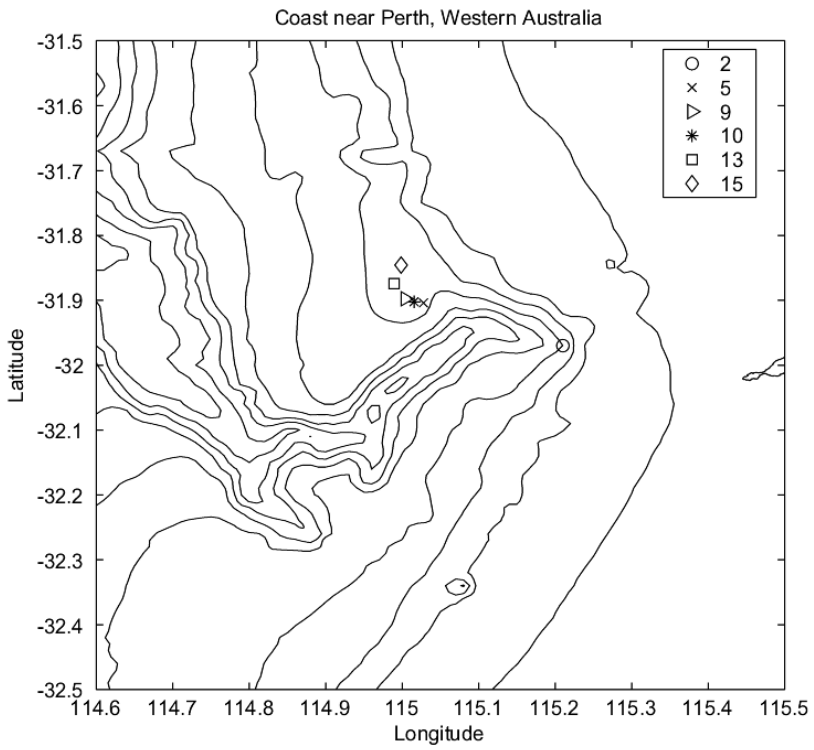


Figure 42: location of temperature logger strings set around the Canyon.

Strong winds and storms produced major changes in the water column that lasted for days as the weather system passed. The effect included a combination of surface (to 200 m) mixing due to strong winds (with re-stratification occurring as the wind relaxed) and intrusions of colder water into the water column which cooled the bottom layers.

The general temperature and profile depended on the location of Leeuwin current. As this current shifted, the temperature rose or fell slowly, by a considerable amount. However, these changes were of the same magnitude as more rapid changes.

Mooring location had a big impact on what variations were seen, which is possibly due to the canyon controlling the 'typical' size of features. This was indicated by the very different records from moorings 2 and 5.

4.6.2) RV Southern Surveyor trips

Two field trips on the NFRV *Southern Surveyor* included data collection at the Perth Canyon. The first, SS09/2003 (24/10/2003-9/11/2003) led by Charitha Pattiaratchi, included two transects of the Perth canyon during the cruise that extended from the Abrolhos Islands to Cape Leeuwin. One transect followed the axis of the canyon from 3000 m and the other cut across the axis at 115.02 E. An example of the temperature structure along the Canyon axis and showing downwelling along the Canyon rim, is shown on Figure 44.

The second cruise, SS02/2004 (29/1/2004-4/2/2004) led by Rob McCauley, focused only on the canyon and for the shift between 2 a.m. and 2 p.m. was devoted to physical oceanographic data collection.

Both cruises included CTD casts which, besides temperature, salinity and pressure, measured fluorescence, dissolved oxygen and light, and collected samples at a range of depths for analysis of nitrate, phosphate and silicate. Additionally SS09/2003 measured transmission, and SS02/2004 used a Lowered ACPD current meter. Both cruises also used the ship's ADCP, which measures current continuously to 200 m or so.

At this time all processed data has been received from the CSIRO except the CTD data from SS02/2004 and the unprocessed LADCP data. Data analysis and its interpretation is still in progress.

4.6.3) Modelling

Development of an ocean model of the canyon has continued using ROMS (Regional Oceanographic Modelling System). At this time the model has been developed to a satisfactory stage to begin analysis, and runs with additional wind forcing.

To get the model running, the bathymetry was extended to between 28° S and 36° S, with modification to the north and south bathymetry to straighten the shelf slope. The model must run for 200 days to reach a quasi steady state so that analysis can begin.

The model replicates the Leeuwin current, and an undercurrent which flows northward. Cyclonic and anticyclonic eddies develop, with the canyon being an initiation point for anticyclonic eddies that migrate south and offshore. Within the canyon, it is common to see an anticyclonic eddy form over the canyon, or a cyclonic eddy to form in the head of the canyon. The anticyclonic eddies form from meanders; as the Leeuwin Current breaks away from the shelf slope, it turns onshore and curls back in on itself to form the eddy. The cyclonic eddies found over deeper water show maximum horizontal velocities at medium depths (around 300-500 m depth) and may reach much deeper.

Small cyclonic eddies form in the head of the Canyon where there is an anticyclonic eddy further offshore. Otherwise cool core cyclonic eddies can form when Indian Ocean water (offshore) is entrained and trapped by the Leeuwin current.

These eddies are a major feature of the circulation of the Canyon. As an example, the formation of an eddy is shown on Figure 45. The resulting anticyclonic eddy over the Canyon results in water being pumped down near the canyon head (last panel of Figure 45). This downwelled water may flow down and along the Canyon axis although as yet we do not know what depth this water penetrates to. It may also result in water being upwelled along the sides of the Canyon axis (to replace the downwelled water). Upwelling does occur at the head of the Canyon when the small cyclonic eddy forms at the head of the canyon, while there is a larger anticyclonic eddy over the canyon. This cyclonic eddy may occur within the canyon and not above the rim.

Any upwelled water may act to transfer nutrients from deeper water into the shallower water photic zone. It also may be that the persistent eddies seen over the Canyon entrain nutrients or macrozooplakton within the eastern Canyon end, although we have yet to test this hypothesis.

