Abundance estimates of the east Australian humpback whale population: 2010 survey

Final Report for the Australian Marine Mammal Centre, Australian Antarctic Division

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Abstract

This is the final report under the agreement between the Australian Marine Mammal Centre and The University of Queensland. The project has progressed largely as detailed in the original funding proposal. Land-based surveys proceeded at the new survey site above Frenchman's Beach thanks to the generous support of the Redland City Council who built us an excellent, dedicated, elevated viewing platform. Throughout the middle part of the eight week survey period, concurrent surveys occurred at Frenchman's and the old site, Norm's Seat. This confirmed that no correction factor was required for data from Frenchman's to maintain comparability with previous surveys. The field season finished on time and within budget.

The survey data indicate that the long-term pattern of rapid increase in the size of the east Australian population of humpback whales continues. The average number of whales passing Pt Lookout per 10h over the peak four weeks of the northward migration was 84.7 whales. The high long-term rate of population growth is maintained at 10.8% per annum (95% CI 10.4-11.3%). There is no evidence at this stage that the rate of growth is slowing, but a logistic function fitted to the survey data suggests that this is likely to occur over the next few years.

Using an updated land-based correction factor for groups available but missed and the 2010 relative abundance estimate, 2010 absolute abundance is estimated at 14,522 whales (95% CI 12,777 – 16,504). The population is estimated to be approximately 50% recovered with a projected *K* of approximately 30,000 whales. This may, however, be an underestimate due to possible non-migration of some cohorts. We recommend conducting a longer absolute abundance survey in 2013. The 2013 survey should include additional work aimed at measuring the sex bias of the population and should be preceded by a short workshop to develop an appropriate methodology for such a study.

Acoustic recordings were collected at Pt Lookout by Ann Allen, a PhD student from the Woods Hole Oceanographic Institute (WHOI), with our help rather than by ourselves. This proved a fruitful collaboration as the methods Ann used were very similar to those we had proposed using in any case, and resulted in the collection of the envisaged data set.

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 30 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 abundance for any population of whales in the world.

This report concerns the latest survey of this population, conducted in the winter of 2010. At eight 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. An important component of the survey was to shift the primary survey site from Norm's Seat to the lookout above Frenchman's Beach, to gain better height and a better angle of view, as well as to reduce competition with locals and tourists for viewing space.

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 summered 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, the New Caledonian population E2, the Tongan population E3 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, while widely dispersed inside the Great Barrier Reef, is probably centred on the waters of the southern lagoon, between 20° and 22°S (Smith *et al.*, 2010). 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 making the whales available for land-based counts (Bryden, 1985; Paterson, 1991; Noad *et al.*, 2008).

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 recently reported catches in the Southern Ocean.

Jackson *et al.* (2006) estimates the original size of Group V to be 35,000 – 40,000 while Jackson *et al.* (2008) estimate the pre-exploitation east Australian population to have been 22,00 – 25,700 while the combined Oceania populations (E2, E3 and F) were 17,800 – 20,600. 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 is not known, the rapid recovery of east Australian whales and apparent lack of recovery of whales migrating past New Zealand (Gibbs and Childerhouse, 2004) and in other parts of Oceania 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 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 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 Douglas Cato of the Defence Science and Technology Organisation (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, the surveys were taken over by us in 2004 (Noad *et al*., 2006a,b, 2008).

While both the original series of surveys were conducted at Pt Lookout, the BB surveys observed from a headland approximately 32m above sea level while the PC surveys were conducted from a 65m high hill approximately 300m 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. The survey included periodic double-counts from an adjacent part of the Pt Lookout headland with a similar elevation and angle of view, and these blind double-counts were used to estimate correction factors for whales missed by observers (as had been done in some previous BB surveys). In addition to estimating both absolute abundance and the rate of population increase, we demonstrated that the analytical techniques used by both previous surveys led to very similar results and that the two original series of surveys were comparable (Noad *et al*., 2006a,b). In 2007 we conducted a shorter, six-week, relative abundance survey, also from Norm's Seat, to continue the long-term monitoring of the population. We also conducted a series of aerial surveys, the first comprehensive flights since Bryden in the early 1980s (Bryden, 1985).

Prior to 2004 the most recent published 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 (eight weeks around the peak) (Noad *et al.*, 2006a,b) while the 2007 survey produced an estimate of 10.9% (95% CI 10.5-11.4%; 1984 - 2007) (Noad *et al.*, 2008). 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.*, 2006a,b).

In terms of absolute abundance, Noad *et al.* (2006a,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. Estimates of absolute abundance for 2007 were made by extrapolating from the 2004 absolute abundance estimate using the 2007-derived rate of increase. Using the land-based correction factor for groups available but missed f_m estimated from the double land counts in 2004, the 2007 absolute abundance was estimated at 9,683 whales (95% CI 8,740 – 10,729) (Noad *et al.*, 2008). The 2007 aerial surveys, however, suggested that the correction factor should be larger, and using the higher correction factor produced an estimate of 12,599 whales (95% CI 9,874 – 16,076).

