An update of the east Australian humpback whale population (E1) rate of increase

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ABSTRACT

A six week land-based survey was conducted at Pt Lookout on the east coast of Australia, in June and July 2007. Over the peak four weeks of the northward migration, an average of 70.7 whales passed per 10h. This was compared with a similar metric from previous surveys at this site yielding a long-term rate of increase of 10.9% per annum (95% CI 10.5 – 11.4%), slightly higher than our previous estimate from a survey in 2004 (Noad *et al.*, 2006). This indicates that the long-term rapid increase in the size of the east Australian population of humpback whales continues without any apparent slowing. Aerial surveys were also conducted concurrently with the land-based surveys during which 249 groups of humpbacks containing an estimated 399 whales were seen from the air. 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 passed within 5km of land and the mean distances offshore for both aerial and land-based surveys were less than 2.5km. This supports one of the key assumptions of the land-based counts, that they are not greatly affected by whales missed as a function of increasing distance offshore. An estimate of absolute abundance for 2007 was 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 8,556 – 10,959).

KEYWORDS: HUMPBACK WHALES, ABUNDANCE ESTIMATE, SURVEY – SHORE-BASED, SURVEY – AERIAL, TRENDS, MIGRATION

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.

Humpback whales undertake annual migrations between high-latitude summer feeding areas and low-latitude winter breeding areas (Chittleborough, 1965; Dawbin, 1966). In the western South Pacific, the International Whaling Commission recognises several breeding populations that probably feed in Area V and western Area VI - east Australia (E1), New Caledonia (E2), Tonga (E3), Cook Islands and French Polynesian (F) (IWC 2005). While these populations 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. Together with massive illegal pelagic whaling in the Southern Ocean in the early 1960s (Yablokov, 1994; Mikhalev, 2000), whales were taken in such abundance that the population collapsed by 1962. Chittleborough (1965) estimated the original Group V population (synonymous with breeding group E) 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 total breeding group E 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 (breeding group E1 only).

Previous land-based surveys at Pt Lookout. Post-whaling surveys of the east Australian population were initiated at Pt 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 southeast 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 and continued by Miranda Brown 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 and Patricia Paterson 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. We took over the surveys in 2004 (Noad *et al.* 2006).

Despite some minor differences in survey site and substantial differences in survey design and data analysis, both the original BB and PC series of surveys were 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 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.*, 2006)

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). The 2004 survey produced a best estimate of 10.6% (10.1-11.1%) for the period 1987 – 2004 (Noad *et al.*, 2006). 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).

In terms of absolute abundance, Noad *et al.* (2006) calculated the population size in 2004 to be 7,090 ± 660 (95% CI) whales. This was consistent with previous BB and PC estimates and rates of increase.

Aerial surveys at Pt Lookout. Bryden (1985) first conducted aerial surveys of east Australian humpback whales in 1980 and 1981 and 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. Since then all Pt Lookout land-based surveys have assumed that essentially all whales in the population pass within 10km of land and are available for visual detection. This was based, however, on sightings of only around 25 groups of whales in the vicinity of Pt Lookout. Brown (1996) conducted more 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. With a long-term rate of increase of around 10.5-11% per year, the 2007 population was expected to have 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 and to again test whether most, if not all, whales pass within 10km of Pt Lookout despite the much higher densities off the Point particularly around the peak of the migration.

Aims of this study. The aims of this study were to (i) measure the rate of whales passing over the four peak weeks of the northward migration in 2007 and compare this to previous rates to update the rate of population increase, (ii) use aerial surveys to determine the distribution of whales off Pt Lookout including the numbers of whales passing beyond 10km from land.

METHODOLOGY

The survey was conducted from Pt Lookout (27° 26’ S, 153° 33’ E) on North Stradbroke Is. over six weeks 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 2004 survey (Noad *et al.*, 2006). Aerial surveys were conducted concurrently with the land-based surveys on 16 days between 3 July and 27 July 2007.

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

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 and were balanced in terms of their mix of previous experience and ability. 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* 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.

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.

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).

Data analysis. Daily whale counts were compiled using the *Cyclopes* files. If days had less than five hours of usable data, they were discarded. For days with more than five 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. The log of the mean number of whales sighted per 10h was then linearly regressed with four-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 groups 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 1km-wide bins.