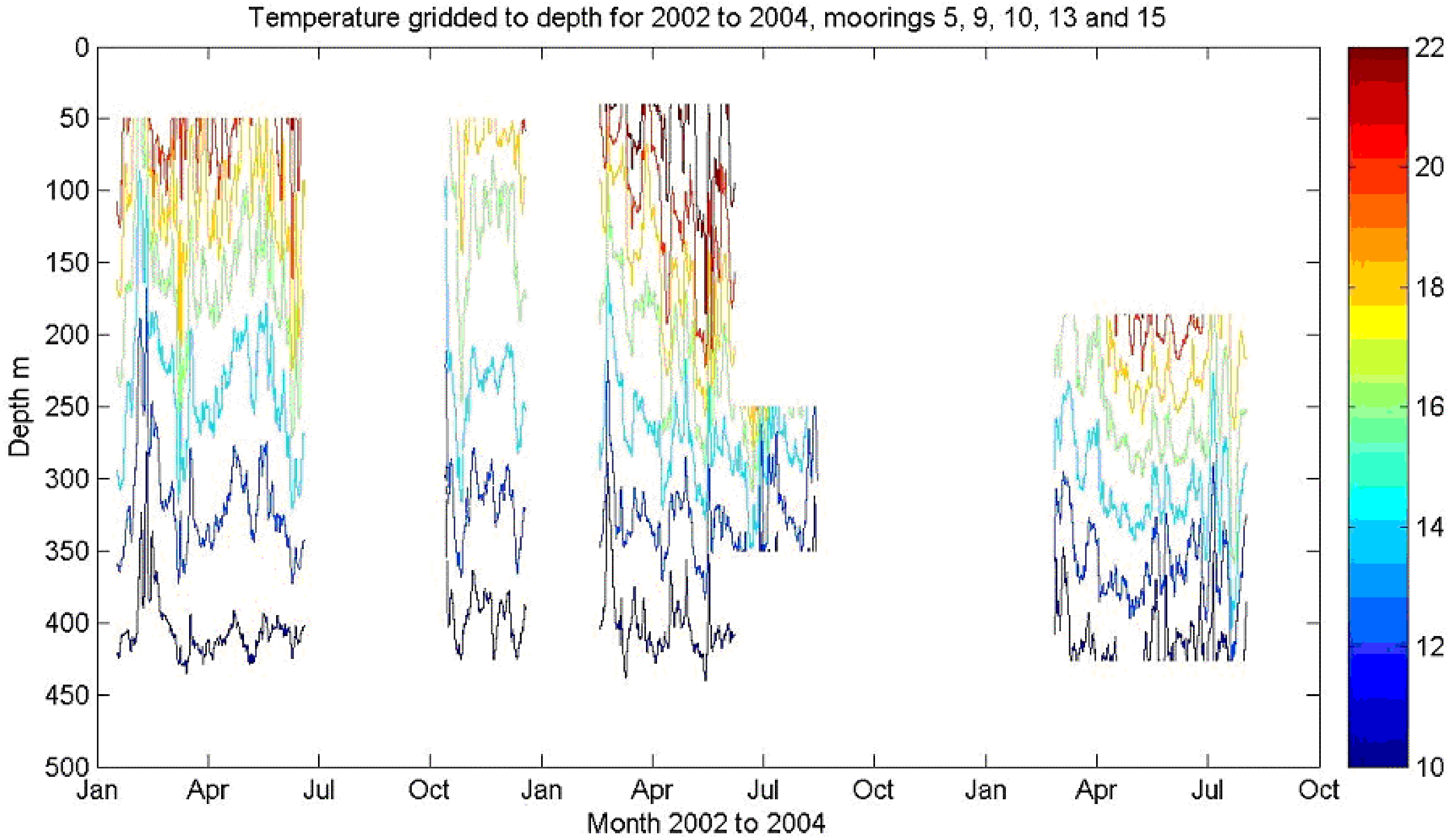


Figure 43: Temperature logger data from the plateau region The colour represents temperature.

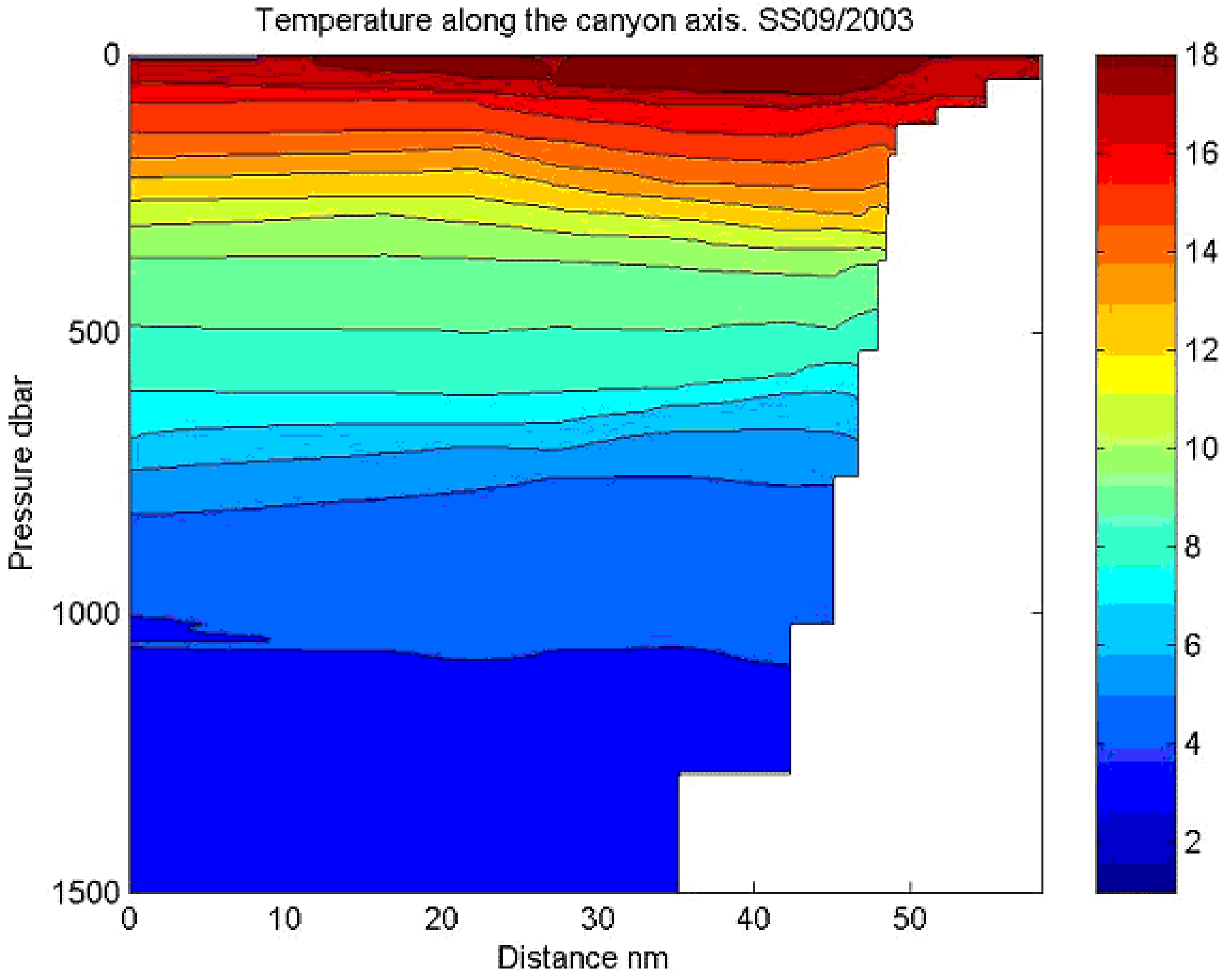
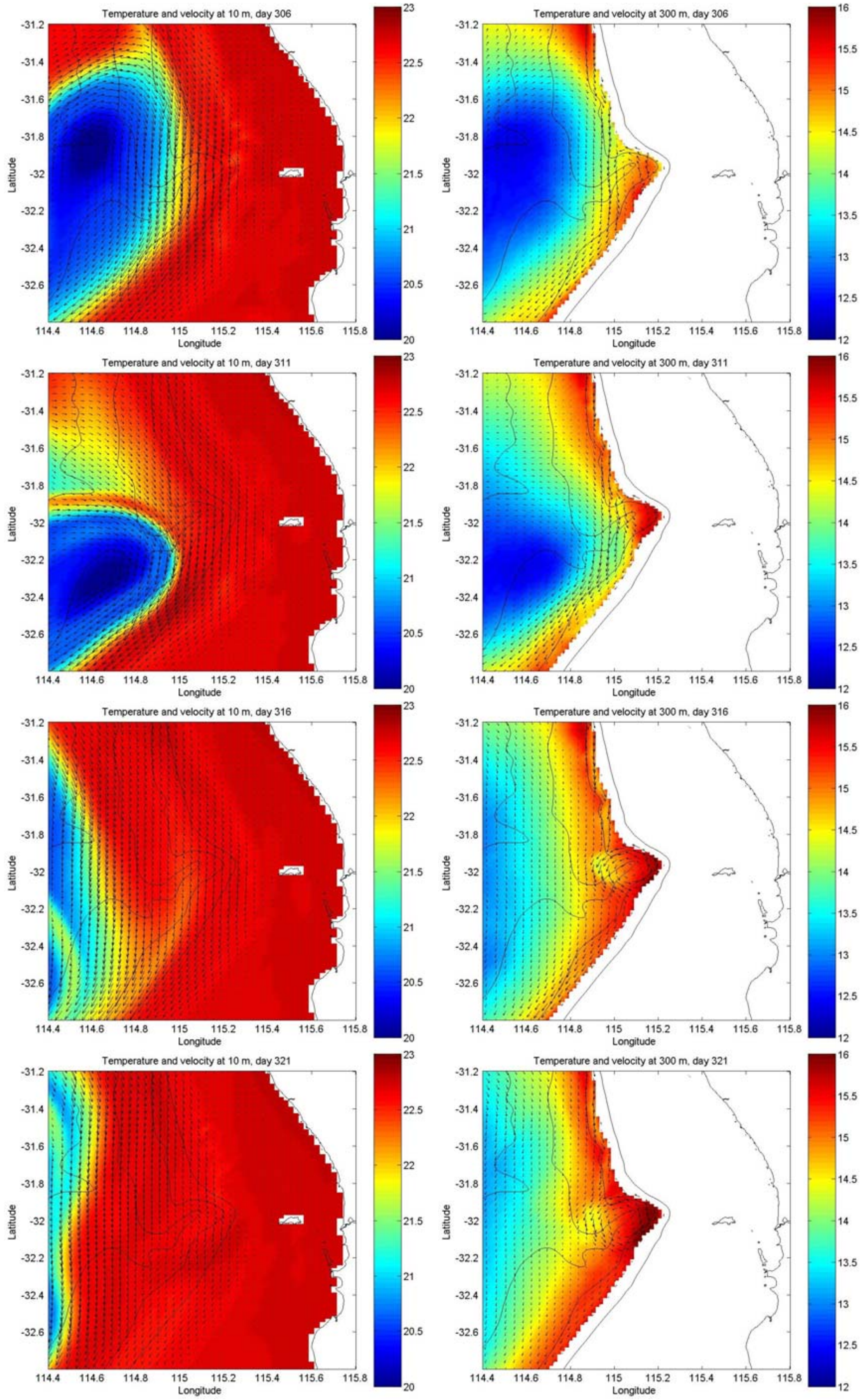


