Abundance estimates of the east Australian humpback whale population

Final Report for the Australian Department of the Environment, Water, Heritage and the Arts

13 May 2008

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Abstract

This is the final report under the agreement between the Commonwealth and the University. The project has progressed largely as detailed in the original funding proposal attached to the funding agreement. Fieldwork, both land-based and aerial, proceeded with only minor delays and all of the anticipated data (except acoustic survey data) have been collected and analysed on time and within budget. The land-based data indicate that the long-term pattern of rapid increase in the size of the east Australian population of humpback whales continues without any apparent slowing. The average number of whales passing Point Lookout per 10h over the peak four weeks of the northward migration was 70.7 whales. When placed in the context of long-term trends, it slightly increases the long-term rate of population growth to 10.9% (95% CI 10.5-11.4%).

During the aerial surveys, 249 groups of humpbacks containing an estimated 399 whales were seen from the air. Extra transects were flown directly off Pt Lookout for matching with the land-based survey with 117 groups spotted from the air in this area. Analysis confirms that only about 3% of groups pass more than 10km of the headland which is consistent with Bryden's (1985) estimates despite an approximately 15-fold increase in the population over this time. Further, the offshore distribution of whales was characterised with no significant difference being found between the patterns of distribution whether measured from land or air. Approximately 89% of groups passing within 5km of land and mean distances offshore for both aerial and land-based surveys less than 2.5km. Matching groups seen from the air and land, however, revealed that 29.1± 6.1% of groups were missed from land. This is much higher than anticipated and requires further analysis.

Estimates of absolute abundance for 2007 were made by extrapolating from the 2004 absolute abundance estimate. Using the land-based correction factor for groups available but missed estimated in 2004, 2007 absolute abundance is estimated at 9,683 whales (95% CI 8,740 – 10,729). Using the higher correction factor derived from the 2007 aerial surveys, 2007 absolute abundance is estimated at 12,599 whales (95% CI 9,874 – 16,076). Further analyses of existing data are required to resolve the discrepancies in the land-based and aerial/land estimates of groups missed. Also we recommend that the next survey at Pt Lookout adopt a triple-platform methodology including both land-based double counts and aerial surveys.

The only aspect of the project which has fallen behind schedule and remains incomplete is the acoustic survey component. The autonomous logger placed off Pt Lookout has not yet been recovered due to poor weather over the summer of 2007/08 restricting recovery opportunities and the inshore movement of the East Australian Current preventing safe recovery when the attempts have been possible. This component of the project, however, is part of a longer term study using acoustic recordings gathered over many years and the delayed recovery of the recorder should not greatly affect this longer term programme.

1. Introduction

The humpback whales (*Megaptera novaeangliae*) that migrate along the east coast of Australia were hunted to near-extinction in the 1950s and early 1960s. Since this time there has been an apparent rapid increase in the population. Surveys conducted over the last 26 years have demonstrated a high but steady rate of increase in the size of the population with surveys conducted by two different teams every one to three years since 1981. These series of surveys now comprise one of the best records of absolute and relative population size for any group of whales in the world.

This report concerns the latest survey of this population, conducted in the winter of 2007. At six weeks in duration, this survey was only relatively brief, but its primary aim was to obtain data on the rate of increase in the population, or 'relative abundance', rather than 'absolute abundance' where the size of the entire population is estimated. In addition to the land-based survey, the 2007 survey also used aerial surveys for the first time since 1991 to test some of the assumptions underlying the land-based surveys.

1.1 Biological and historical background

Humpback whales undertake annual migrations between high-latitude summer feeding areas and low-latitude winter breeding areas (Chittleborough, 1965; Dawbin, 1966). Until recently, the western South Pacific has been thought of as having one population of humpbacks, the Group V population, that summers in the Southern Ocean between 130°E and 170°W, migrating to various low-latitude coastal and island areas in the region during winter. More recently, the International Whaling Commission changed the nomenclature of the region to describe breeding stocks with east Australian whales named E1, New Caledonian and Tongan whales E2 and Cook Island and French Polynesian populations F (IWC 2006). While it is now considered that this area contains several populations that inter-mingle to a variable but probably small extent (Garrigue *et al.*, 2000, 2007), it is apparent that the largest stock or population of this meta-population migrates along the east coast of Australia.

Off the east coast of Australia, the winter breeding area is probably widely dispersed inside the Great Barrier Reef and the migration to and from these waters is along the eastern continental coastline. Off the headlands of the southern coastline of Queensland the migratory corridor is narrow with most whales passing close to land (Bryden, 1985; Paterson, 1991; Brown, 1996), making the whales available for land-based counts.

Prior to the 1950s, there was little exploitation of the east Australian humpback whale population. In 1952 industrial shore-based whaling commenced at Tangalooma on Moreton Is. and a year later at Byron Bay, and together with massive illegal pelagic whaling in the Southern Ocean in the early 1960s (Yablokov, 1994; Mikhalev, 2000), took whales in such abundance that the population collapsed by 1962. Chittleborough (1965) estimated the original Group V population to be ~10,000 whales but this has been upwardly revised in light of the only recently reported catches in the Southern Ocean to 35,000 – 40,000 (Jackson *et al.*, 2006). Further revisions may occur once all Soviet catch data have been analysed. Estimates of the Group V population size in the early to mid-1960s include 104 (Bannister and Hedley, 2001) and 400 to 500

(Chittleborough, 1965), while Paterson *et al.* (1994) estimated there were 34 to 137 whales remaining in the east Australian stock. Although the distribution of surviving whales was not known, the rapid recovery of east Australian whales and apparent lack of recovery of whales migrating past New Zealand (Gibbs and Childerhouse, 2004) suggests that most of these were of the east Australian population.

1.2 Previous land-based surveys at Pt Lookout

Post-whaling surveys of the east Australian population were initiated at Point Lookout, North Stradbroke Is., in 1978, and have continued every one to three years since then. At the latitude of Pt Lookout (27°30'S) in south-eastern Queensland, the northward migration peaks between mid-June and mid-July (Chittleborough, 1965; Bryden *et al.,* 1990; Paterson *et al.,* 1994). Between the late 1970s and early 2000s, two independent teams conducted surveys from this location. The first series was initiated by Michael Bryden, then at the University of Queensland, and continued by his student, Miranda Brown, from the University of Sydney, until 2000 (Bryden, 1985; Bryden and Slade, 1988; Bryden *et al.,* 1990, 1996; Brown, 1996; Brown *et al.,* 2003). These surveys are hereafter known as the 'BB' (Bryden-Brown) surveys. The other series of surveys, from the early 1980s to 2002, were conducted by Robert Paterson, a Brisbane radiologist, and his wife, Patricia, with data analysis by one of the current authors, DC (Paterson and Paterson, 1984, 1989; Paterson, 1991; Paterson *et al.*, 1994, 2001, 2004). These are hereafter referred to as the 'PC' (Paterson-Cato) surveys. With the completion of Miranda Brown's thesis, the retirement of Michael Bryden and the sad and untimely death of Robert Paterson, these surveys were taken over by us in 2004 (Noad *et al.,* 2006a,b).

While both the original series of surveys were conducted at Pt Lookout, the BB surveys observed from a headland approximately 32 m above sea level while the PC surveys were conducted from a 65 m high hill approximately 300 m inland from the headland. Despite some differences in survey site, survey design and data analysis, both series of surveys are in broad agreement concerning the number of migratory whales and their rate of increase. In 2004, we conducted a 14 week survey from the BB 32m high site, 'Norms's Seat', as this had public access while the PC site did not. In the analysis of data, however, we demonstrated that the analytical techniques used by both groups lead to very similar results and that the two original series of surveys were comparable (Noad *et al.,* 2006a,b).

Prior to 2004 the most recent estimates of annual rates of population increase (with 95% CI) were 12.3% (10.1-14.4%) (Bryden *et al.*, 1996) and 10.5% (10.0-11.1%) (Paterson *et al.,* 2004). Our 2004 survey produced a best estimate of 10.6 (10.1-11.1%) for the period 1987 – 2004. These growth rates are among the highest recorded for any humpback whale population in the world (but similar to those of the Australian west coast population) and are close to the theoretical reproductive limit of the species (Best, 1993; Brandao *et al.,* 2000; Bannister and Hedley, 2001). The rates of increase are also remarkably consistent over time with a very tight correlation between log-transformed, normalised whale counts and year (Noad *et al*., 2006 a,b).

In terms of absolute abundance, Noad *et al.* (2006 a,b) calculated the population size in 2004 to be 7090 ± 660 (95% CI) whales. This was consistent with previous BB and PC estimates and rates of increase.

1.3 Other east coast surveys

Surveys have been conducted from Cape Byron since 1978, initially by Project Jonah/ the Australian Whale Conservation Society, and more recently by David Paton (Southern Cross Univ.) and Eric Kniest (Univ. Newcastle). Although these have usually only been conducted for two weeks each year and the data are more variable than those gathered over longer surveys at Pt Lookout, the general population trend is similar with a rate of increase for 1998 to 2004 of 11% ± 9% (95% CI) (Paton and Kniest, 2006).