Aerial survey. The aerial surveys used a Partenavia high-wing, twin-engine aircraft flying at 1500' and 100 – 110 knots. Flights were initially delayed by strong westerly winds and some rain. The first full flight was conducted on 3 July. 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 (Fig. 3). All long and short transects were flown either east-west or west-east. The long transects extended from the shoreline of Moreton and North Stradbroke Islands to the longitude 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 of 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 10kts) but once on the water, the wind was up to 15kts on some days. Usually the flight coordinator sat in the front seat next to the pilot while the two observers sat in the middle seats. The same observers were used for all flights and sat in the same positions for all flights. After completion of the first short Shag Rock transect and first four long transects (ending with the long Shag Rock transect), the aircraft would land to allow the observers to have a break. After half an hour or so, the aircraft would takeoff again 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 six 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.

A total of 16 full sets of transects were completed on different days between 3 July and 27 July. From flight 11 onwards, we also started conducting extra short Shag Rock transect flights in addition to the main flights. These were spaced at least an hour apart to allow for whales to move through the area. The aircraft would fly out from Shag Rock to the 12km offshore waypoint, do a tear-drop turn, and return along the same path to Shag Rock. Whales were observed on both legs but only one leg was generally used in analysis to preserve independence.

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 aircraft 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. Data collected for each group observed included time, horizontal and vertical angles (using protractors and inclinometers), sighting cue and group size. *Cyclopes* recorded the position of the aircraft and calculated the position of the sighted group in real-time.

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.

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.

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. The short Shag Rock transects were conducted approximately 2.5km north of the visual observation site at Norm's Seat so that whales directly east of Norm's Seat could be seen from the plane. This also meant that whales seen from the plane could effectively be anywhere from 12km or so north of Pt Lookout to 8km 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 from the air 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 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 five (Sokal and Rohlf, 1995, p.702).

RESULTS

Relative abundance estimate. Land-based surveys were conducted from 20 June to 27 July 2007. Over the six weeks of the survey, full 10h surveys were completed on 25 days, surveys with less than 10 but at least five hours were completed on four days, and surveys were severely curtailed or called off completely on nine days. A total of 996 groups of confirmed northbound groups passed consisting of 1,824 whales including 17 calves. Mean group size was 1.83 whales (Fig. 4).

The numbers of whales seen was very high initially and declined gradually over the six week survey (Fig. 5). The peak four weeks was therefore the first four 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 bimodal. 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 was calculated to be 10.9% (95% CI 10.5 - 11.4%), up slightly from the 2004 estimate which was 10.6% (Fig. 6).

Aerial surveys. More than 8,400km were flown during the aerial surveys. This included 16 full sets of long transects with a total of 3,616km '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 1,162km of 'on effort' survey.

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.

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 concluded 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).

Offshore distribution of whales. From land, only eight 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 one group out of 32 spotted (3.1%) was beyond 10km (11.1km; Fig. 7). 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.

Using land-based 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 Rock 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. 8). 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 2,495m and 1,788m, respectively. For the aerial surveys, the mean and median distances offshore were 2,263m and 1,642m, respectively.

Absolute abundance of the east Australian population. To calculate an updated absolute abundance estimate for the east Australian population, we applied the long-term rate of growth from this study to the 2004 estimate of 7,090 ± 337 whales. This produced an estimate for 2007 or 9,683 ± 612 whales (95% log-normal confidence interval 8,556 – 10,959 whales).

DISCUSSION

Relative abundance estimate. The six week land-based survey determined that, on average, 70.7 whales passed every 10h during the peak four 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 four weeks of the migration was the first four 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 six week survey, allowing a week's leeway either side of the peak four 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 four-week mean is already high even 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 four weeks much further forward or to significantly increase the four-week average number of whales passing.

The reason for the early peak in 2007 is unknown. The migration of the humpbacks 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 four 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 might cause this.

Aerial surveys. 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. The data confirm that Pt Lookout is an excellent site, perhaps the best in Australia, for surveying humpback whales from shore.

Offshore distribution of whales at Pt Lookout. 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 around one-fifteenth of those in 2007 indicating that there has been no shift in the migratory pathway with time or increasing population and 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 (Fig. 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 there 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 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.

Group size estimation. We found it 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, 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 accurate.