Figure 44: Temperature profile along the Canyon axis as seen in Sep 2003. Some downwelling was evident along the Canyon rim.

Figure over page:

Figure 45: Panels of developing cyclonic eddy over the Canyon (two depths, 10 m and 300 m shown each day in five day blocks). The final panel at 300 m depth shows a strong eddy focussed over the Canyon head, with water being pushed down the Canyon head and pushed up to the north of the Canyon axis.



Temperature and velocity at 10 m, day 306
Temperature and velocity at 300 m, day 306
Temperature and velocity at 10 m, day 311
Temperature and velocity at 300 m, day 311
Temperature and velocity at 10 m, day 316
Temperature and velocity at 300 m, day 316
Temperature and velocity at 10 m, day 321
Temperature and velocity at 300 m, day 321
Latitude
Longitude

5) Follow up work for the Perth Canyon

Suggestions for follow up work are presented in Table 12.

Table 12: Key questions relating to Naval interactions with great whales along the WA coast and in the WAXA in particular. The priority is given with respect to management of Naval operations and not management of great whale populations. (PBW=pygmy blue whales)

Question	Use to Defence	Priority	Techniques to address
1) Understand movements of PBW outside of Canyon – particularly remainder of WAXA, Lancelin, Cape Naturaliste	Delineation of migratory corridor/s, (eg. offshore Lancelin) and identification of additional concentration areas (eg. Cape Naturaliste)	High	Passive acoustic tracking grids, visual surveys, satellite tagging
2) Usage of Canyon / WAXA by other threatened or endangered whales – particularly true blue whales, sperm whales and beaked whales	Has a high conservation value & importance for planning	High	Passive acoustics & visual surveys, plus biopsy / genetics
3) Definition of source and calling habits of "*bioduck*"[1]	Submarine operations	High	Passive acoustics & visual surveys
4) Determine how Naval operations influence PBW and other great whales	Management of operations and short term mitigation	High	Passive acoustics & visual surveys, analysis of existing data sets
5) Long term PBW pop size in the Canyon and breeding parameters (ie. calving frequency / intervals)	Need to predict numbers and refine within season movements / abundance for future operations and establish '*carrying capacity'* of Canyon for PBW	Mod	Aerial surveys, passive acoustics, long term photo-ID
6) How critical is the Canyon to PBW population? Determine level of interaction of Canyon PBW with other known PBW populations,	Determine population boundaries and migration destinations/paths other feeding areas	Low	Photo-ID , Satellite tagging, genetic sampling
7) Define the small scale oceanographic drivers which lead to great whale aggregations along the southern WA coast	Understanding of physical oceanographic process in exercise areas	Low	Oceanographic measures / cruises combined with whale / krill observation techniques (visual & acoustic) – outcomes of current analysis will define future studies -possible future *Southern Surveyor* cruise?
8) Investigate behavioural patterns in feeding PBW's and their interactions with plankton and fish choruses in Canyon	Understanding of fine scale use of Canyon by PBW and subsequent insights into wider spatial scale patterns pertinent to sub-sea acoustical operations	Low, but possibly wide scale payoff	Visual obs., fine scale acoustic tracking, attached packages for dive monitoring, collection & experimentation of plankton / fish

1 - The "*bioduck*" refers to a sound type which is widely heard by submariners, but whose source identity is not known.

The program of work carried out to date has generated much information on the use of the WAXA by presumed pygmy blue whales. But many of the basic population parameters for pygmy blue whales show high variability and thus require long term data sets to elucidate trends. Hence there is a need to continue monitoring the population of whales to address these issues. A separate document, *'WAXA Blue Whale Project - Proposal for follow up work: Blue and other Great whales in the WAXA'*, presents two options for base level funding of these questions.