Further analyses of existing data were recommended to resolve the discrepancies in the land-based and aerial-land estimates of groups missed. Dunlop *et al.* (2010) undertook this study and showed that (i) some matches had been missed in the original analysis, (ii) significant heterogeneity in sighting probabilities had not been included in the original analysis, and also (iii) by relaxing the strict matching criteria we used for matching the land and aerial sightings, almost all groups sighted from the air were in fact accounted for by the land-based observers. This effectively increased the value of f_m for the land-based double count experiments of 2004 and reduced it for the aerial to land-based experiments of 2007, largely resolving the discrepancy between the two.

1.3 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.

1.4 Other east coast surveys

Surveys were conducted at Cape Byron from 1978 to 2008. Initially conducted by Project Jonah (later the Australian Whale Conservation Society) from the ridge north of the lighthouse, two of the current authors, DP (then at Southern Cross Univ.) and EK started running surveys from the lighthouse itself in 1995. These surveys continued most years until 2008. Although the later lighthouse surveys were usually only conducted for 16 days each year and the data were, as a consequence, more variable than those gathered over longer surveys at Pt Lookout, the general population trend was 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, 2004, 2008, 2009 and 2010 (Noad and Cato, 2001, 2007; Noad, 2002, 2010; 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 (unpub. data).

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.

1.5 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 Pt Lookout and to use this, with previous survey results, to calculate the rate of population increase.

b) To move the primary survey site from Norm’s Seat to the ridge above Frenchman’s Beach.

c) Use the updated rate of increase together with updated estimates of the numbers of whales missed and the revised 2004 population estimate to make an estimate of absolute abundance for 2010.

d) To collect acoustic data concurrently with the visual sighting data 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 an eight-week period from 29 May to 25 July 2010 (Fig. 1). The field methodology for the 2010 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 surveys of 2004 and 2007 (Noad *et al.*, 2006 a,b, 2008). The main departure from these surveys, however, was the use of the ridge above Frenchman’s Beach as the primary survey site at Pt Lookout rather than Norm’s Seat.

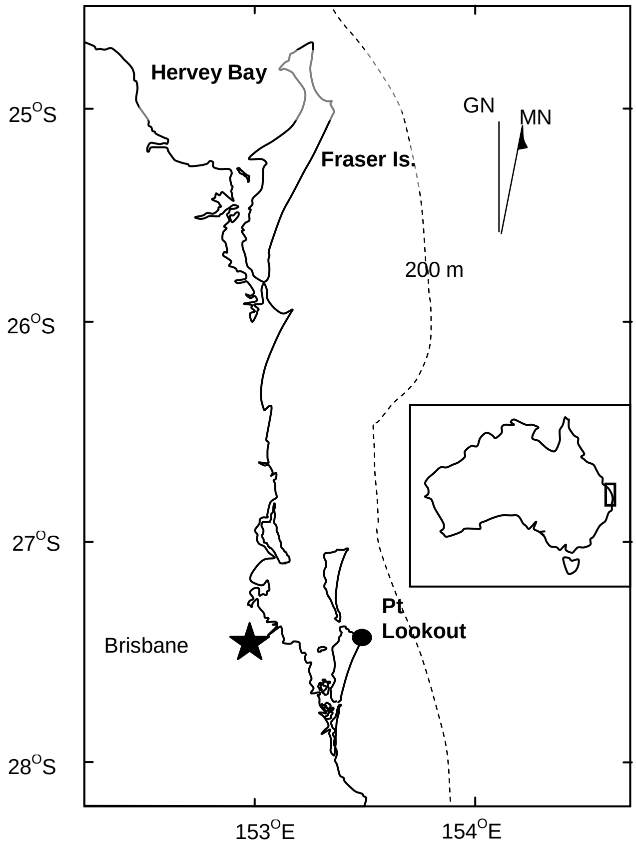

Figure 1. Southeast Queensland showing the position of Pt Lookout on North Stradbroke Is. The edge of the continental shelf is indicated by the 200m isobath (dashed line).

2.1 Survey site

Previous surveys used ‘Norm’s Seat’ (27° 26.067’ S, 153° 32.770’ E) as the primary survey site. This location is approximately 32m above sea level with a field of view from the east-south-east to the north-west (Fig. 2). The lookout on the ridge above Frenchman’s Beach is located at 27° 25.692’ S, 153° 32.448’ E with a height to the theodolite of 58m. The view from Frenchman’s was more easterly than that of Norm’s Seat, with unobstructed views from the south-east to north-north-east.

Surveys were conducted from Frenchman's Lookout every good-weather day during the survey. Simultaneous, full time surveys were conducted from Norm's Seat from 24 June to 10 July to enable the new site to be calibrated against the old.