Absolute abundance of the east Australian population. Our estimate of absolute abundance is an extrapolation based on our 2004 estimate (Noad *et al.*, 2006) and is therefore also prone to any errors in that survey. The current study, however, does test one of the major assumptions that was made for the 2004 survey: that all whales can be expected to be sighted from Pt Lookout. The current study not only confirms Bryden's (1985) original assertion that the great majority of whales pass within 10km of Pt Lookout, but also shows that most of these pass within 5km. Further we demonstrate that there is no significant difference between the offshore distribution as measured by land or air suggesting that sightings from land do not suffer greatly as a function of distance. This allows greater confidence in the 2004 result with regards to whether or not many whales are missed as a function of distance.

The other outstanding question regarding absolute abundance, however, is the whether or not the entire population migrates, and this remains unaddressed. 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 due to the non-migration of some females, our abundance estimates would be too low. It would seem unlikely, however, that any bias would be of this magnitude 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.

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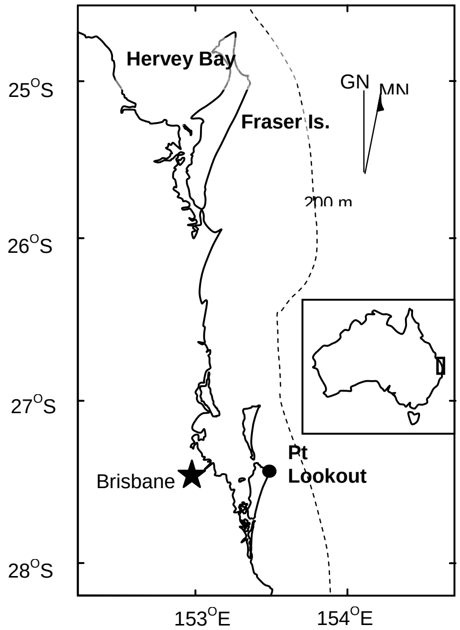

Figure 1. Southeast Queensland showing the position of Pt Lookout on North Stradbroke Is. The edge of the continental shelf is indicated by the 200m isobath (dashed line).

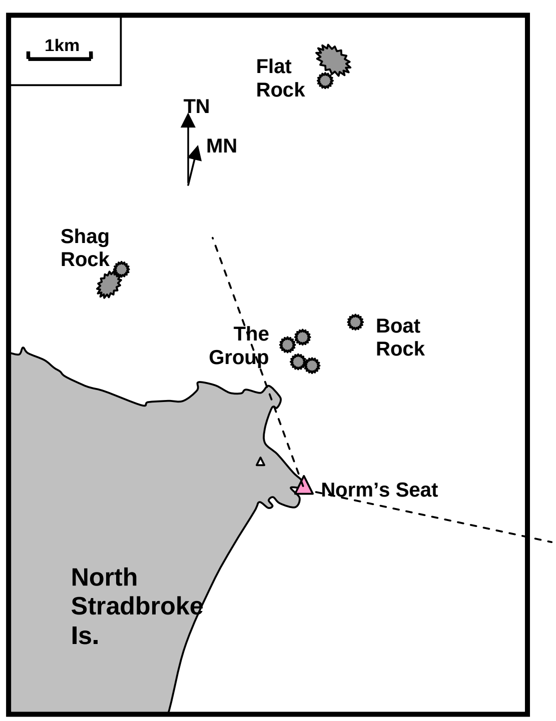

Figure 2. Pt Lookout and environs. Norm's Seat is the land-based survey site. Field of view is indicated by dashed lines. TN = true north; MN = magnetic north. The offshore islets are exposed rocks that may have seas breaking over them in heavy weather.