To assist in designing long term sampling of the Canyon a power analysis, or analysis of the sampling effort required to detect changes in the pygmy blue whale population size, has been undertaken. This was carried out on the raw aerial survey data and the acoustic detection data. The raw aerial survey data used did not account for the proportion of whales not seen (G_o or % below the water surface) or the effective strip width, as these were assumed to be constant and so to not affect the outcome. The analysis was also undertaken for the acoustic detection rates, which are used as a proxy for whale numbers. The power analysis was not undertaken for small vessel surveys, as the types of vessel surveys conducted in the Perth Canyon were targeted at known areas of whales and were thus not carried out in a rigorous fashion to census pygmy blue whales, although they have been effective at highlighting temporal and spatial patterns of visitation.

In comparing the aerial and passive acoustic techniques it must be realised that the aerial techniques give straight estimates of whale numbers based on established statistical techniques, whereas the passive acoustic detections give the number of singing whales, potentially over a much larger region than the aerial surveys. Typically, aerial surveys for great whales suffer from a high variability and low number of sightings for the effort which can be realistically maintained, and thus have low sampling power. In contrast, the high effort which can be easily obtained by passive acoustic techniques reduces the measured variability in detecting the numbers of individual calling animals and thus increases the sampling power. But, despite this discrepancy in variability and associated sampling power, the techniques balance overall, as aerial surveys give straight estimates of whale numbers whereas at this stage it is not fully clear how the passive acoustic detection techniques relate to pygmy blue whale population numbers. Passive acoustic detection rates, and thus their use as a proxy for population estimates, may be potentially biased by: range from source; background noise removing distant singers; call rates and day-night, lunar, seasonal or spatial differences in call rates; and the sex and age structure of the animals present at any set time in an area, with this population structure possibly changing throughout a season.

5.1) Sampling effort –aerial surveys

A power analysis of the Perth Canyon aerial survey data was performed to obtain an estimate of the aerial survey effort required to detect a 10 % per year increase in the number of blue whales. A 10 % per year increase has been observed in some other populations of whales, eg humpbacks. The power analysis was conducted to predict several parameters for future observations based on those and the inherent variance observed from 1999 to 2004. The baseline parameters chosen were: a mean population of 20 and 50 whales and a standard deviation of 14. The analysis assumed that these parameters were derived from aerial surveys at similar times every year (so that there would be no bias from observations made at a certain time in one year, but not repeated during any subsequent years). Previous studies show that the occurrence of whales over any given season is not evenly distributed. This is an important finding which indicates that future studies should sample at similar times each year to remove bias due to sampling time (or changes throughout a season). Aerial surveys that are focused during the peak of the season will likely increase the mean number of whales observed and so decrease the standard deviation, thus rendering future analyses more powerful. The analysis below assumes a study with little power (based on previous pygmy blue whale aerial survey data), and is therefore conservative.

The first analysis, for an initial population of 20 animals, suggests that for an acceptable Type I error rate (Alpha) of 0.05 and power goal above 0.8, the number of aerial surveys required per year to detect a 10% increase would be between five aerial surveys / year over 10 years and eight aerial surveys / year over 7 to 9 years (see Figure 46 and Table 13).

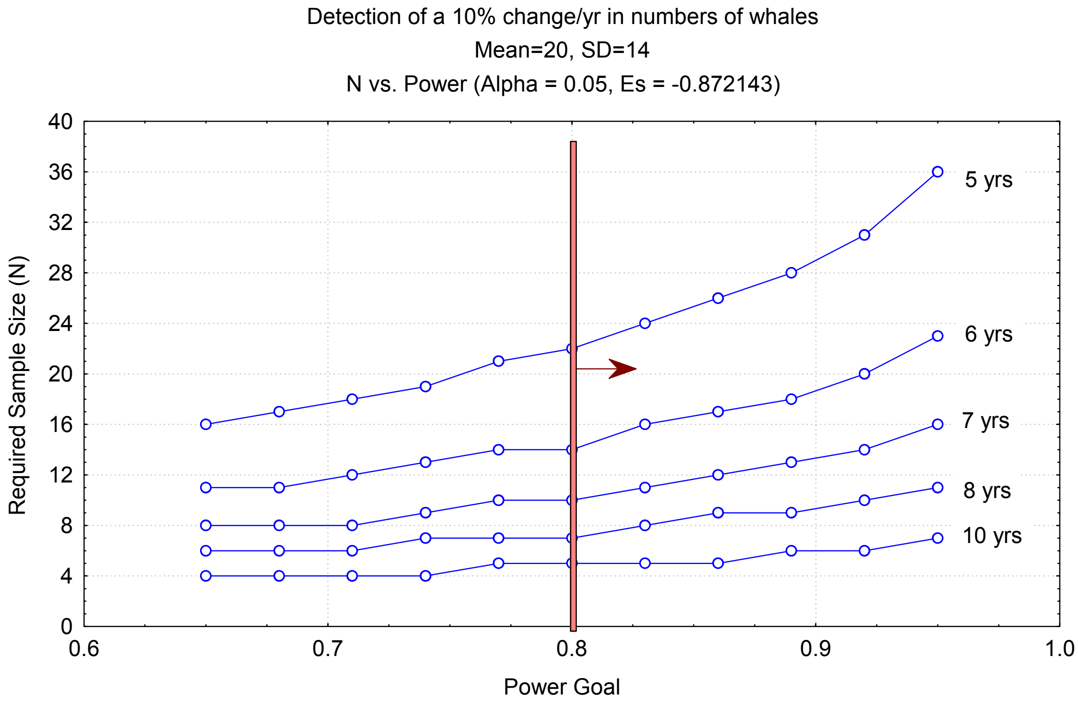


Figure 46: Power analysis for a detection of a 10% increase in number of whales using an estimated mean of 20 whales and SD of 14. The required sample size (N) is the number of aerial surveys. The red bar with an arrow to the right indicates the widely acceptable power goal (> 0.8).

Table 13: Estimated sample size required for detection of a 10% increase in number of pygmy blue whales observed by aerial surveys in the Perth Canyon (Alpha = 0.05, Power = 0.8).

Number of years	**Sample size (number of aerial surveys)**	
	Mean = 20 whales	Mean = 50 whales
5	-	5
6	-	4
7	10	3
8	7-9	3
9	6	-
10	5	-

The second analysis (Figure 47) assumes an initial mean of 50 whales present. This mean could be approximated if most surveys were concentrated around the peak of the season. Having a high initial mean number of whales reduces the estimated sampling effort to detect a 10 % change to about 4 aerial surveys / year over a period of 6 years (see Table 1).