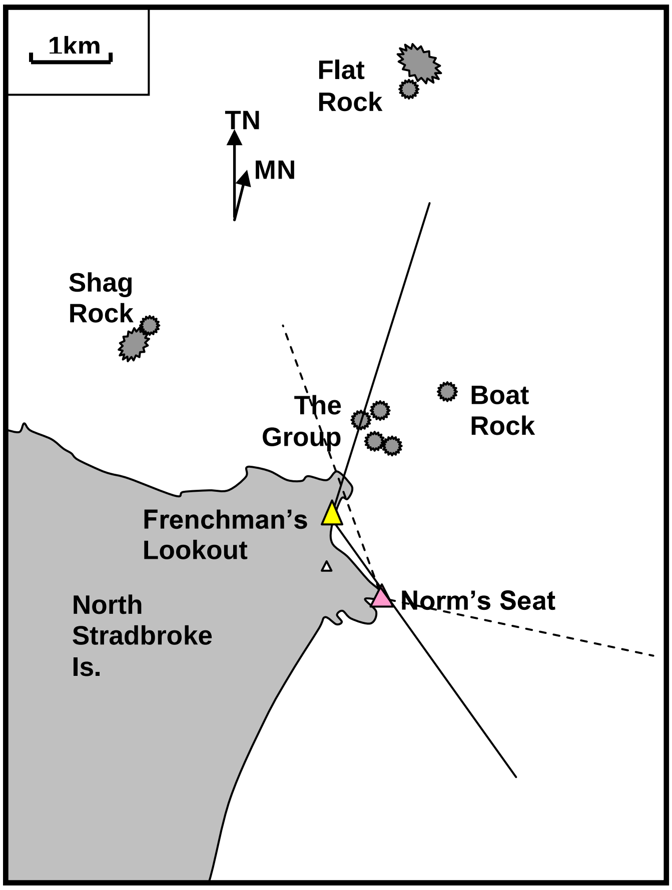

Figure 2. Pt Lookout and environs. The lookout above Frenchman's Beach is shown as a yellow triangle with limits of field of view indicated by solid lines. Norm's Seat is indicated with a pink triangle with field of view indicated by dashed lines. TN = true north; MN = magnetic north. The offshore islets are exposed rocks that may have seas breaking over them in heavy weather.

2.2 Watch structure and data collection

At both sites 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 20kts). 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 at each site and sightings were input directly into a notebook computer running *Cyclops Tracker* software (written by EK). A theodolite, connected directly to a notebook computer at each site, was also used to measure the positions of passing groups of whales in *Cyclops* 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 evenly as possible.

Figure 3. The original lookout platform above Frenchman's Beach. This platform would have been a tight fit for our team and the Redland City Council were concerned that our exclusive use of the platform would deny access to ratepayers and tourists. Additionally the view from the platform was partly obstructed to the south and the platform would not have been stable enough for the use of a theodolite.

As in previous surveys, at least one observer in each watch was 'experienced' with a minimum of one month (approximately 150h) survey time at Pt Lookout, or several seasons of prior field experience with humpback whales at other locations. In practice, this was usually RD, DP or Louise Bennet, all highly experienced observers, DP and RD having coordinated the 2004 and 2007 surveys at Pt Lookout as well as all three being involved in many other previous humpback whale land-based surveys at different sites. After the first few weeks, some of the volunteers took over 'team leader' roles once we were confident that they were excellent observers.

Cyclops software was developed specifically for the tracking of marine mammals. The theodolite operator pointed the theodolite at a surfacing group (one or more whales) and, by pushing a button, sent the vertical and horizontal angles directly to the laptop computer running *Cyclops*. The position of the group was calculated correcting for tides, curvature of the earth and refraction, and was plotted immediately on an on-screen map of the area. *Cyclops* also accepted information on the group's composition, behaviour and direction of travel (added by the computer operator) and computed the group's speed, course and distance from any reference point. For each group sighted the following information was recorded using *Cyclops*:

- 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

Figure 4. To get around the problems of view, use by rate payers, stability, etc, the Council elected to fund and have built for us a scaffolding tower and platform for our exclusive use above the existing wooden platform. While the initial platform had a floor height of approximately 5m above the ground (pictured here) the tower was much higher than required and the excessive height caused some instability. The top of the tower was therefore dismantled to reduce the height to the floor to about 3m from the ground.

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 usually diagnostic 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). It should be noted, however, that while minkes, Bryde's and southern right whales have all been seen from Pt Lookout, they are rare and vastly outnumbered by humpbacks.

Figure 5. The modified tower was an excellent survey platform. Although the platform itself moved slightly and vibrated, the theodolite was mounted on the top of a thick pole which went through the platform floor to the ground and which was securely fixed to the underlying wooden platform. This provided great stability. In this photo we can see the theodolite operator (standing), the computer operator (right) and the three spotters looking at their respective sectors (from left to right: south-east, east and north-east).