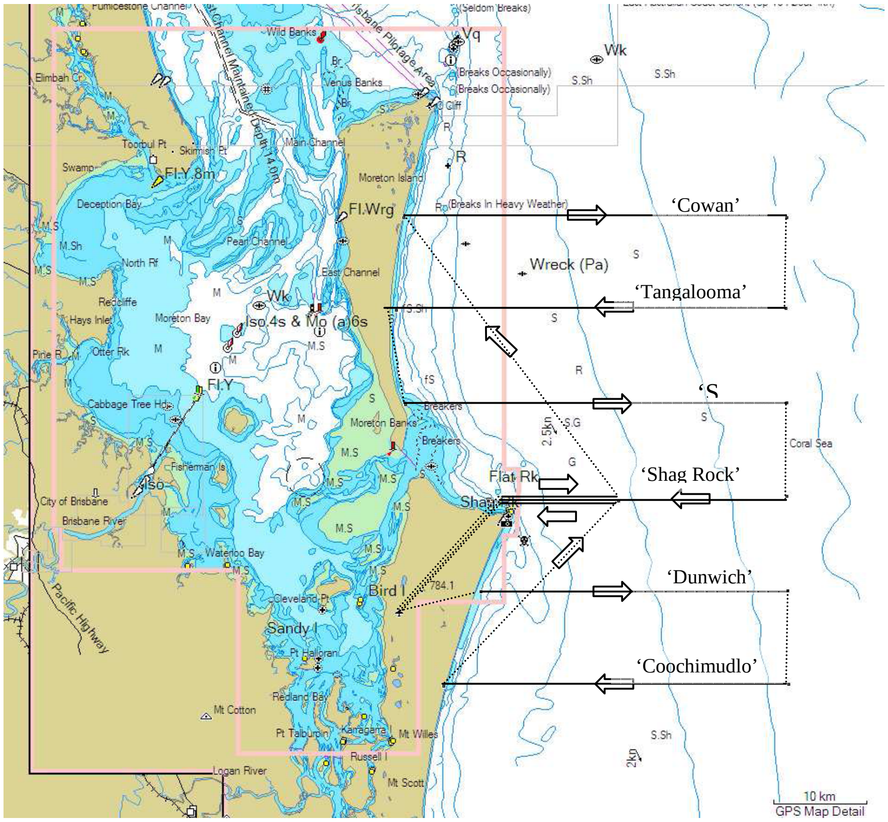

Figure 3. Flight pattern for aerial observations. East-west or west-east lines are 'on effort' while lines with any north or south component are connecting 'off-effort' legs. Arrows indicate flight direction.

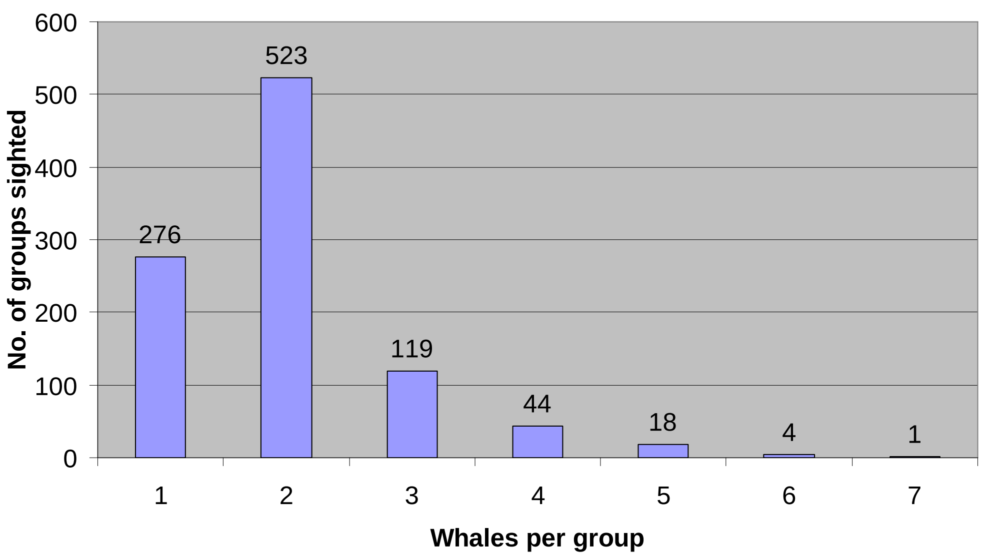

Figure 4. Number of groups seen for each size class from Norm's Seat.