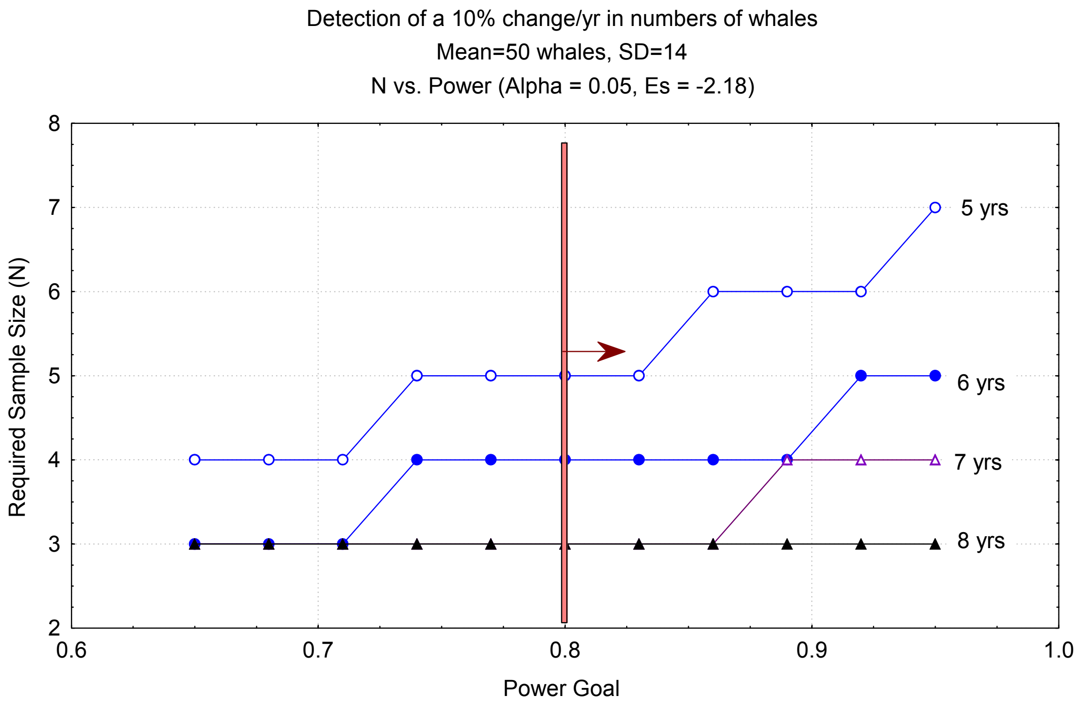


Figure 47: Power analysis for a detection of a 10% increase in number of whales using an estimated mean of 50 whales and SD of 14. The required sample size (N) is the number of aerial surveys. The red bar with an arrow to the right indicates the widely acceptable power goal (> 0.8).

In conclusion, past surveys have identified an uneven occurrence of whales throughout the pygmy blue whale season, a low number of whales observed, and a high standard deviation. This finding suggests that it is important that future surveys are conducted at similar times every year, during periods of high numbers of whales, and preferably with a higher number of surveys each year than has been conducted in previous years. An ideal design might include a set of 7-8 surveys spaced approximately 10 days apart based around the peak of the season.

5.2) Acoustic surveys

The nature of modern passive acoustic surveys, with many closely spaced or continuous sampling over long periods (typically many month), allows for powerful studies due to the high number of samples possible, although as stated above the detection rates of calling may not directly relate to population size. The power analysis conducted based on data collected (mean = 1.36 individual callers at any given time and a SD = 1.6) suggests that an increase in the number of pygmy blue whales calling of 5 % / yr is detectable with 1000 samples (with a sample equal to one 200 second recording every 15 minutes) or greater over a period of 2 years (see Figure 48). But, because the power is so high (from a high sample size), very small changes may be detected that may not reflect “real” changes in the population size. As an example, the very small variability detected could hypothetically be due to factors such as behaviour or a change in the presence of one or several animals. For the purposes of this study, ideally the power would be reduced by averaging to detect bigger changes that reflect “real” changes in the population size, which means that a greater than two, number of years of sampling would be needed. A more realistic sample size would be 200 to 600 samples / year over a 3 to 5 year period. The current sampling regime can be ‘binned’ or averaged in blocks, to remove the excessively high power. This has the advantage of removing daily patterns in call behaviour. The larger number of years would also allow for further comparisons to numbers of observed pygmy blue whales during aerial surveys.

It is important in this case (as for the aerial surveys) that data would be collected at similar times each year for unbiased comparisons (to compensate for differential calling rates throughout the pygmy blue whale season), and similar times as aerial surveys for comparison with visual observations of pygmy blue whales.

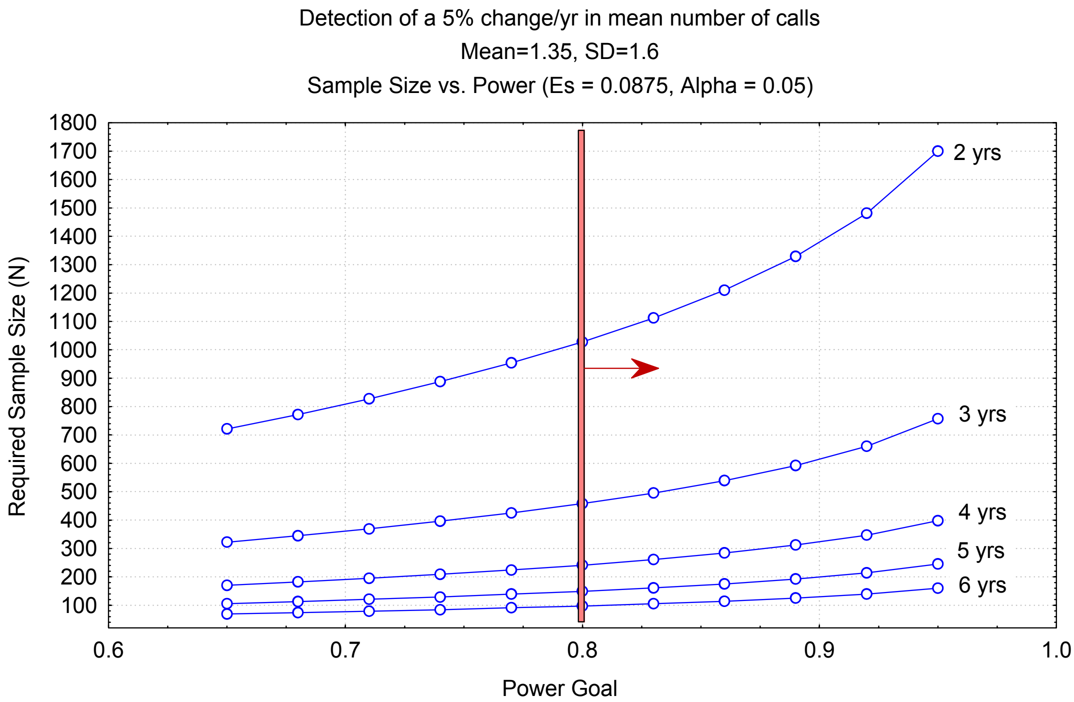


Figure 48: Power analysis for a detection of a 5% increase in number of whales calling using an estimated mean of 1.36 calls and SD of 1.6. The required sample size (N) is the number of 200 sec recordings. The red bar with an arrow to the right indicates the widely acceptable power goal (> 0.8).