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 both sites 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 ‘abeam’ extending seawards 70° from magnetic north (81° from true north) between 0700 and 1700. For whales not observed on both sides of the line (particularly at the beginning and end of the survey day) their time of crossing the line was estimated using their swim speed derived by theodolite tracking. 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).

2.3 Data analysis

Daily whale counts were compiled using the *Cyclops* files. If days had less than 5h of usable data, they were discarded. For days with more than 5 but less than 10h 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 and the average number of whales passing per 10-h over the peak four weeks of the study was calculated. The log of this was then linearly regressed with logged four-week count data from previous surveys to obtain the long-term rate of increase.

Absolute abundance for 2010 was estimated using a combination of the results of the 2004 absolute abundance survey (Noad *et al.*, in press), a revised value for f_m, the proportion of whales missed from land (revised initially by Dunlop et al, 2010, and further refined by Dudgeon *et al.*, in prep.), and the long-term rate of increase to update this to 2010 (as calculated above). For each parameter (2004 estimate prior to correction by f_m, the revised estimate of f_m and the rate of increase), the CVs were combined using the delta method to provide a SE for the resultant population method. This was then used to calculate asymmetrical 95% confidence intervals.

2.4 Acoustic survey

To record humpback whale song, an autonomous underwater recorder was deployed just east of Boat Rock in about 20m of water from 28 June to 11 July. The recording system was deployed by Ann Allen, a PhD student from the Woods Hole

Oceanographic Institute (WHOI) in the USA. Ann aimed to record song and ambient noise, then, in a second part of the study, play some of the noise back to the whales to see if they thought it might be a rocky reef with breaking waves and avoid it. Unfortunately this second phase did not occur due to problems with sourcing appropriate gear, but the recordings did provide a good record of passing singing humpbacks.

3 Results

3.1 Relative abundance estimate

Land-based surveys were conducted from 1 June to 24 July 2010. Over the eight weeks of the survey, full 10h surveys were completed at from the lookout above Frenchman's Beach on 33 days, surveys with less than 10 but at least 5 hours were completed on 14 days, and surveys were severely curtailed or called off completely on seven days. A total of 1169 groups of confirmed northbound groups were observed from Frenchman's consisting of 2458 whales including five calves. Mean group size was 2.12 ± 0.031 whales. Group size is shown in Figure 6.

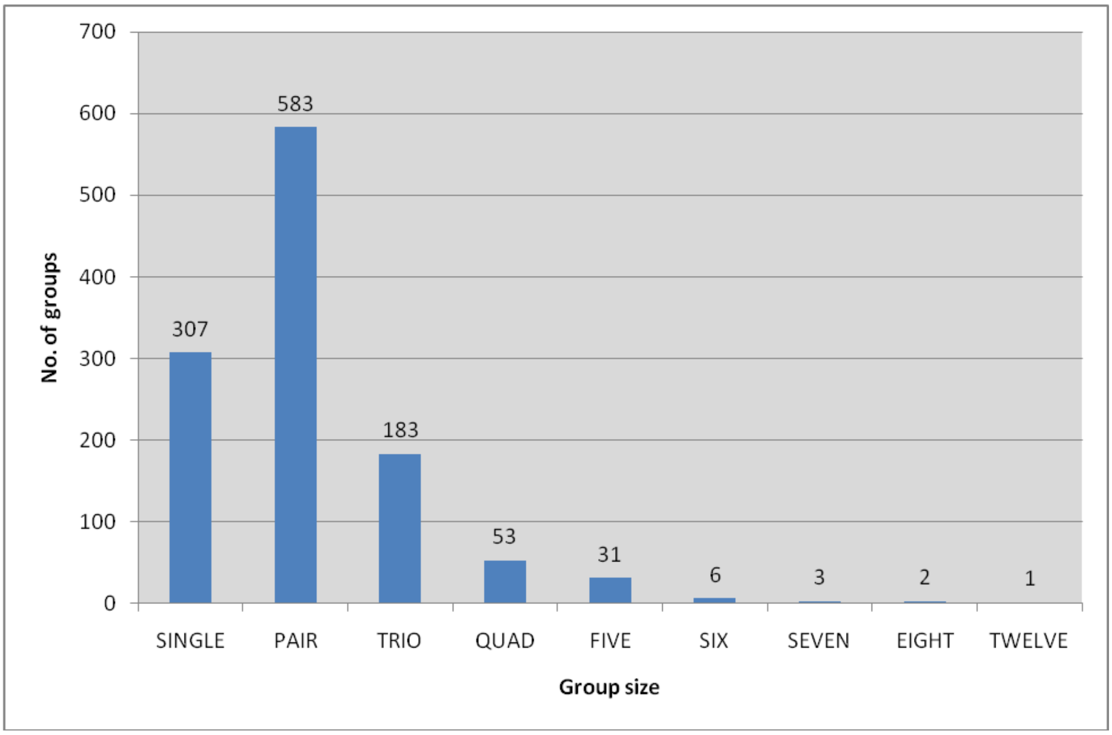

Figure 6. Number of groups observed for each size class from Frenchman's. Group size was recorded as the size when seen initially and so did not take into account subsequent joining together or splitting apart of groups.