Combined visual and acoustic surveys have been conducted during the southward migration near Peregian Beach, 120 km north of Pt Lookout, in 1997, 2002, 2003 and 2004 (Noad and Cato, 2001, 2007; Noad, 2002; Noad *et al.*, 2004). Although not intended primarily as a census of whales, whales were counted during these southward migrations with a similar trend (with wider confidence intervals) in relative abundance to those obtained at Pt Lookout.

Chaloupka *et al.* (1999), using mark-recapture techniques on photo IDs of humpback whales in Hervey Bay, estimated an increase in abundance over the years 1988 to 1996 of 6.3% (95% CI 2-11%). While the large confidence interval overlaps the estimates obtained from Pt Lookout, it is not directly comparable, since it was confined to the portion of the stock that passed through Hervey Bay. This was updated by Forestell *et al.* (2006) with a 2002 population estimate for Hervey Bay of 3711 whales (se = 679.68). Although not calculated, the data series presented provides an annual rate of increase of 16.3% ± 2.7%. Also using mark-recapture photo-ID techniques, Paton *et al.* (2006) determined a population size of 7024 (5163 – 9685 95% CI) for 2005 using photo catalogues from Cape Byron, Ballina and Hervey Bay.

1.4 Aerial surveys at Pt Lookout

Aerial surveys have been used previously to determine how close the whales pass to Pt Lookout and hence whether they should be visible from the headland. Bryden (1985) first conducted aerial surveys of east Australian humpback whales in 1980 and 1981 with transects from Fraser Is. to Cape Byron but concentrating on the waters east of Moreton and North Stradbroke Islands. Bryden reported that 96% of humpbacks passed within 10km of the headlands of southeast Queensland and northern New South Wales, the distance at which he considered whales to be available for visual detection. Although this was based on sightings of 85 groups between Ballina and Maroochydore, only around 25 groups of whales were in the vicinity of Pt Lookout. Using these and further surveys in 1982 and 1986, Bryden *et al.* (1990) showed that there was no bias in group size estimation from the land-based counts. Brown (1996) conducted aerial surveys in 1991 concentrating more closely on the Pt Lookout area, again to attempt to quantify the proportion of the passing population available for visual counting. While she did not see any whales beyond 10km, again this was based on a total of only 37 groups of whales. For logistical reasons no attempt was made to determine a correction factor for group size bias.

With a long-term rate of increase of around 10.5-11% per year, the population has increased five-fold since Brown's surveys and approximately 15-fold since Bryden's early surveys, presenting an opportunity to conduct more aerial surveys to gain a larger sample size. We also attempted, for the first time, a direct comparison of numbers of whales seen from the air and from the land-based survey site at Pt Lookout. Whether the increased density of whales on the migration path has pushed some whales further out to sea is not known. If only a small proportion of whales is migrating beyond the effective limits of the visual survey, the population is now so large that even a small proportion could represent a considerable number of whales.

1.5 Acoustic surveys of whales

Cetaceans are difficult animals to survey visually as the spend most of the time underwater and are often cryptic when at the surface. Many cetaceans, however, vocalise and recording their vocalisations may offer a proxy to counting individual animals. For acoustic recordings to be tuned into meaningful abundance estimates careful calibration is required. Once calibrated, acoustic surveys could be used in places where visual surveys are not possible. Additionally acoustic surveys can be conducted 24h per day and also have the potential to be largely automated.

Humpback whales sing long complex ‘songs’ making them very good candidates for developing acoustic census techniques. While early attempts have produced some results (Noad and Cato 2001, Cato *et al.,* 2001) more data and a more complex modelling approach is required to achieve robust results. Surveys at Pt Lookout offer a good opportunity to collect more data on the ratio of singers and song produced, and passing whales.

1.6 Objectives of this study

a) To obtain a measure of the numbers of passing whales during the peak four weeks of the northward migration at Point Lookout and to use this, with previous survey results, to calculate the rate of population increase.

b) To determine whether there has been any changes in the width of the migratory corridor off Point Lookout with increasing numbers of whales and resultant higher densities in the area and specifically to determine the proportion of the population passing more than 10km from Point Lookout (assumed by Bryden and Brown to be the effective limit of visibility for sighting whales).

c) Using concurrent aerial and land-based surveys, to determine the proportion of whales missed using both survey techniques. This will be used to calculate *g(0)* for humpback aerial surveys (detectability of whales along a survey line) which can then be used to help improve the accuracy of west coast humpback population surveys as well determine a correction factor for the land-based east coast surveys.

d) Using concurrent aerial and land-based surveys, measure any bias in the estimation of the size of groups of whales as seen from shore. This will also be used to determine a correction factor for the land-based east coast surveys.

e) To determine the ratio of singing activity to numbers of passing whales during the northward migration at Point Lookout. This will be used to help develop stand-alone acoustic survey techniques for humpback whales.

2. Methodology

The survey was conducted from Pt Lookout (27° 26' S, 153° 33' E) on North Stradbroke Is, a large island off the coast of southern Queensland near Brisbane, over a 6 week period from 20 June to 27 July 2007 (Fig. 1). Except in duration, the field methodology for the 2007 land-based survey closely followed BB's structured surveys of 1996, 1999 and 2000 (Bryden *et al.*, 1996; Brown, 1996; Brown *et al.*, 2003) and our survey of 2004 (Noad *et al.*, 2006 a,b). Aerial surveys were conducted on 16 days between 3 July and 27 July 2007.

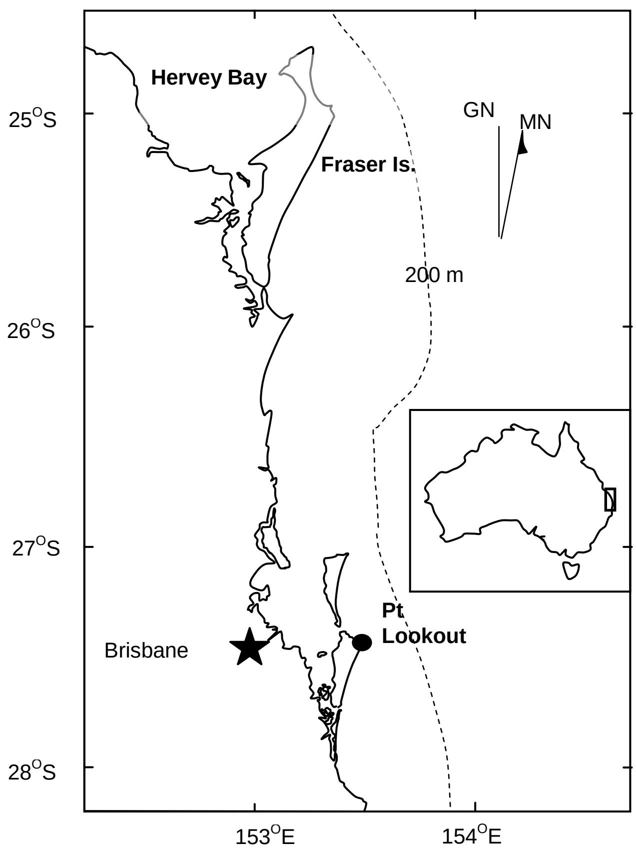

Figure 1. Southeast Queensland showing the position of Pt Lookout on North Stradbroke Is. The edge of the continental shelf is indicated by the 200m isobath (dashed line).

2.1 Land-based survey

2.1.1 Survey site

The survey site was 'Norm's Seat' (27° 26.067' S, 153° 32.770' E). This location is approximately 32 m above sea level with a field of view from the east-south-east to the north-west (Fig. 2).

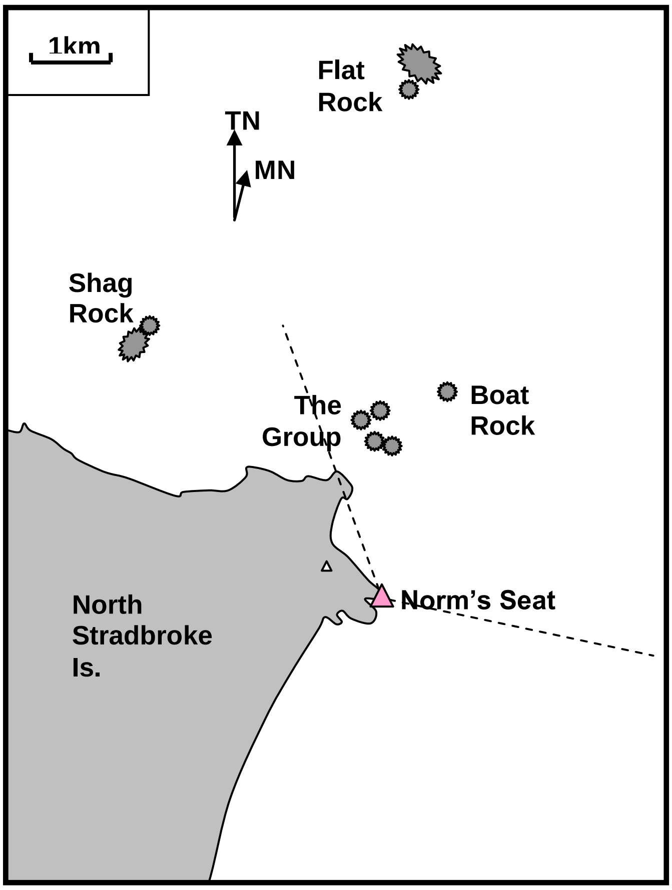

Figure 2. Pt Lookout and environs. Norm’s Seat is the land-based survey site. Field of view is indicated by dashed lines. TN = true north; MN = magnetic north. The offshore islets are exposed rocks that may have seas breaking over them in heavy weather.