6) Summary tables

Summary tables of data obtained over the five years of the project (ie including the period funded by Environment Australia, 1999-2001) are presented below.

6.1) Passive acoustic recording sets available from the Perth Canyon and wider context

Table 14: Details of recording sets available, Superscripts: * – freq band given as useable upper frequency limit to 3 dB down point of anti-aliaising filter roll off.

Num.	Moor.	latitude	longitude	Water / hyd depth (m)	Good records	Date first good record (WST)	Date last good record (WST)	Freq band* (kHz)	Sample length (s)	Sample inc. (min)
2466		31° 55.13' S	114° 59.96' E	450 / 450	4-4760 (4757)	8-Mar-2000 00:00	10-Apr-2000 00:50	10 /	90	10
2565	5	31° 54.29' S	115° 01.54'E		23-313 (291)	17-Jan-2002 14:30	20-Jan-2002 15:00	10 / 4.8	110	15
2594	6	31° 54.28' S	114° 58.90' E		13-310 (298)	17-Jan-2002 12:15	20-Jan-2002 14:30	10 / 4.8	110	15
2595	7	31° 52.23' S	115° 00.18' E		19-313 (295)	17-Jan-2002 13:30	24-Jan-2002 06:45	10 / 4.8	110	15
2612	9	31° 53.75' S	115° 00.11' E	450 / 450	1-6450 (6451)	14-Oct-2002 08:00	20-Dec-2002 12:15	4 / 1.3	120	15
2615	10	31° 53.77' S	115° 01.00' E	440 / 440	11-10490 (10480)	18-Feb-2003 11:00	17-Jun-2003 14:45	4 / 1.8	200	15
2616	11	31° 54.68'S	114° 58.26' E	490 / 490	25-4154 (4130)	18-Feb-2003 13:10	02-Apr-2003 16:45	5 / 2.3	200	15
2617	12	31° 51.72' S	114° 59.19' E	450 / 450	34-8146 (8114)	18-Feb-2003 15:30	14-May-2003 09:00	5 / 2.3	200	15
2628	13	31° 52.76' S	114 ° 59.72' E	449 / 449	3-11146 (11144) 11147-11150 = cal	10-Jun-2003 12:00 mooring cut on	06-Oct-2003 17:15:01 Note cal=2621	5 / 2.3	150	15
2643	SS0204 RE	Drift 1 Drift 2 Drift 3		310 / vary 310 / vary 310 / vary	50 210 250 860 925 1550	29-Jan-2004 22:12:01 31-Jan-2004 16:18:16 02-Feb-2004 16:33:02	30-Jan-2004 06:48:20 01-Feb-2004 23:33:01 03-Feb-2004 23:48:01	22 /	61	3
2653	SS0204	Drift 2 DAT		62 / vary				32 / 16	continual	continual
2654	SS0204	Drift 3 DAT		62 / vary		02-Feb-2004 16:37:48	02-Feb-2004 20:14:57	32 / 16	continual	continual
2655	14	31 52.774	114 59.991	446 / 446	To be recovered					
2656	15	31 50.864	114 59.922	426 / 426	1-10356 (10356)	26-Feb-2004 17:00:05	14-Jun-2004 07:45:02	5 / 2.3	180	15

Table 15: Details of other sea noise data sets available to McCauley for perusal for blue whales.

Num.	location	Water / hyd depth (m)	Recording period	True / pygmy blue & other whale presence	Notes
2536	Cape Naturaliste	1500/1100	Jun – Jul 1998	Distant true / pygmy blue calling evident, Not thoroughly searched for blue whale calls	Logger in deep sound channel
2505	Exmouth	250/250	Oct – Nov 2000	Pygmy blue whales, bioduck, 20 Hz 'click'	
2564	Otway Basin		Nov-2001 – Mar-2002	Pygmy blue whales from Feb on	
2608-2609	Inshore Geraldton / Abrohlos	Up to 50 m	Oct-Nov 2002	No blue whales, plenty of humpbacks	Loggers to far inshore to detect animals in deep water
2623	NW Broome	181/181	Mar – Aug 2003	No blue whales detected – not thoroughly searched; Several unknown call types probably attributable to great whales	Thorough analysis pending
2624	CTBTO Cape Leeuwin	1200/1000	2002 - 2003	Yes, true, pygmy & other great whales	1 years data, three hydrophones supplied, strict data release restrictions apply

6.2) Small boat, pygmy blue whale observations

Table 16: Species sighted during small vessel trips.

date	blue	sperm	dolp	beak	risso
10-Jan-2000	0	0	0	0	0
11-Jan-2000	0	0	0	0	0
12-Jan-2000	0	0	0	0	0
13-Jan-2000	0	0	0	0	0
18-Jan-2000	0	0	0	0	0
21-Jan-2000	0	0	0	0	0
28-Jan-2000	0	0	0	0	0
29-Jan-2000	0	0	10	0	35
30-Jan-2000	0	0	0	0	0
03-Feb-2000	4	0	0	0	0
06-Feb-2000	0	0	20	0	0
07-Feb-2000	3	0	0	0	0
11-Feb-2000	0	0	0	0	0
12-Feb-2000	0	0	0	0	0
14-Feb-2000	2	0	0	0	0
17-Feb-2000	0	0	0	0	0
24-Feb-2000	0	0	0	0	0
27-Feb-2000	0	0	0	0	0
28-Feb-2000	0	0	0	0	0
29-Feb-2000	1	0	0	0	0
06-Mar-2000	1	0	0	0	0
07-Mar-2000	0	0	0	0	0
08-Mar-2000	1	0	0	0	0
09-Mar-2000	0	0	0	0	0
13-Mar-2000	1	0	0	0	0
14-Mar-2000	1	0	0	0	0
20-Mar-2000	0	0	0	0	0
21-Mar-2000	0	0	0	0	0
24-Mar-2000	0	0	0	0	0
29-Mar-2000	1	0	0	0	0
30-Mar-2000	2	0	0	0	0
06-Apr-2000	1	0	0	0	0
10-Apr-2000	0	0	0	0	0
04-Jan-2001	0	0	0	0	0
05-Jan-2001	0	0	0	0	0
11-Jan-2001	0	0	0	0	0
12-Jan-2001	0	0	0	0	0
15-Jan-2001	2	0	0	0	0
16-Jan-2001	0	0	0	0	0
18-Jan-2001	0	0	0	0	0
21-Jan-2001	0	0	0	0	0
03-Feb-2001	3	0	0	0	0
04-Feb-2001	1	0	0	0	0
05-Feb-2001	1	0	0	0	0
06-Feb-2001	0	0	0	0	0
10-Feb-2001	0	0	0	0	0
14-Feb-2001	0	0	0	0	0
15-Feb-2001	3	0	0	0	0
16-Feb-2001	3	0	132	0	0
19-Feb-2001	6	0	15	0	0
22-Feb-2001	2	0	0	0	0
23-Feb-2001	0	0	0	0	0
26-Feb-2001	1	0	1	0	0
27-Feb-2001	7	0	0	0	0
28-Feb-2001	2	0	0	0	0
02-Mar-2001	3	0	0	0	0
03-Mar-2001	0	0	0	0	0
04-Mar-2001	13	0	0	0	0
05-Mar-2001	2	0	2	0	0
06-Mar-2001	2	0	10	0	0
10-Mar-2001	10	0	0	0	0
11-Mar-2001	9	0	0	0	0
14-Mar-2001	6	0	25	0	0