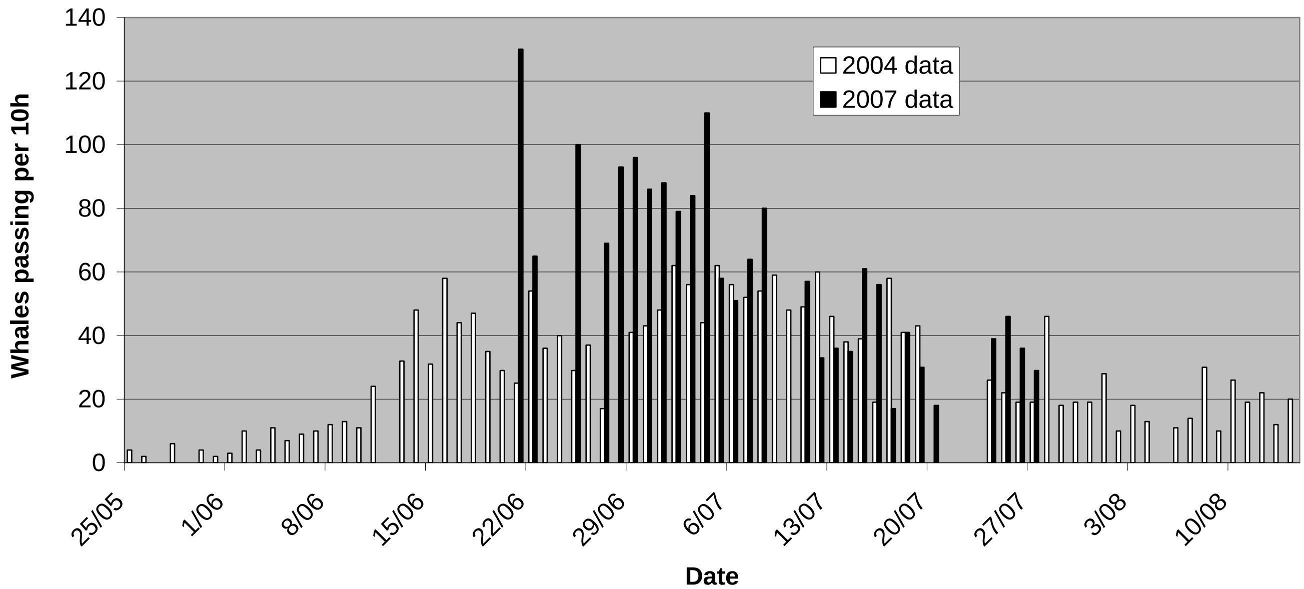

Figure 5. Whales seen per 10h for each day of survey in 2004 and 2007 where more than 5h of observations were collected. Observations have been corrected to 10h if observations were truncated.

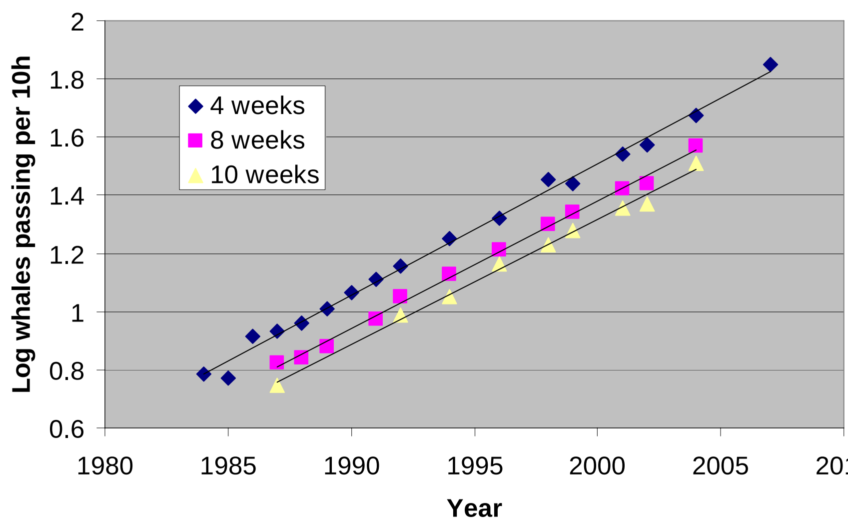

Figure 6. Log_{10} of the numbers of whales passing per 10h during the 4, 8 and 10 weeks of the peak in various years from 1984 to 2007. (Using the log of the number passing means that a constant rate of increase will appear as a straight line.) The rate of increase for the four week line is 10.9% (95%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