2.1.2 Watch structure and data collection

Observations were undertaken from 0700 to 1700 each day, except during inclement weather including heavy rain or a sea state > mid 5 (open water wind speed of 20 kts). Each 10-h day was divided into four shifts conducted by two teams or watches. The ‘early’ watch observed from 0700 – 1000 and 1200 – 1400 and the ‘late’ watch ran from 1000 – 1200 and 1400 – 1700.

Watches usually consisted of five observers (increased from two observers used in BB surveys and three to four observers used in the 2004 survey due to increased whale numbers expected). Whales were spotted by the observers and sightings were input directly into a notebook computer running *Cyclopes* software (E. Kniest, Univ. Newcastle). A theodolite, connected directly to the notebook computer, was also used to measure the positions of passing groups of whales in *Cyclopes* for comparison with the aerial surveys, to determine their distance offshore and to prevent confusion between sightings of groups in the same area or on a similar bearing from the observation point. One observer operated the theodolite, while another operated the computer. The other three observers were ‘spotters’ who used bare-eyes or 7x50 binoculars to sight whales. The spotters were allocated adjacent sectors of the ocean to scan to spread sighting effort as much as possible. One spotter was also nominated as the ‘floater’ who answered questions from the public when required so that there was no disturbance to the rest of the team.

As in previous surveys, at least one observer in each watch was ‘experienced’ with a minimum of one month (approx 150 hours) survey time at Pt Lookout, or several seasons of prior field experience with humpback whales at other locations. In practice, this was usually RD or DP who were the field coordinators of the project and who are both highly experienced having coordinated much of the 2004 survey at Pt Lookout as well as being involved in many other previous humpback whale land-based surveys at different sites.

The notebook computer at Norm’s Seat ran *Cyclopes* software, developed specifically for the tracking of marine mammals. The theodolite operator points the theodolite at a surfacing group (one or more whales) and, by pushing a button, sends the vertical and horizontal angles directly to the computer running *Cyclopes*. The position of the group is calculated correcting for tides, curvature of the earth and refraction, and is plotted on a map of the area. *Cyclopes* also accepts information on the group’s composition, behaviour and direction of travel (added by the computer operator) and will compute the group’s speed, course and distance from any reference point. For each group sighted the following information was recorded using *Cyclopes*:

- Time (to the second)
- Group name (A, B, C, etc.)
- Confirmation of species
- Group composition (group size was estimated at each fix, so that some refinement in group size resulted during the tracking of a group)
- Direction of travel
- Sighting cue (e.g. breach, blow, pectoral flipper slap, unidentified surface activity)
- Any other relevant comments including presence of a calf

Most whales were sighted several times allowing ample opportunity for positive identification based on characteristics of the blow and roll of the back, flukes or pectoral fins. Single sightings of a blow only were noted but not included in the analysis as these were too easily confused with sea spray in windy conditions and are not sufficiently diagnostic of a humpback.

Three categories used for assessing species identification included ‘confirmed humpback’, ‘probably a humpback’ and ‘probably not or definitely not a humpback’.

1. *Confirmed humpback*. The observer is certain the sighting is a humpback: (a) at least two good sightings of a blow and back/dorsal, or (b) obvious humpback surface-active behaviours including pectoral fin slapping, fluke slapping, peduncle slapping and clear breaching.

2. *Probably a humpback*. The observer is reasonably sure but not certain it is a humpback. For experienced observers this includes (a) a single good sighting

of a back/dorsal, (b) multiple distant, quick or obscured sightings of a back/dorsal, (c) repeated sightings of a blow or group of blows, (d) a poorly sighted breach, spy hop or other surface-active behaviour. For an inexperienced observer this includes (a) multiple good sightings of a blow and/or back, (b) a sighting of a surface-active behaviour where the observer is still unsure of species.

3. *Probably not or definitely not a humpback*: (a) a single blow (splashing or whitecaps, possibly dolphins), (b) surface splashing without sighting of a whale (other whales, dolphins, fish, large whitecaps), (c) small whale's back with a large falcate dorsal fin (probably a minke whale), (d) whale with white patches on its head, no dorsal fin or short stumpy pectoral fins (probable southern right whale), (e) long slender whale with small falcate dorsal moving quickly or lunging erratically especially around shoals of small fish (probably a Bryde's whales).

Once a whale was observed, priority was given to confirm species to at least 'probable' level and group composition ascertained.

All sightings were noted with some measure of the group's position. From Norm's Seat position could be measured in three ways (in decreasing order of accuracy): (a) by theodolite, (b) by reticle/compass binoculars and (c) by estimating distance by comparing with other recently positioned groups or offshore rocks of known distance. Where possible, at least two theodolite fixes were obtained on all new groups to confirm direction of travel and distance offshore. Priority was then given to locating and theodolite-fixing new groups. Existing groups continued to be visually tracked and the behaviour and positions were noted if resources permitted.

For the purpose of the census, whales were only included in the analysis if they crossed a line extending seawards 70° from magnetic north (81° from true north) between 0700 and 1700. Both numbers of groups and group size were recorded for all survey periods. South-bound groups, though recorded, were excluded from the analysis.

Weather conditions were recorded every hour and at the beginning and end of each day. Data recorded included sea state, swell height and direction, wind speed and direction, cloud cover (in oktas), glare (scale of 0 – 3) and any other factors affecting visibility (e.g. smoke, haze, squalls).

2.1.3 Data analysis

Daily whale counts were compiled using the *Cyclopes* files. If days had less than 5 hours of usable data, they were discarded. For days with more than 5 but less than 10 hours of data, a correction was made for time missed based on sighting rate for that day. A running four week average was calculated starting with each day of the survey to identify the peak four week period. This log of the mean number of whales sighted per 10-h was then linearly regressed with 4-week count data from previous surveys to obtain the long-term rate of increase.

Sighting data were also compared with sea state by compiling the numbers of new sightings made each hour along with the sea state recorded and comparing sighting rates by simple paired two-tailed t-tests assuming unequal variance. Where sea states were recorded as borderline (e.g. 3-4) the higher value was used.

The distance at which each group passed Pt Lookout was also estimated. For consistency, we used the imaginary 70° line used for daily counts as a reference. Some group were fixed by theodolite close to this line or either side of the line making this relatively straight forward, while the theodolite tracks of other groups had to be extrapolated to the line. If groups did not have enough fixes to reliably estimate their course and therefore the distance at this bearing, they were excluded from analysis. The passing distances were grouped into 1 km wide bins.

2.2 Aerial survey

2.2.1 Flight pattern

The aerial surveys were initially delayed by strong westerly winds and some rain. The first full flight was conducted on 3 July. The pattern of the long transects was modified slightly from the original proposal to enable more flights to be conducted directly out from Pt Lookout for comparison with the land-based observers. Each main flight consisted of six 'long' transects and two additional 'short' transects off Pt Lookout at the start and end of the main series of transects. The transects were named after nearby place names or features at or near the western end of the transect (Fig. 3). All long and short transects were flown either east-west or west-east. The long transect extended from the shoreline of Moreton and North Stradbroke Islands to a line 30km east of Pt Lookout and were spaced 10km apart (Fig. 3). The transects off Pt Lookout were known as 'Shag Rock' transects (named after Shag Rock at the western end of the transect) and were either 'long' or 'short'. Short Shag Rock transects extended to only 12km east off Norm's Seat. Sightings from the long Shag Rock transect within 12km of the Point were used as short Shag Rock transect data as well as long Shag Rock transect data.

We attempted to fly only in low-wind conditions (winds less than 10 kts) but once on the water, the wind was up to 15 kts on some days. Each flying day the Partenavia high-wing, twin-engine plane would take off from Archerfield Aerodrome in Brisbane, usually with the flight coordinator, MN, onboard, and land at Dunwich Airstrip on North Stradbroke. There it would pick up RD and Stephen Robey, our principal spotters. We would then take off and complete the first short Shag Rock transect and first four long transects ending with the long Shag Rock transect before landing for a break. After half an hour or so we would take off and complete the last two long transects and the final short Shag Rock transect.

Aerial double counts were not conducted for three reasons: (i) we did not have enough personnel to have four spotters plus a coordinator in the plane and run the Pt Lookout land survey; (ii) due to the length of the Dunwich airstrip, it was not possible to take off safely fully fuelled with 6 persons on board; (iii) the object of the flights was not to conduct a comprehensive aerial survey, but to measure comparative metrics that would not benefit greatly from using a double count.