date	blue	sperm	dolp	beak	risso
16-Dec-2001	3	0	0	0	0
07-Jan-2002	0	0	3	0	0
17-Jan-2002	0	0	25	0	0
22-Jan-2002	0	0	13	0	0
23-Jan-2002	0	0	0	0	0
26-Jan-2002	0	0	50	0	0
27-Jan-2002	4	0	0	0	0
29-Jan-2002	0	0	0	0	0
30-Jan-2002	2	1	6	0	0
31-Jan-2002	0	0	6	0	0
06-Feb-2002	1	0	2	0	0
08-Feb-2002	0	0	1	0	0
10-Feb-2002	2	0	7	0	0
11-Feb-2002	0	0	15	0	0
16-Feb-2002	1	0	0	0	0
17-Feb-2002	0	0	0	0	0
22-Feb-2002	0	0	0	0	0
23-Feb-2002	0	0	0	0	0
24-Feb-2002	0	0	0	0	0
02-Mar-2002	0	0	0	0	50
03-Mar-2002	0	0	150	0	0
11-Mar-2002	8	0	0	0	0
12-Mar-2002	12	0	100	0	0
17-Mar-2002	0	0	0	0	0
18-Mar-2002	0	0	0	0	0
19-Mar-2002	2	0	30	0	0
20-Mar-2002	0	0	50	0	0
26-Mar-2002	1	0	0	0	0
07-Apr-2002	1	0	0	0	0
12-Apr-2002	2	0	0	0	0
20-Apr-2002	2	0	0	0	0
21-Apr-2002	0	0	56	0	0
24-Apr-2002	3	0	10	0	0
25-Apr-2002	4	0	0	0	0
27-Apr-2002	3	0	0	0	0
08-Jan-2003	0	0	0	0	0
15-Jan-2003	0	0	0	0	0
18-Jan-2003	0	0	110	0	0
21-Jan-2003	0	0	0	0	0
23-Jan-2003	0	0	0	0	0
26-Jan-2003	0	0	0	0	0
27-Jan-2003	1	0	0	0	0
31-Jan-2003	1	0	0	0	0
01-Feb-2003	0	0	0	0	0
05-Feb-2003	2	0	6	0	0
08-Feb-2003	4	0	6	0	0
09-Feb-2003	4	0	0	0	0
10-Feb-2003	2	0	212	0	0
14-Feb-2003	3	0	100	0	0
15-Feb-2003	0	15	2	0	0
18-Feb-2003	4	0	200	0	0
26-Feb-2003	1	0	0	0	6
01-Mar-2003	0	0	0	0	0
04-Mar-2003	4	0	20	0	0
05-Mar-2003	2	0	50	0	0
06-Mar-2003	3	0	0	0	0
08-Mar-2003	5	0	200	0	0
09-Mar-2003	9	0	200	0	0
10-Mar-2003	5	0	10	0	0
15-Mar-2003	2	0	200	0	0
25-Mar-2003	3	0	5	4	0
26-Mar-2003	0	0	0	0	0
27-Mar-2003	6	0	0	0	0
28-Mar-2003	2	0	0	0	0
30-Mar-2003	8	0	0	0	0

date	blue	sperm	dolp	beak	risso
10-Jan-2004	2	0	85	0	0
11-Jan-2004	9	0	6	0	0
17-Jan-2004	17	0	70	0	0
23-Jan-2004	0	0	0	0	0
24-Jan-2004	0	0	0	0	0
25-Jan-2004	0	0	0	0	0
28-Jan-2004	2	0	0	0	0
02-Feb-2004	1	0	0	0	0
03-Feb-2004	4	0	0	0	0
06-Feb-2004	1	0	0	0	0
07-Feb-2004	14	0	0	0	0
08-Feb-2004	11	0	200	0	0
09-Feb-2004	8	0	40	0	0
12-Feb-2004	6	0	0	0	0
17-Feb-2004	1	0	0	0	0
18-Feb-2004	3	0	0	0	0
24-Feb-2004	0	0	0	0	0
06-Mar-2004	2	0	10	0	0
09-Mar-2004	3	0	12	0	0
10-Mar-2004	1	0	12	0	0
11-Mar-2004	0	0	0	0	0
13-Mar-2004	7	0	100	0	0
14-Mar-2004	12	0	0	0	0
19-Mar-2004	9	0	0	0	0
21-Mar-2004	7	0	20	0	0
22-Mar-2004	2	0	0	0	0
26-Mar-2004	12	0	0	0	0
29-Mar-2004	4	0	0	0	0

6.3) Aerial survey data

Table 17: Blue whale aerial survey flights carried out since 1999.

date	blue	Hump.	sperm	minke	South right	Dolphin	Beaked	risso	Flight No	Transect
02-Feb-1999	0	0	0	0	0	26	0	0	1	EA Rottnest
07-Mar-1999	1	0	0	0	0	30	0	0	2	EA Rottnest
11-Apr-1999	0	0	0	0	0	0	0	0	3	EA Rottnest
11-May-1999	0	0	0	0	0	0	0	0	4	EA Rottnest
11-Oct-1999	0	17	0	0	0	0	0	0	5	EA Rottnest
11-Nov-1999	0	5	0	0	0	0	0	0	6	EA Rottnest
14-Nov-1999	0	5	0	0	0	0	0	0	7	EA Rottnest
06-Jan-2000	0	0	0	0	0	0	0	0	8	EA Rottnest
02-Feb-2000	7	0	0	0	0	146	0	0	9	EA Rottnest
23-Feb-2000	9	0	0	0	0	42	0	0	10	EA Rottnest
02-May-2000	4	2	0	0	0	0	0	0	11	EA Rottnest
25-July-2000	0	0	0	0	0	0	0	0	12	EA Rottnest
11-Sept-2000	0	16	0	0	0	20	0	0	13	EA Rottnest
01-Nov-2000	1	15	0	0	0	50	0	0	14	EA Rottnest
28-Feb-2001	14	0	0	0	0	50	0	0	15	EA Rottnest
31-Mar-2001	4	0	0	0	0	0	0	0	16	EA Rottnest
03-May-2001	2	0	0	0	0	526	0	0	17	EA Rottnest
06-June-2001	0	0	0	0	0	0	0	0	18	EA Rottnest
04-Jul-2001	0	2	1	0	0	0	0	0	19	EA Rottnest
13-Sep-2001	0	4 (3)	0	0	0	0	0	0	20	EA Rottnest
16-Dec-2001	3	0	0	0	0	0	0	0	21	EA Rottnest
21-Dec-2001	3	6	0	0	0	53	0	0	1	Defence-Green
11-Jan-2002	2	0	0	0	0	0	0	0	22	EA Rottnest
11-Feb-2002	2	0	0	0	0	56	0	0	2	Defence-Red
04-Mar-2002	2	0	0	0	0	0	0	0	23	EA Rottnest
08-Mar-2002	1	0	0	0	0	31	0	0	3	Defence-Blue
29-Apr-2002	0	0	0	0	0	0	0	0	24	EA Rottnest
19-May-2002	0	0	2	0	0	20	0	0	25	EA Rottnest
26-May-2002	0	0	0	0	0	0	0	0	4	Defence-Green
21-Jun-2002	0	10	0	0	4	0	0	0	5	Defence-Red
19-Aug-2002	0	3 (7)	0	0	0 (2)	16 (62)	0	0	6	Defence-Green
08-Sep-2002	0	15	0	2	0	12	0	0	7	Defence-Blue
21-Oct-2002	0	21 (18)	0	0	0	11 (10)	0	0	8	Defence-Red