The numbers of whales seen rose gradually to about 27 June then plateaued more or less until the end of the survey on 24 July (Fig. 7). The peak four weeks was calculated to be from 26 June to 23 July with an average of 84.7 ± 3.2 whales per 10h over that period.

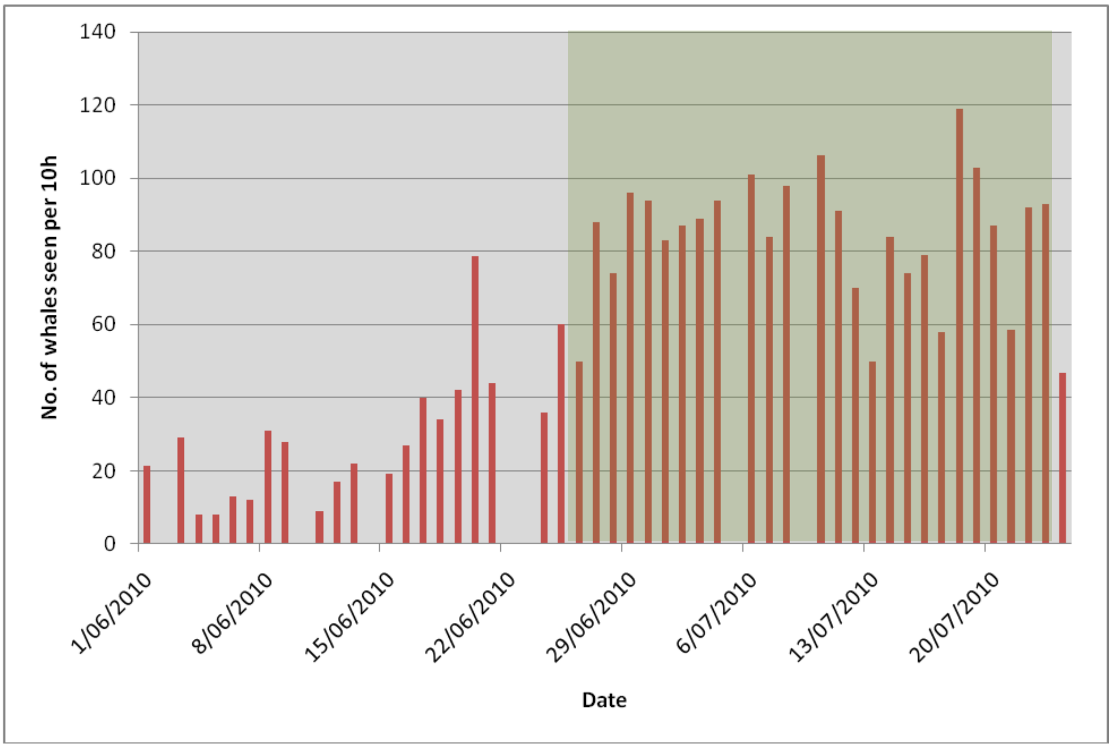

Figure 7. Daily counts normalised to 10h from Frenchman's Lookout. The peak four weeks is shaded green.

This pattern of sightings had a later peak than is typical for Pt Lookout. When compared with the 2004 and 2007 surveys, however, it can be seen that the timing of the peak is similar to 2004, while 2007 was abnormally early (Fig. 8). While many of Paterson *et al.*'s (1991, 2001, 2004) previous surveys show a bimodal peak with a small early peak, a dip around mid June then a larger peak from late June into July, this was not evident in either the 2007 or 2010 surveys although a weak bimodal peak can be seen in 2004.

Between 24 June and 10 July, full time (weather permitting), simultaneous surveys were carried out at Frenchman's and Norm's Seat. Although we had planned to start these parallel surveys on 22 June, bad weather delayed this by two days. Over the 17 day period, full 10h counts were conducted at both sites on 11 days and matching 5h counts were conducted on two other days. For these matched periods, daily counts were in close agreement with totals of 956 and 944 whales at Frenchman's and Norm's Seat, respectively, a difference of 1.3% (Fig. 9). A paired T-test on the matched data shows no significant difference (P=0.61). Group composition estimation was also similar at both sites (Fig. 10). No correction was deemed necessary for data from Frenchman's for comparison with data collected previously from Norm's Seat.