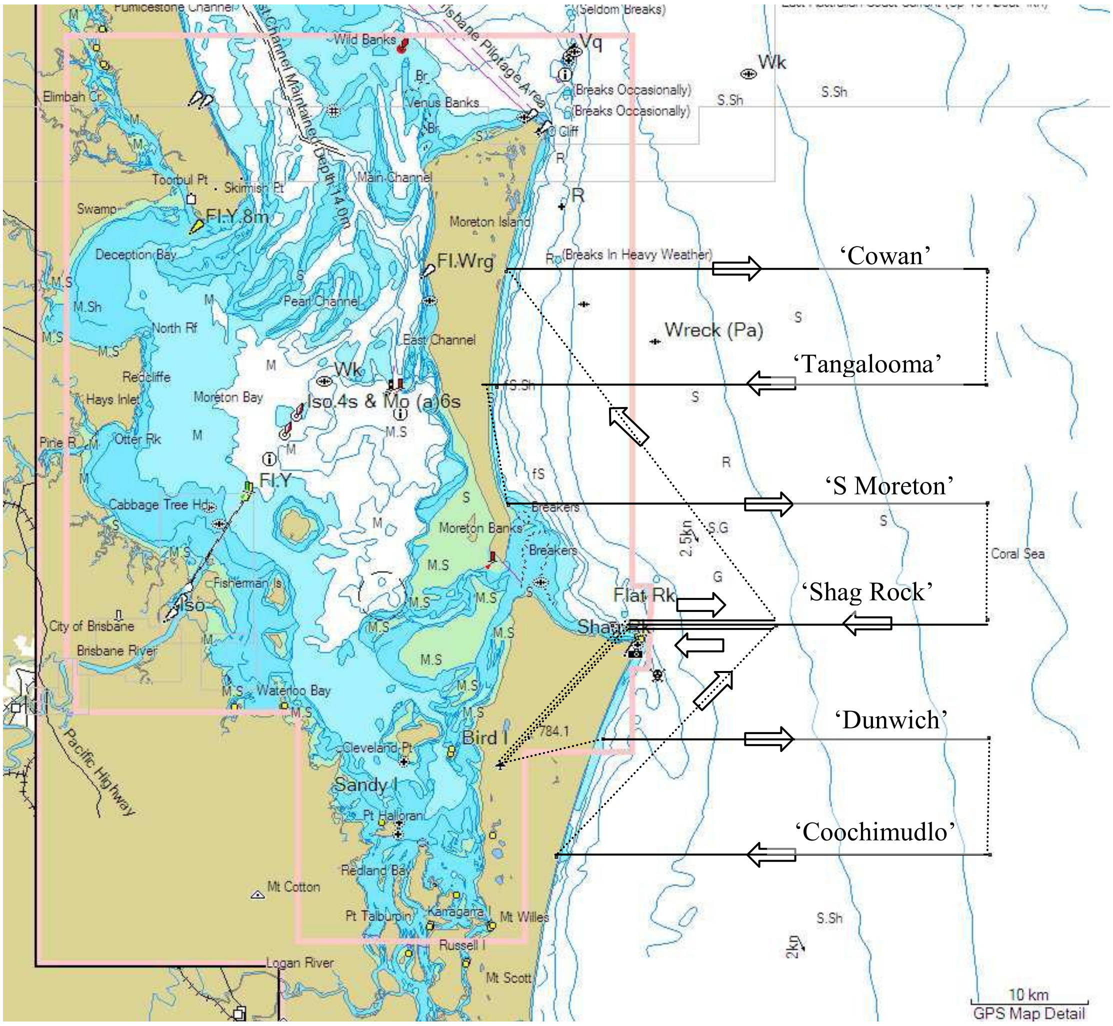

Figure 3. Flight pattern for aerial observations. East-west or west-east lines are 'on effort' while lines with any north or south component are connecting 'off-effort' legs. Arrows indicate flight direction.

A total of 16 full sets of transects were completed between 3 July and 27 July (Table 1). From flight 11 onwards, we also started conducting extra short Shag Rock transect flights in addition to the main flights. In these flights we took off from Dunwich, flew the short leg off Pt Lookout, turned and returned on the same short leg, then landed. These were spaced at least an hour apart to allow for whales to move through the area. In total 16 sets of long transects, 47 single and 20 double short Shag Rock transects were completed. The total distance of long transect 'on effort' was 3616km while the total 'on effort' short Shag Rock transects was 1218km.

Table 1. Aerial surveys. Short Shag Rock transects with * include extra flights after completing the main flight of the day, and these consisted of a leg out and another leg back in which have been counted separately. Depending on the analysis, however, only one leg per flight might be used.

Date	Flight no.	Long transects	Short Shag Rock transects
3/7/07	1	6	3
4/7/07	2	6	3
8/7/07	3	6	3
11/7/07	4	6	3
12/7/07	5	6	3
13/7/07	6	6	3
14/7/07	7	6	2
15/7/07	8	6	3
16/7/07	9	6	3
17/7/07	10	6	3
19/7/07	11	6	11*
20/7/07	12	6	9*
24/7/07	13	6	9*
25/7/07	14	6	7*
26/7/07	15	6	9*
27/7/07	16	6	9*

2.2.2 Data collection

Cyclopes was again used for data collection. The flight coordinator used a laptop computer running *Cyclopes* connected to a GPS unit (Garmin GPS Map 76CS). *Cyclopes* recorded the position of the plane every 2 km. The coordinator and spotters were connected with headsets so that they could hear each other talking. The communication system was also connected to an M-Audio Microtrack 24/96 acoustic recorder as a backup record of the flight.

At the beginning of each transect, once the turn was complete, the plane had levelled out and was at the correct height, the coordinator would notify the spotters that they were ‘on effort’. When a group was sighted, the spotter would notify the coordinator by calling a sighting cue (e.g. blow, breach) who immediately entered the sighting on *Cyclopes* to capture the time and position of the plane at that time. The spotter would then quickly provide the vertical and horizontal angles to the group followed by group composition and any other relevant details. The vertical angle to the group was estimated using a mechanical or electronic inclinometer while the horizontal angle was provided using a protractor with a swinging arm that could be lined up with the whale held against the window of the plane. *Cyclopes* automatically converted the angles into a position (assuming a height of 457m) and plotted it in real time on the laptop.

At the end of each transect the coordinator called ‘off effort’ and the spotters would relax for the few minutes it took to head down to the start of the next transect.

Weather and sea state were recorded at the start of each transect and if there was any noticeable change during the transect.

After each survey the *Cyclopes* file was reviewed. If there were any times where details had been missed, these were identified in the *Cyclopes* comments files by the coordinator. The audio recordings of the flight could then be reviewed and any missing sightings or details added.

2.2.3 Data analysis

Several analyses were undertaken using the aerial data.

Using the long transect flight data, the perpendicular distances of all groups seen from the flight transect line were calculated and grouped into 1 km wide bins to produce a detection curve as a function of distance. The maximum vertical viewing angle was estimated at 55° and the strip width under the plane not visible for this angle and a height of 457m is 640m (320m on one side). Sighting data were therefore left truncated at 500m and right truncated at 10.5km.

For each long transect, the easting of all groups sighted were analysed for mean and median values to determine the general path and spread of the whales as they moved along the coast.

To determine the proportion of whales missed by the land-based survey, the short Shag Rock transect transects off Pt Lookout were analysed in detail. Where extra short Shag Rock transects had been performed following the main transect flights, only one leg from each flight was used to ensure independence of data. To ensure there was no bias due to travel direction, we used alternating easterly and westerly transects (east, west, east, etc) from these extra flights (the short transects during the main transect flights were east, west, west). We then filtered the aerial observations to make sure that the groups seen would have been visible from Norm's Seat so that a match would be possible. To do this we restricted groups to those seen within 10km of Norm's Seat and between 350° and 100° (mag.).

On each flight we initially attempted to match aerial sightings using time, position and, to a lesser extent, group composition, with land-based sightings. We also interrogated *Cyclopes* to determine if there were any other groups in the area during the flight that were not seen by the land-based observers during the flight that might have matched the aerial sightings. This maximised the reasonable likelihood of groups observed from land being matched with aerial observations whether or not those groups were seen by the land observers during the very short period of the flight (approximately 4 mins). A 0-1 vector was created from the mark-recapture data where 0 was a group seen from the air but not land and 1 was a group seen by both. A non-parametric bootstrap was then performed on this vector 1000 times. In each re-sample, items from the vector were randomly chosen with replacement n times where n was the total number of groups seen from the air that were theoretically visible from land (i.e. the length of the 0-1 vector). For each re-sample we calculated p, the proportion of groups missed from land, and a correction factor f_m, to be applied to the land data to correct for the proportion missed. The correction factor $f_m = 1/(1-p)$. A mean value each of p and f_m was calculated for the 1000 re-samples and the standard error of each was the standard deviation of the 1000 estimates.

In order to determine the bias in land-based sightings due to distance from shore, an unbiased distribution of whales off Pt Lookout was determined from the short Shag Rock transect aerial data. This distribution was then compared to the land-based offshore distance distribution. However, the short Shag Rock transects were conducted approximately 2500m north of the visual observation sight at Norm's Seat so that whales directly east of here could be seen from the plane. This also meant that whales seen from the plane could effectively be anywhere from 12 km or so north of Pt Lookout to 8 km or so south (assuming 10km maximum detection range). From both land-based observations and the long transect data it was evident that many whales headed north-west after rounding the Point so that their easterly positions once much north of Pt Lookout would not accurately reflect their easterly position while passing the Point. Similarly, whales more than a few kilometres south of the Point were also likely to be more westerly than when rounding the point. We therefore decided to limit the groups measured to those in a 5km wide strip extending east of the Point (effectively the strip 5km south of the flight transect as it was 2.5km north of the Point). Within this area it was assumed the whales were travelling north-south and so the easting of the Norm's Seat was subtracted from the eastings of the groups' positions to determine a distance offshore. As with the land-based offshore distribution data, these were grouped into 1km-wide distance classes. The sample size for the land-based observations was much greater than that for the aerial surveys and so the two distributions were then compared using the land-based distribution to determine an 'expected' distance distribution of the aerial survey groups and comparing this using a *G*-test with William's Correction to the observed aerial survey group distribution. The *G*-test is similar to the Chi-squared test but is preferred for expected values of less than 5 (Sokal and Rohlf, 1995, p.702).