date	blue	Hump.	sperm	minke	South right	Dolphin	Beaked	risso	Flight No	Transect
08-Jan-2003	0	0	0	0	0	0	0	0	9	Defence-Blue
11-Jan-2003	1	0	0	0	0	0	0	0	26	EA Rottnest
09-Feb-2003	1	0	0	0	0	130	0	0	10	Defence-Green
14-Feb-2003	31	0	0	0	0	239	0	0	27	EA Rottnest
17-Feb-2003	5	0	0	0	0	93	0	0	11	Defence-Red
03-Mar-2003	17	0	0	0	0	0	0	0	28	EA Rottnest
27-Mar-2003	16	0	10	0	0	70	12	15	29	EA Rottnest
15-Apr-2003	0	0	1	0	0	0	0	0	30	EA Rottnest
28-Apr-2003	7	0	0	0	0	160	0	0	31	EA Rottnest
07-May-2003	6	0	0	0	0	82	0	0	32	EA Rottnest
10-Jan-2004	10	0	0	0	0	72	0	0	12	Defence-Green
23-Jan-2004	5	0	0	0	0	0	0	0	33	EA-Rottnest
29-Jan-2004	11(2)	0	4	0	0	0	0	0	13	Defence-Red
2-Feb-2004	4	0	0	0	0	4	0	0	14	Defence-Blue
6-Feb-2004	14	0	0	0	0	72	0	0	34	EA-Rottnest
18-Feb-2004	9	0	0	0	0	515	3	0	15	Defence-Green
23-Feb-2004	11	0	0	0	0	420	0	0	35	EA-Rottnest
13-Mar-2004	1	0	0	0	0	353	0	0	16	Defence-Red
21-Mar-2004	40	0	26	0	0	60	0	0	36	EA-Rottnest
16-Apr-2004	20	0	0	0	0	0	0	0	37	EA-Rottnest
26-Apr-2004	7(6)	0	0	0	0	66	0	0	17	Defence-Blue

Note: Numbers in brackets are those sighted outside of survey area.
2004 Defence RGB flights refer to the Extended Lancelin to Mandurah area.

6.4): Sundry blue whale observations

Table 18: List of incidental cetacean sightings recorded from late 2000.

date	vessel	sighting	position	notes
06-Nov-2000	CALM	1 blue whale - stranding	Troughton Island, Kimberleys	21 m length
01-Jun-2001	Naturaliste Charters	1 blue whale	Flinders Bay, Augusta	
20-Jun-2001	CALM	5 blue whale	Albany Harbour	
09-Dec-2001		1 pygmy blue - stranding	Contos Beach, Margaret River	Blubber samples taken, 22.3 m long
07-Feb-2002	Navy	4 blue whales	10 km W Rottnest (~ 32° 0' S 115 ° 22' E)	Reported through HMAS Stirling
11 to 13 Feb-2002	Seahorse Standard	0 blue whales, [?include]	Perth Canyon	Dedicated observations during exercise across Perth Canyon
13-Feb-2002	Ocean Odyssey	1 blue whale	28° 46.3' S 114 ° 36.1' E	
18-Feb-2002	Seahorse Standard	6 blue whales	31° 55' S 114° 43' E	Reported through Christopher Donald, cow-calf pair within pod; heading E-ENE
18-Feb-2002	Seahorse Standard	Group sperm whales	31° 55' S 114° 44.7' E	Reported through Christopher Donald, heading S
19-Feb-2002	Seahorse Standard	Group sperm whales	31° 55' S 114° 44.7' E	Reported through Christopher Donald,
19-Feb-2002	Seahorse Standard	~ 50 Spinner dolphins?	31° 55' S 114° 44.7' E	Reported through Christopher Donald
25-Feb-2002	Ocean Odyssey	2 blue whales	Off Abrolhos	Off web page
1-Mar-2002	Ocean Odyssey	Sperm whales	Perth Canyon ~ 32 ° 3.85 S 114 ° 44.88' E	Off web page
12-Apr-2002	Ocean Odyssey	Sperm whales	Perth Canyon ~ 32° 3.61' S 114 ° 44.69' E	Off web page
28-Apr-2002	Ocean Odyssey	Blue whale	31° 10.4' S 113 ° 54.6' E	Reported by J Murdoch
20-May-2002	CALM	Blue whales	Albany Harbour	Reported by Doug Coughran
Jan-Jun 02	hydrophones	Acoustic detections pygmy & true blue	Offshore Cape Leewuin	Persistent pygmy blue whale calling and some nearby Antarctic blue whale calling
25-Jun-2002	Whale Watching	2 blue whales	Outer Albany Harbour	

date	vessel	sighting	position	notes
Oct 02	Seahorse Standard	No blue whales	Perth Canyon	Systematic and comprehensive visual and acoustic survey detected no blue whales
10 Dec 2002	AQWA boat	1 large blue whale	1 nm NW of Fairway marker Perth-Rottnest waters (31 55.99 S, 115 36' E)	
18-Jan-2003	Dave Gordon	1 blue whale	Blowholes, Albany	Probable cow-calf pair
20-Jan-2003	Jason Mant	1 blue whale	Jurien Bay (68 fathoms) 30 9' S, 114 34.4' E	
26-Feb-2003	C & G Johnston	2 blue whales	mid west coast (29 33.7 S, 113 59.6' E)	
26-Feb-2003	C & G Johnston	1 possible blue whale	mid west coast (30 27.9 S, 114 19.2 E)	
26-Feb-2003	C & G Johnston	1 blue whale	mid west coast (30 21.7 S, 114 17.9' E)	
14-Jun-2003	Seahorse Standard	2 blue whales	West of Lancelin (114 31.8'E)	Moving west
31-May-2003	Chris Burton	2 blue whales	Flinders Bay, Augusta	Moving west ~ 1 km off beach
Mid May 04	Shark fisherman	5 blue whales	SW of Cape Leeuwin	Moving north
3-June-2004	Naturaliste Charters	2 blue whale	Flinders Bay, Augusta	Moving west ~ 1 km off beach

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