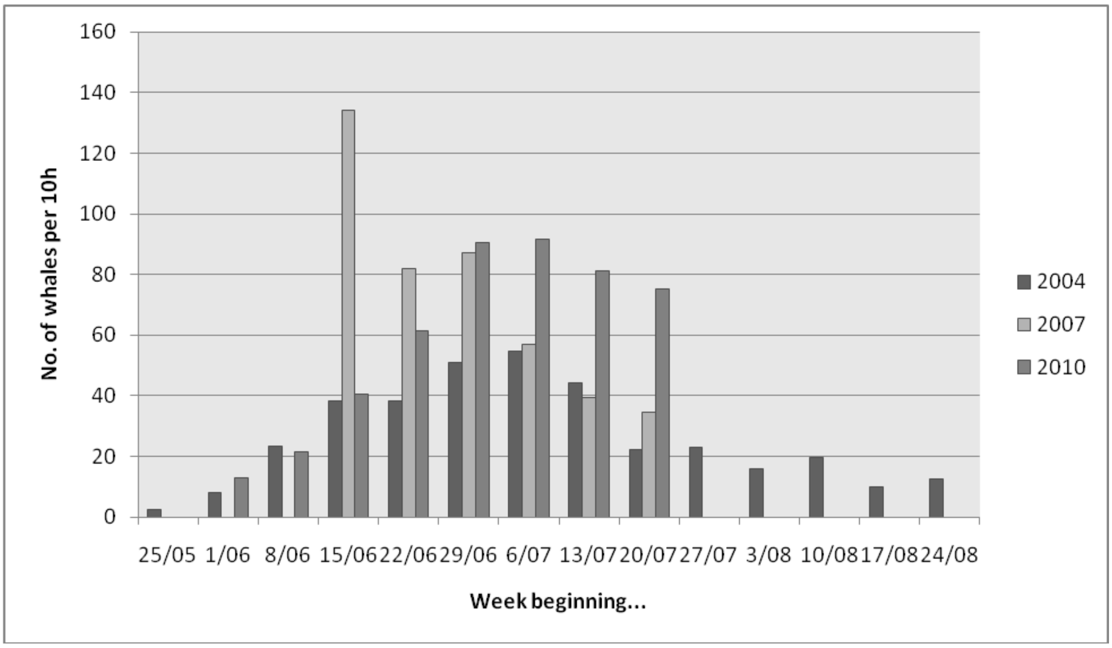

Figure 8. Weekly average counts of whales passing per 10h for the last three Pt Lookout surveys – 2004, 2007 and 2010. Weeks with only one day of data have been excluded. It is worth noting that the very high count during the first week of the 2007 survey was based on only 1.5 days of data and is unlikely to be an accurate representation of the full week.

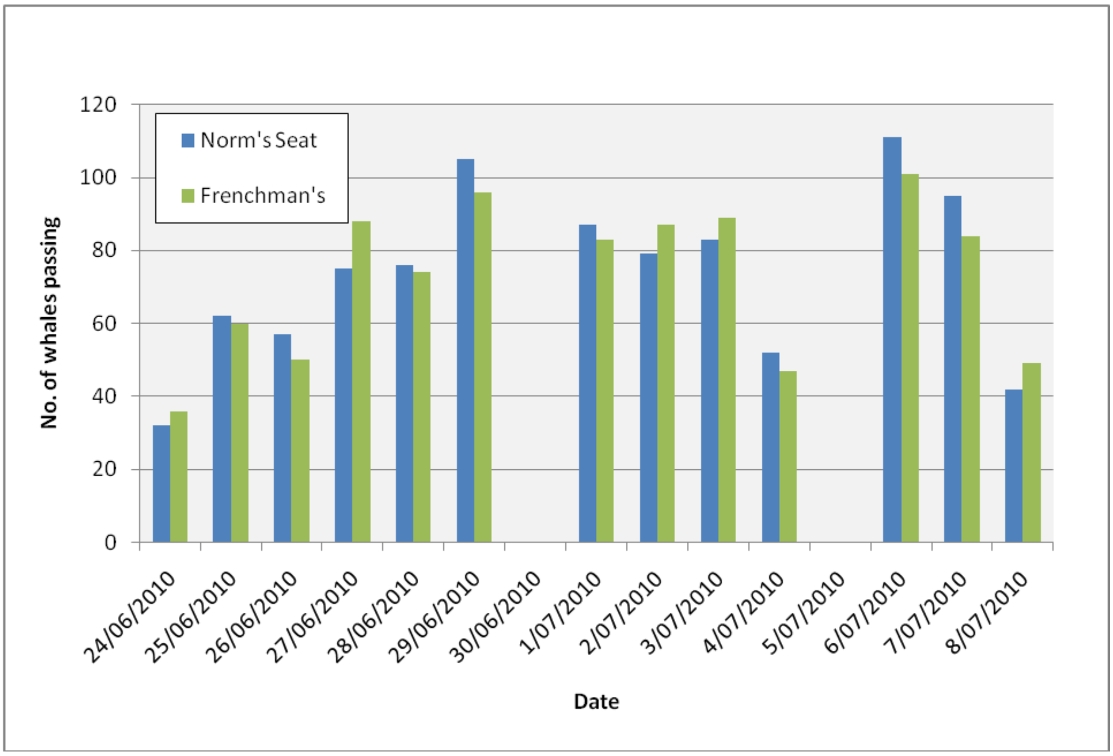

Figure 9. Whales observed independently from the two platforms, Frenchman's and Norm's Seat. Only days with matching periods of observations (usually a full 10h day) are shown so data are directly comparable.