2.3 Acoustic survey

To record humpback whale song, an autonomous underwater recorder (Curtin University of Technology) was deployed 2km south-east of Pt Lookout in 27m of water on 1 July 2007. Unfortunately we have yet to recover this recorder and the data on it. We originally planned to collect it in September but from September onwards the weather has been poor. A number of La Nina-induced sub-tropical low pressure systems over summer have produced strong winds and rough seas with little respite. While we managed one day of search dives, these were in border-line conditions. Although we have attempted further dives on three other occasions, we have been prevented from diving or even grappling for the recorder by the strong East Australian Current which has set in unusually close to shore since deployment. We are hopeful that with the end of summer, the EAC may move further offshore and, together with fairer weather, provide more opportunities to recover the recorder.

3. Results

3.1 Relative abundance estimate

Land-based surveys were conducted from 20 June to 27 July 2007. Over the 6 weeks of the survey, full 10h surveys were completed on 25 days, surveys with less than 10 but at least 5 hours were completed on 4 days, and surveys were severely curtailed or called off completely on 9 days. A total of 996 groups of confirmed northbound groups passed consisting of 1824 whales including 17 calves. Mean group size was 1.83 whales. Group size is shown in Figure 4.

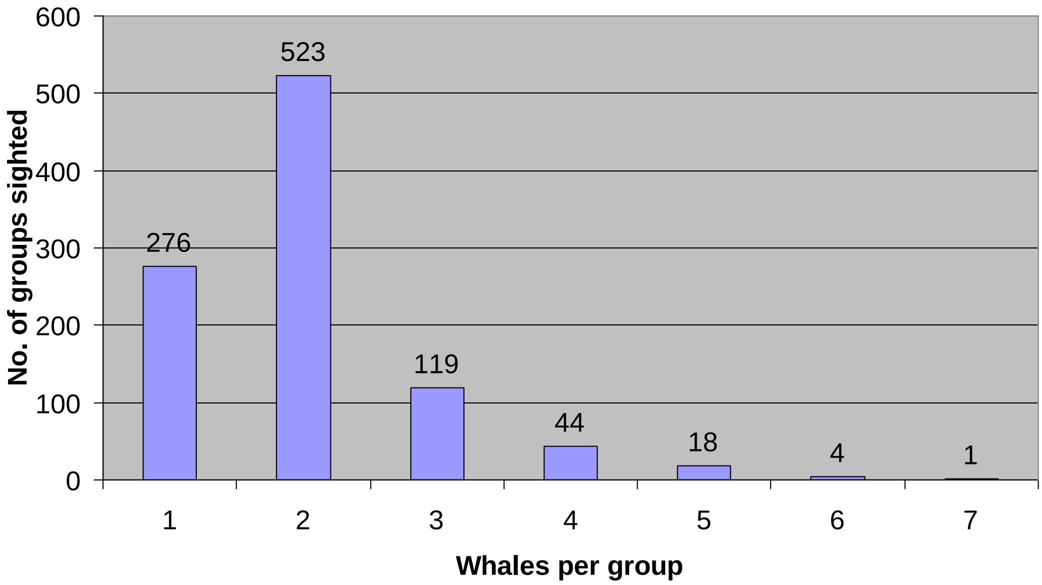

Figure 4. Number of groups seen for each size class from Norm's Seat.

The numbers of whales seen was very high initially and declined gradually over the 6 week survey (Fig. 5). The peak 4 weeks was therefore the first 4 weeks with a mean of 70.7 whales per 10h. This pattern of sightings was unusual as it was earlier than in most previous years and was apparently not bi-modal. Compared with the 2004 survey, numbers early in the 2007 survey (late June, early July) were much higher, often with more than twice as many whales per day (Fig. 5). The long-term annual rate of increase for the 24 years from 1984 to 2007 is 10.9% (95% CI 10.5 - 11.4%), up slightly from the 2004 estimate which was 10.6% (Fig. 6).

3.2 Aerial surveys

More than 8400km were flown during the aerial surveys. This included 16 full sets of long transects with a total of 3616km 'on effort'. The 16 full transects included 47 short Shag Rock transects (including the component of the long Shag Rock transects within 12km of shore). In addition, 18 extra short Shag Rock transect flights were conducted, each with an east and west transect. In total this was 1162km of 'on effort' survey.

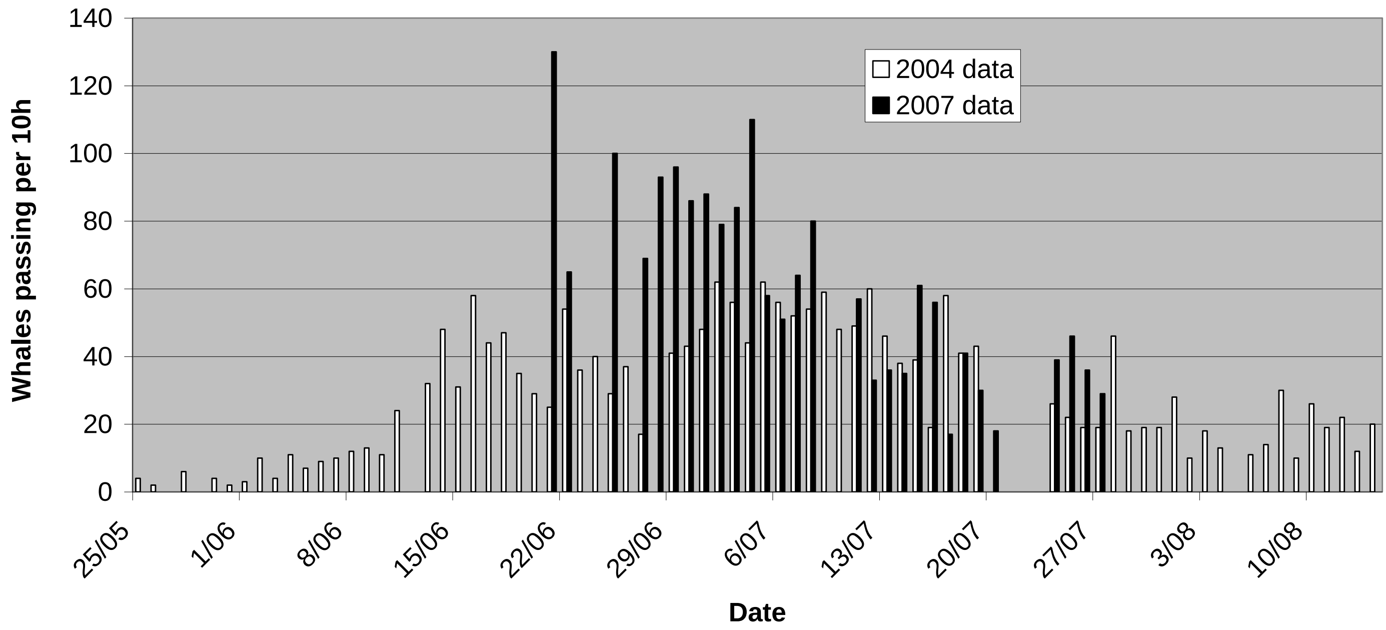

Figure 5. Whales seen per 10h for each day of survey in 2004 and 2007 where more than 5h of observations were collected. Observations have been corrected to 10h if observations were truncated.

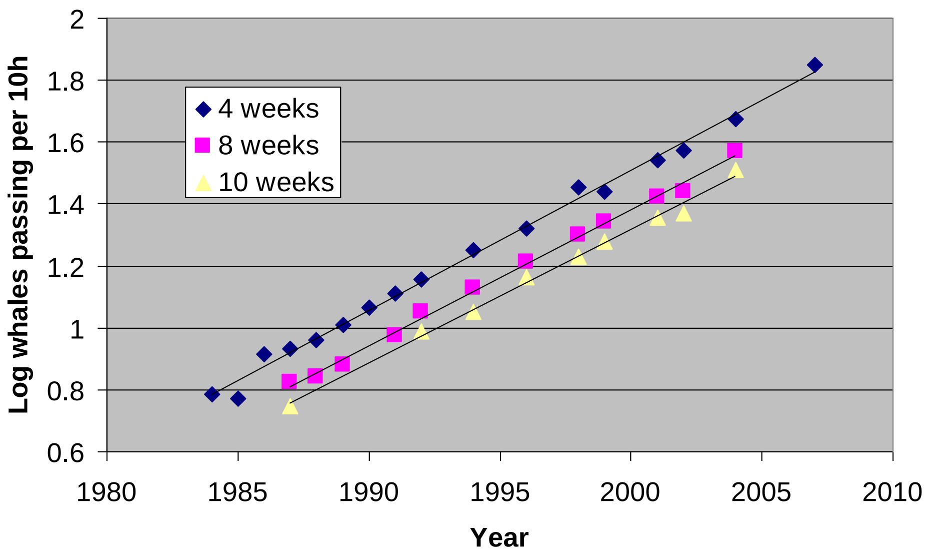

Figure 6. Log of the numbers of whales passing per 10h during the 4, 8 and 10 weeks of the peak in various years from 1984 to 2007. (Using the log of the number passing means that a constant rate of increase will appear as a straight line.) The rate of increase for the 4-week line is 10.9% (95% CI 10.5-11.4%). All data 1984 – 2002 from Paterson *et al.* (2004).