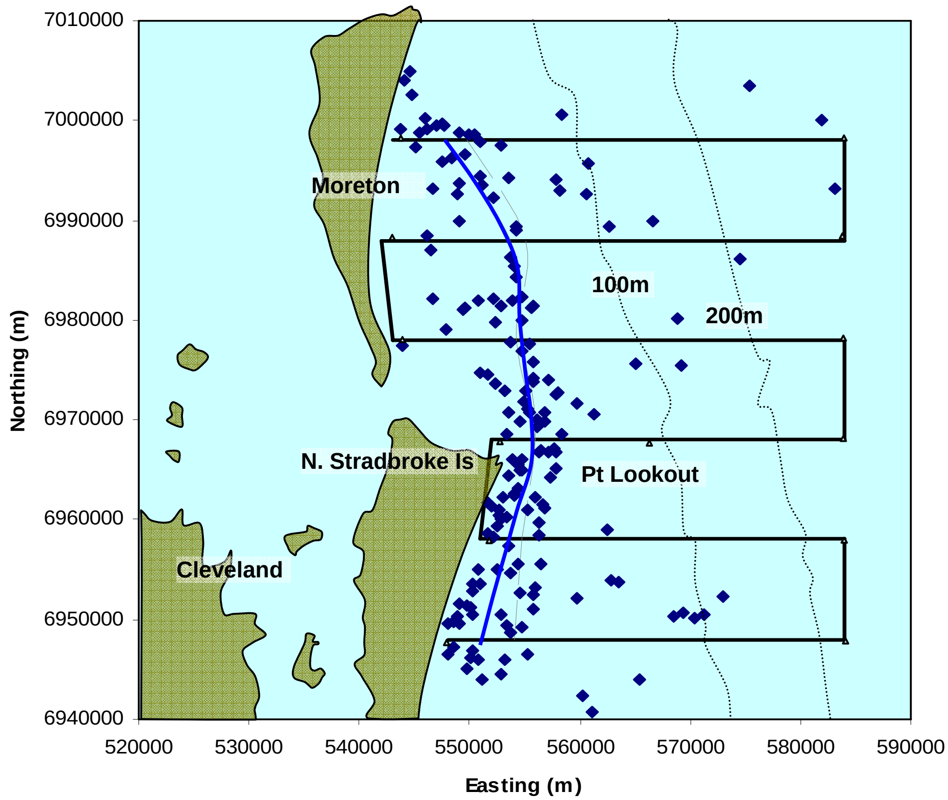

Figure 7. All groups sighted during the long transects. The dark blue line represents the mean median group distance offshore.

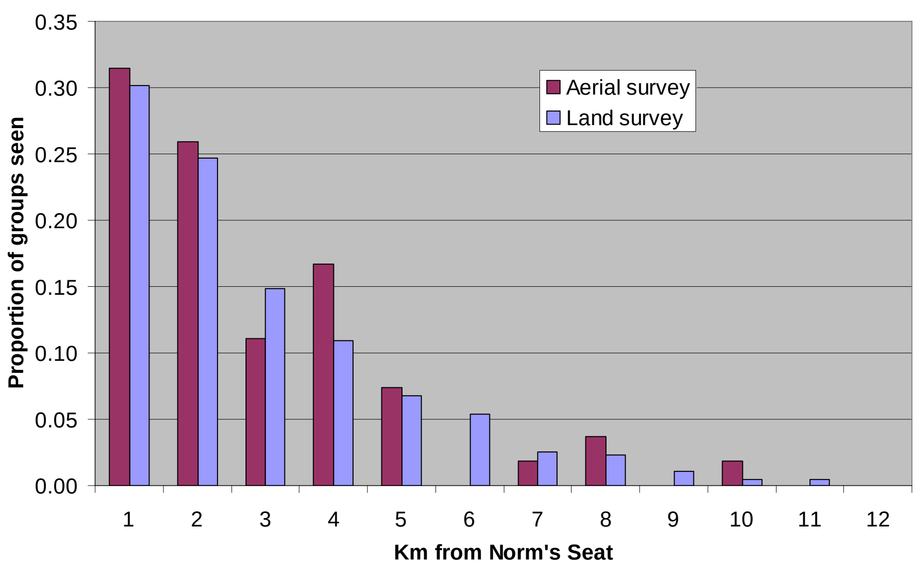

Figure 8. The distributions of groups off Pt Lookout as assessed from Norm's Seat and from aerial surveys.