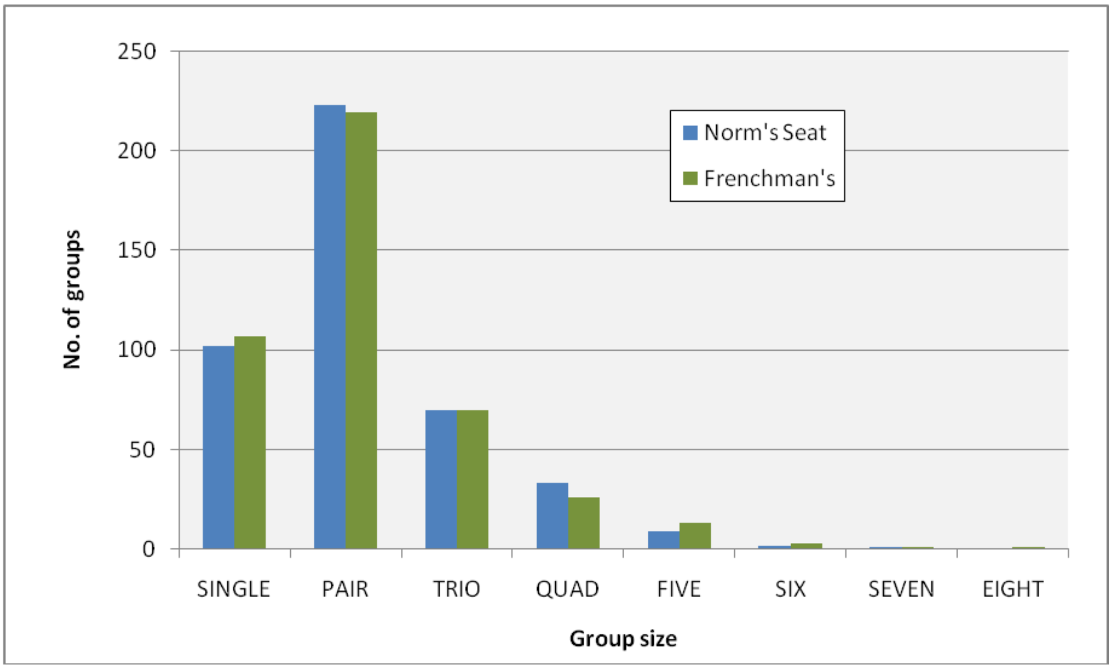

Figure 10. Groups size estimates from the two survey sites for directly comparable days.

The long-term annual rate of increase for the 24 years from 1984 to 2010 is 10.9% (95% CI 10.5 - 11.3%), up slightly from the 2004 estimate which was 10.6% but almost unchanged since the 2007 estimate (Figs 11 & 12).