During the long transects, we spotted 162 groups including 255 whales (Fig. 7). During the short Shag Rock transects we spotted 117 groups including 187 whales. Thirty groups with 43 whales were seen during long Shag Rock transects within 12km of shore and counted in both data sets. Allowing for this, in total we spotted 249 groups with 399 whales.

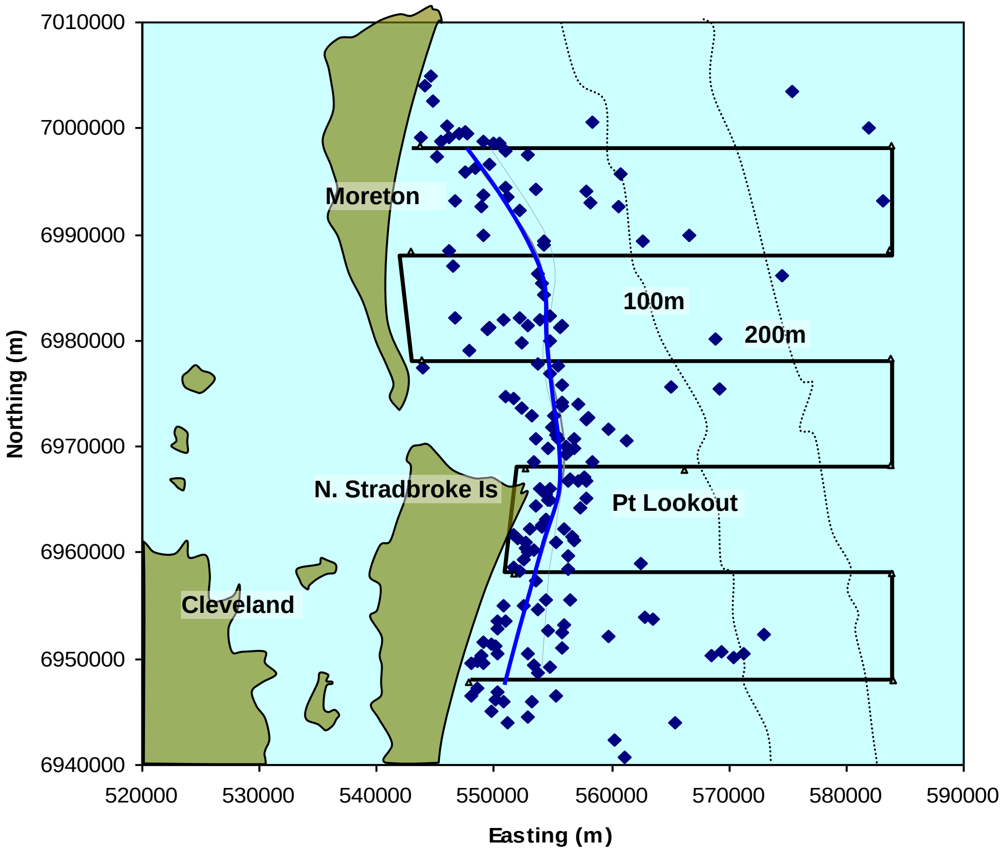

Figure 7. All groups sighted during the long transects. The dark blue line represents the mean median group distance offshore.

Using Archerfield Aerodrome in Brisbane as the primary base and the Dunwich airstrip as a staging post for daily operations worked well. It enabled the Partenavia to be chartered on a day-to-day basis to take advantage of good weather without paying for standby or bad weather days. It also allowed us to pick up spotters on Stradbroke Is. who were part of the visual surveys the rest of the time. It was only 5 min flying from Dunwich airstrip to Shag Rock which was just enough time to get to our correct altitude, start up *Cyclopes* and check that all systems were operating before commencing each survey. Being able to land half way through the long transects was greatly valued as it gave the observers a chance to stretch their legs and have a short break. Similarly it was extremely convenient to be able to land for 50 mins or so between the additional short Shag Rock transect flights.

Weather during the flights was generally good as we only flew when favourable weather was predicted. Visibility was reduced on some days due to haze, but no attempt has been made to account for this at this stage.

3.2.1 Detection of whales during aerial surveys

The detection curve showed a rapid drop off in detection of groups as a function of perpendicular distance to our flight path (Fig. 8). The increased number of sightings between 4.5 and 5.5km may indicate some bias in searching middle ground distances.

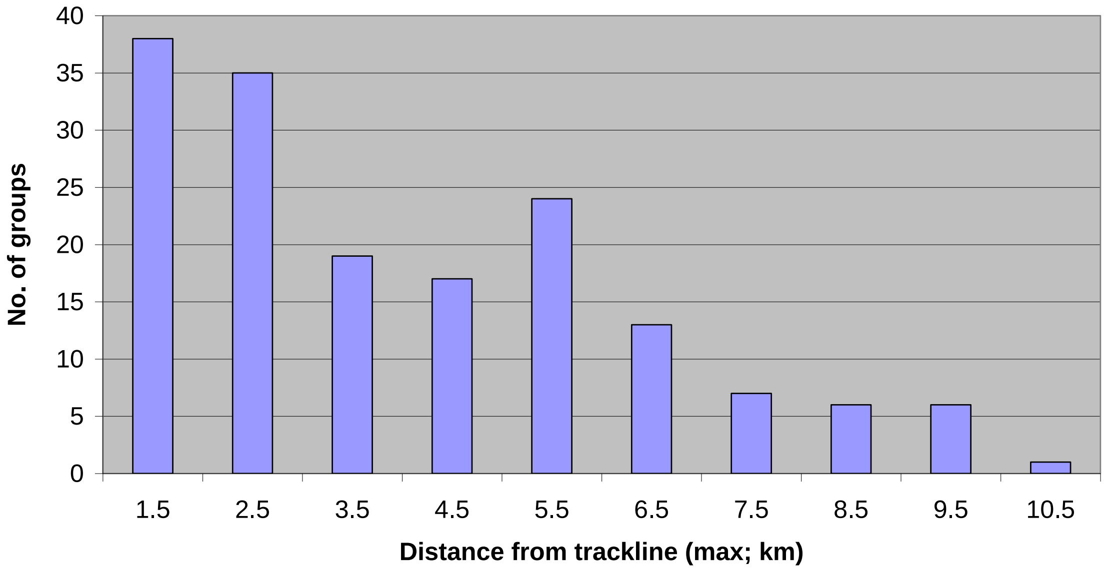

Figure. 8. Detection function curve for groups sighted during aerial surveys. Distance is measured as the perpendicular distance from the track line or flight path, not the distance from the plane. Data have been left-truncated at 500m as groups beneath the plane were not available, and right truncated at 10.5km.

3.2.2 Aerial observations of group size

The most common sighting cues were surface splashes and blows. Very few whales were seen down through the water and those that were had generally been seen first at the surface. For the most part, aerial observations were similar to land-based observations except that the elevation was much greater and there was far less time to observe the whales. As the whales could only be observed for a few surfacings at the most (depending on their distance from the track line), we found it difficult to estimate group size with any certainty. With the generally higher number of observations possible for each group with land-based observations, we felt that the group size estimates made from land were likely to be far more accurate than those from the air. Aerial surveys were likely to underestimate group size. Mean group size for aerial surveys was 1.57±0.06 while for the land-based survey it was 1.83±0.05. These were significantly different ($P<0.01$, Student's t-test).

3.2.3 Proportion of groups within 10km of Pt Lookout

From land, only 8 groups out of 815 (1.0%) were determined to pass beyond 10km and the furthest group seen was 13.6km. Using the narrowly defined 5km-wide strip directly off Norm's Seat for aerial surveys resulted in no groups seen beyond 10km. During the long Shag Rock transects, only 1 group out of 32 spotted (3.1%) was beyond 10km (11.1km). If we consider the long Shag Rock transect as well as its neighbouring transects (Dunwich and South Moreton), 2.9% of groups were seen beyond a line running north-south 10km off Pt Lookout. If this is expanded to include all long transects, 7.1% of groups were seen beyond a line running north-south 10km off Pt Lookout.

3.2.4 Whales missed from Norms Seat

Fifty-five groups of whales were seen during the short and long Shag Rock aerial transects that were within 10km and between 350° and 100° from Norm's Seat (and hence available for matching by the land-based observers). Of these 39 were matched to groups seen from Norm's Seat and 16 were not. Data were bootstrapped by re-sampling with replacement 1000 times. The mean proportion of passing groups missed by Norm's Seat observers was 29.1± 6.1%. A correction factor f_m to be applied to the land-based counts was estimated at 1.43±0.16.

Using Norm's Seat observations, the offshore distribution (the distance at which the groups passed on a bearing of 70° mag.) of 815 groups was obtained. The aerial surveys, restricted to a strip 5km wide south of the short Shag transect line, yielded offshore distribution data for 54 groups. There was no significant difference in the offshore distribution of whales out to 5km as determined by land or air (G = 4.04, d.f. = 4, P = 0.40; Fig. 9). The G-test was unable to be used for the full distribution as expected numbers were too low or observed values were zero but this included 89% of expected groups (as determined by land). The mean and median offshore distances for groups spotted by Norm's Seat were 2495m and 1788m, respectively. For the aerial surveys, the mean and median distances offshore were 2263m and 1642m, respectively.

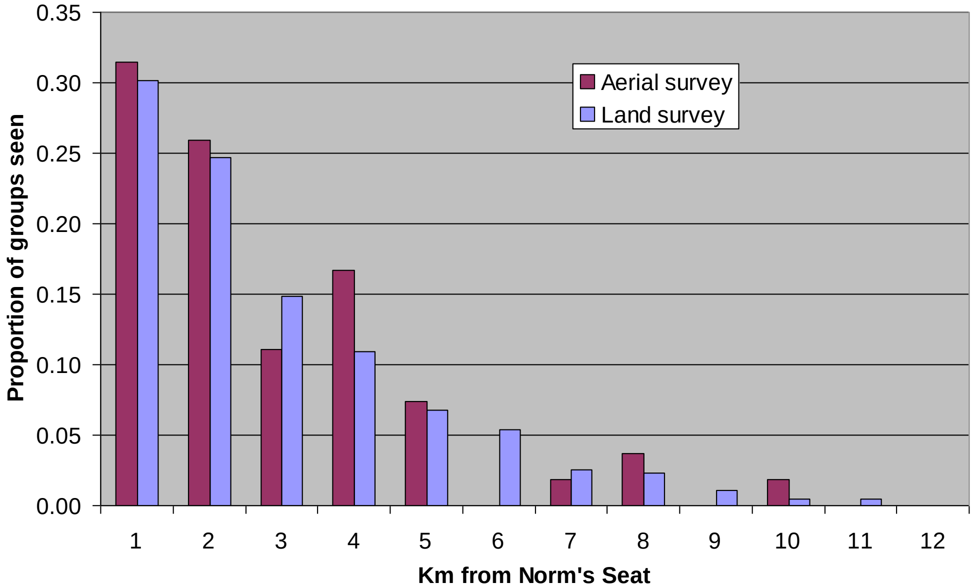

Figure 9. The distributions of groups off Pt Lookout as assessed from Norm's Seat and from aerial surveys.

3.2.5 Detectability of whales on the aerial transect line – *g(0)*

From the land based observations, we estimate that there were 207 groups of whales present in the 2.5km strip either side of the short Shag Rock transect during the short Shag Rock transect flights (regardless of whether they were seen by land or air during the transect). The aerial survey detected 61 groups in this area during the transects providing a raw *g(0)* of 32.3±4.2%. However, if 29.1±6.1% of groups are missed by the land observers then there may have been around 296±34 groups in the area leading to an adjusted estimate of *g(0)* is 22.6±3.9%.

3.3 Absolute abundance of the east Australian population

To calculate an updated absolute abundance estimate for the east Australian population, we can apply the long-term rate of growth to the 2004 estimate (Table 2). The 2004 absolute abundance estimate contains a correction factor f_m for groups available but missed as determined by double land-based counts in that year. This was estimated as 1.099±0.021. As well as applying the long-term growth rate to the 2004 absolute abundance estimate, we can therefore also calculate an alternative absolute abundance estimate using the new correction factor determined from the aerial surveys in 2007 instead of the land-based correction factor obtained in 2004.

Table 2. Two estimates of absolute abundance based on the 2004 absolute abundance estimate and the updated long-term population growth rate. Two different estimates of f_m, the proportion of groups available but missed, are used.

	Population size	SE	CV	Lower 95% CL	Upper 95% CL
Extrapolation from 2004 using 2004 estimate f_m	9,683	507	5.2%	8,740	10,729
Extrapolation from 2004 using 2007 estimate f_m	12,599	1,573	12.5%	9,874	16,076

4. Discussion

The 2007 east Australian humpback whale relative abundance and aerial surveys were successful in that most of the objectives of the studies were achieved.

4.1 Relative abundance estimate

The six week land-based survey estimated that, on average, 70.7 whales passed every 10h during the peak 4 weeks of the northward migration. This fits the pattern of the long-term trend established over the last 24 years and updates the long-term rate of growth for the population to 10.9% (95% CI 10.5 - 11.4%). There is no evidence at this stage of any slowing in the high rate of growth of the east Australian population. One problem that was encountered, however, was that the peak 4 weeks of the migration was the first 4 weeks of the survey. When planning the survey, we attempted to time it so that the peak, which is usually during the first week of July, would lie approximately half way through the 6 week survey, allowing a week's leeway either side of the peak 4 weeks. Unfortunately, the peak appears to have been early pushing the start of the peak four weeks to the start of the survey period. Although we do not know what happened prior to June 20, the peak 4-week mean is already high when placed in the context of the high upward historical trend. We therefore think it unlikely that whale numbers would have been high enough to bring the peak 4 weeks much further forward or to significantly increase the 4-week average number of whales passing.

The reason for the early peak in 2007 is unknown. The migration of the humpback is often bimodal with an early peak in mid-June (for example see 2004 data in Fig. 5), and a later, larger peak centred around early July. As previous trend analyses have used the 4 congruent peak weeks, it is this later peak that is used for trend analysis. One possibility, rather than the entire migration being early in 2007, is that the first peak was in fact delayed. If this was the case, and the second, main peak was only a little early, then the two peaks may have converged to provide a single longer, higher, more sustained peak. Chittleborough (1965) and Dawbin (1966, 1997) showed that both northward and southward migrations are segregated to some extent, with peaks of different sex- and reproductive-classes passing at different times effectively making them a series of staggered but extensively overlapping migrations. While it is possible that shifts in the timing of one or more migratory cohorts may have produced shifts in the first and second peaks, we currently have no idea what influences might cause this.

The high numbers of whales passing during busy days around the peak is becoming increasingly problematic. Norm's Seat is used because it is convenient and because it has been used by the Bryden/Brown surveys previously. It is, however, low at 32m above sea level, and has a very limited view southwards. With the increasing number of whales, a better view abeam, that is from south-east to north-east would be better than our current field of view of east-south-east to north-north-west. Viewing the passing whales abeam, rather than largely from behind as they disappear northwards, will reduce group confusion. We also need to use a narrower field of view in general, and the more this faces abeam, the better. Another aspect of moving the site is possibly to move it further back from the water. The problem with being right on the water is that groups passing in close by move through the field of view very quickly forcing us to use the entire field of view available. If we moved to a site further from the migration path, this problem would be reduced.

The remarkable consistency of the relative abundance estimate as a function of time (Fig. 6) and the small confidence interval in rate of increase is unique for whale populations in the Australian region and there are very few similar examples world wide. When a change in the rate of growth occurs, it can be expected to be detected far sooner for this population than for any other population of any species in the region. As Australian humpback whales feed almost exclusively on krill in the Antarctic and are likely to do so over wide areas, the data and survey methodology provides a very sensitive diagnostic of changes in the rate of population growth that has the potential to be an indicator of changes in conditions in the Southern Ocean, particularly regarding krill abundance. East Australian humpback whales should therefore be viewed as one of the most important Antarctic sentinel populations.

4.2 Aerial surveys

We were pleased with the outcome of the aerial surveys. We gathered data on 249 groups containing an estimated 399 whales, a much larger sample size than Brown (1996) who reported 37 groups with 63 whales in 30 flights.

The long transects provide us with the first detailed picture of the migratory path of the whales as they pass North Stradbroke Is and most of Moreton Is. As expected, the majority of the whales are inshore, effectively bottle-necking as the migratory path passes Pt Lookout, then continuing north and north-west to converge again towards the northern end of Moreton Is. Although we did not survey as far north as Cape Moreton, it would seem likely that it also acts as another bottle-neck. This though is perhaps not as tight a one as off Pt Lookout as some of the animals passing Pt Lookout appear to maintain a northerly course which takes them someway offshore from the Cape. The data confirm that Pt Lookout is an excellent site, perhaps the best in Australia, for surveying humpback whales from shore.

4.2.1 Proportion of whales passing beyond 10km

One of the aims of this study was to determine the proportion of whales passing beyond 10km of the Point. It turns out that this is rather a moot point. The most parsimonious estimate was that made using the transects closest to Pt Lookout – South Moreton, long Shag Rock and Dunwich transects – and this provides an estimate of around 3% of whales beyond 10km. This agrees remarkably well with Bryden’s original estimate of 4% based on a much smaller sample size and produced at a time with whale densities less than one-tenth of those in 2007 indicating that there has been no shift in the migratory pathway with time or increasing density.

Interestingly, if we move further north or south of the Point, the spread of whales seems to increase to some extent with 7.1% of groups being beyond a north-south line 10km out from the Point, and this increased spread can be seen in Figure 7. It is possible that the reduced eastward spread off the Point itself is just the result of sampling randomness. It might also be possible that the higher densities of whales at

Pt Lookout forced by the eastward jutting of the land attracts outlying whales in towards the Point at that latitude, and that they then spread out again once in the more open water off southern Moreton Is. One thing that is evident, however, is that they are a small number of whales much further offshore than we anticipated with groups seen at the outer limit of our transects, more than 40km from land off the middle of Moreton Is. While these are so few in number that they are not likely to affect our population estimates greatly, it is interesting to speculate that they might be heading out toward breeding grounds other than the Great Barrier Reef. The Chesterfield Reefs in the middle of the Coral Sea between Mackay and New Caledonia were once humpback whaling grounds (Townsend, 1935). Whether or not they are still frequented by humpbacks is unknown. If they are, it would be important to ascertain this population's relationship with the east Australian population.

4.2.2 Proportion of whales missed by the land-based observers

One of the most surprising results of the survey was that the land-based observers appear to be missing around 30% of the passing groups of whales. If this is the case, then the 2007 population is estimated to be 13,619 whales (95% CI 8,880 – 20, 888). This result is based on a simplistic analysis, however, and more work needs to be done to refine this figure using a distance sampling approach where covariates are introduced into a capture-recapture model in an attempt to reduce unmodelled heterogeneity (e.g. density of groups in the areas, distance offshore, sea state, visibility, observer, group size, time of day, etc.). To further complicate things, in 2004 we conducted land-based double counts and estimated that we were missing approximately 10% of the passing groups. Why this estimate should differ so much from the aerial/land-based twin platform estimate is not known at this stage. A triple-platform methodology (air and two land-based platforms) during the next survey may help resolve this issue.

The other surprising result was that there was no significant difference in the offshore distribution of whales off Norm's Seat whether measured by air or from land (Fig. 9). This was initially counter-intuitive as, once we realised we were missing groups from land, we were sure these would be the more distant groups passing. However, this analysis shows that the missing groups do not seem to be from any particular distance category. Importantly, this also demonstrates that most of the whales are passing very close to Pt Lookout with a median distance of less than 2km and 89% passing within 5km. This again demonstrates the unique situation of Pt Lookout in terms of proximity to the whales and suitability for land-based surveys.

Although these results are unexpected, they do demonstrate the value of the mixed platform aerial/land-based survey methodology. No other marine mammal survey has been ground-truthed as thoroughly as this previously.

4.2.3 Estimation of *g(0)*

In distance sampling, one critical factor in any survey is the estimation of *g(0)*, the proportion of animals that are detected along the transect line. If *g(0)* = 1, then distance surveying is extremely robust. If it is <1 then every effort has to be made to accurately estimate its value. For aerial surveys of cetaceans, *g(0)* is certainly <1 as the passage of the aircraft is so rapid that many of the whales will be underwater for the entire period when they might be seen from the aircraft, and even when at the surface, they may be missed as there will be few sighting opportunities available.

For aerial surveys of cetaceans, estimates of *g(0)* have usually relied on calculations based on average dive times and surface intervals and have not been empirically derived. Our aerial/land-based two platform design allowed us to estimate *g(0)* directly from our observations. The assumption we used here was that sighting probability was uniform out to about 2.5km from the aircraft allowing us to compare the number of groups estimated to be in a 5km-wide strip of water beneath the plane and the number of groups the aerial observers observed. There are several potential problems with this method. One is that it assumes the track-line is the flight path of the aircraft and hence takes into account the strip of water not observable beneath the plane. However, for our detection function, to take this into account, we have left-truncated the data so that the track-line effectively becomes split into a line 500m either side of the aircraft. It would be difficult to determine exactly which whales were within that 1km wide strip to account for this, but it might be possible to do so by assuming random distribution and reducing the number of groups estimated to be in the 5km-wide strip by 20%.

Further work is required to refine our estimate of *g(0)*. We need to improve our estimate of the proportion of whales missed from land so that this can be used to better estimate the number of whales within the 5km-wide strip. We also need to determine the best method of dealing with the left-truncation issue.

4.2.4 Group size estimation

One of the other aims of the aerial surveys was to determine if there was any bias with distance in accurately estimating group size. This is the one aim that could not be directly fulfilled as it soon became apparent to us that it is very difficult to estimate group size from the air as there are so few observations available for each group. Bryden (1985) determined that there was no bias in group size estimation from land, however he used closing mode, where the aircraft leaves the transect to approach and closely observe any detected group in order to provide multiple observation opportunities at close range. We did not do this during our surveys as we wanted to maximise sample size particularly off Pt Lookout for the comparison of detection rates between air and land.

We did, however, address this in a less direct way. While group size estimation may be expected to fall with distance of group, the aerial surveys confirmed that the whales do pass very close to the Point with few whales beyond 5km. Together with Bryden's (1985) previous observations, we conclude that group size estimation from the Pt Lookout land survey is reasonably accurate.

4.3 Absolute abundance of the east Australian population

Two estimates of absolute abundance estimate are presented using different values of f_m, the proportion of groups available but missed, one estimated using double land counts in 2004 and the other from the aerial/land-based matching trials presented here

(Table 2). While these estimates differ substantially, there is a great deal of overlap in their confidence intervals. This highlights the need to develop a robust correction factor. The land-based double count factor was similar to those derived in previous surveys at this site (Brown, 1996). As mentioned earlier, more work should be carried out on the 2007 aerial and land-based matching trials, to identify any errors in the current analysis. It is also possible that there are genuine differences in the estimates due to different perception biases from different platforms. This means that land-based double counts may not be independent, a necessary but possibly incorrect assumption underlying all land-based and ship-based double counts. In an attempt to correct for this, Brown (1996) attempted to account for unmodelled heterogeneity, but found this had only a small effect of her land-based double count estimates of f_m. Where the discrepancy lies between the land-based and aerial/land-based double counts is not known. Further work is required both in terms of analysis of current data and further double count experiments at Pt Lookout.

The other outstanding question regarding absolute abundance is the whether or not the entire population migrates. Brown et al. (1995), in a study at Pt Lookout in the early 1990s, determined that the ratio of males to females in the migratory population was 2.4:1. They hypothesised that this was due to the non-migration of immature females (although this would not fully account for the bias). If there is a real sex bias of this magnitude in the population dur to the non-migration of some females, our abundance estimates would too low. It would seem unlikely, however, that the bias is this large as, at least theoretically, all mature females would need to breed every second year to maintain the high rate of population growth observed and this would required them to migrate every year for alternate mating and calving. Further studies are required.

4.4 Acoustic survey

The 2007 acoustic survey has not yet produced results as we have been unable to recover the autonomous recorder. We are hopeful, however, that conditions with change, particularly regarding the EAC, and enable a successful recovery.

This is part of a long-term acoustic monitoring program and the results of the 2007 acoustic survey will be seen in context of the longer term data sets available.

4.5 Recommendations

The 2007 survey has provided an updated estimate of the rate of growth of the population and improved confidence in some of the assumptions underpinning our abundance estimates (proportion of groups within 10km, group size estimates). It has also, however, created some uncertainty, particularly with regards to the proportion of groups that we may be missing from Norm’s Seat. The land-based survey was also challenging in terms of being able to cope adequately with the high densities of passing whales on some days.

We recommend the following:

1. Land-based surveys should be continued at Pt Lookout to assess the relative and absolute abundance of the east Australian population of humpback whales.
2. Surveys should be conducted every three years with two shorter relative abundance estimates to every one longer absolute abundance survey until a departure from the current consistent trend is detected. The frequency and length of the surveys should then be reviewed.
3. The survey site should be moved from Norm’s Seat to a higher site with an improved view to the south-east.
4. Future surveys should consider a triple-platform design with land-based double counts and concurrent aerial surveys focusing on the Pt Lookout area.
5. Relative abundance surveys should be conducted for 8 weeks rather than 6 weeks to ensure that the peak 4 weeks can be adequately captured.
6. Volunteer observers should be provided with better training prior to the surveys to facilitate data collection particularly during busy periods.
7. More support should be provided for more extensive analysis of the data, not only for future surveys, but also of previous surveys.
8. The question of sex ratio of the population needs to be addressed with a review of all current information on the subject and probably a dedicated, carefully-designed study in conjunction with a future land-based survey at Pt Lookout.
9. Future deployment of autonomous acoustic recorders should be further inshore and every effort should be made to keep them out of the East Australian Current.

Acknowledgements

The 2007 east Australian humpback whale survey would not have been possible without a great number of volunteers who gave their time to spot whales, often in uncomfortable conditions, from Pt Lookout. These included Louise Bennet, Marlene Brito, Rachel Carlton, Lindsay Curtis, Anne-Cecile Dragon, Nicole Filby, Danielle Gibas, Laurent Guillaud, Kelly Keen, Jennie Lamb, Padma 'Sebastian' Mynott, Angela Recalde and Stephen Robey. Stephen Robey deserves special thanks as he also served many hours in a confined and noisy environment as the one of the two principal aerial spotters and assisted in the analysis of the aerial survey data after the end of the field season. Dr Eric Kniest, as in previous years, provided excellent support for his *Cyclopes* software, particularly in its modification for the aerial component of the survey. Dr Tim Page acted as a spotter on several flights. We would like to thank the staff of Flight Training Australia for their help in organising and conducting the necessary flights, particularly Ben Leece and our pilots Tom Christopher, Neil Waterman and Jacquie Holmes

The survey was funded by the Commonwealth Environment Research Facilities (CERF) fund through the Australian Centre for Applied Marine Mammal Science (ACAMMS).

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