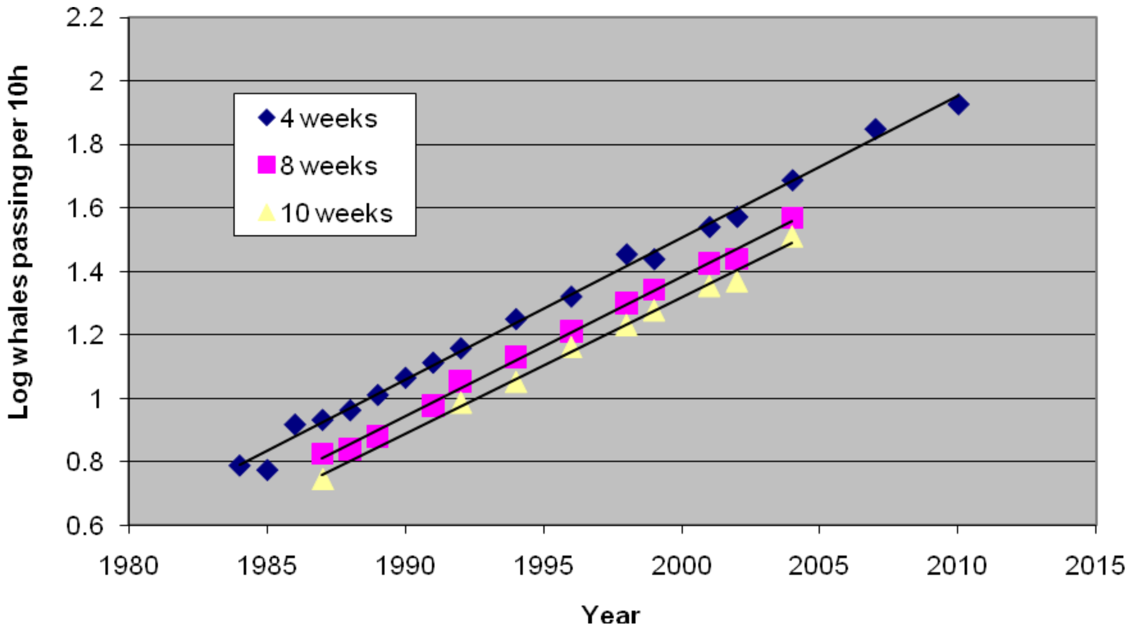

Figure 11. Log of the numbers of whales passing per 10h during the 4, 8 and 10 weeks of the peak in various years from 1984 to 2010. (Using the log of the number passing means that a constant rate of increase will appear as a straight line.) The rate of increase for the 4-week line is 10.9% (95% CI 10.5-11.3%). All data 1984 – 2002 from Paterson *et al.* (2004).

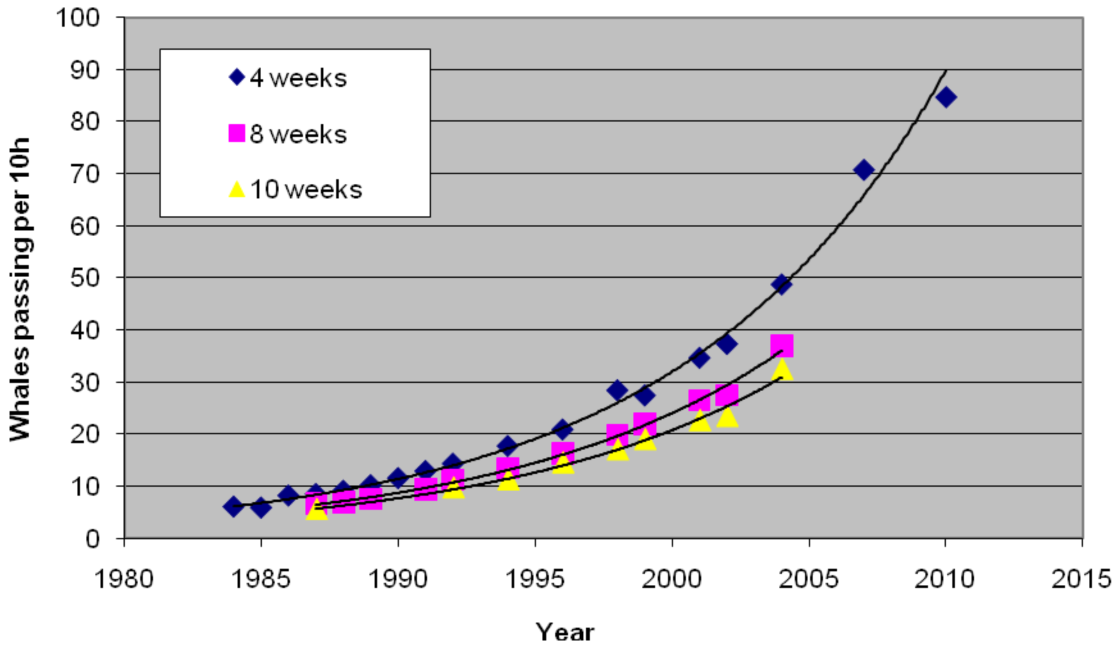

Figure 12. Linear scale version of Fig. 11.

3.2 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 to a revised absolute abundance estimate for 2004. 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 originally estimated using a simple reverse Lincoln-Petersen method as 1.099 ± 0.021. Further work by Christine Dudgeon with RD and MN produced revised estimates of f_m by undertaking more sophistically modelling to take into account sighting heterogeneity due to changed sighting conditions. This has provided a revised estimate of 1.212 ± 0.049 (Dunlop *et al*., 2010, and further revised Dudgeon *et al*., in prep.). This produced an updated estimate for 2010 of 14,522 (95% CI 12,777 – 16,504).

3.3 Acoustic recordings of humpback song

An autonomous underwater acoustic recorder was deployed from 28 June to 11 July resulting in 12 days 19 hours and 33 minutes of recordings. These are near-continuous recordings with each sample just under 1 minute long. Sampling rate was 9765Hz. These recordings have been briefly reviewed to check they contain humpback whale song but have not yet been analysed further. This was always intended as a sampling exercise which will form the basis of a larger body of work in the future in an attempt to develop robust statistical methods of estimating humpback population size acoustically.

4 Discussion

The 2010 east Australian humpback whale relative abundance survey was successful with all objectives achieved.

4.1 Relative abundance estimate

The eight week land-based survey estimated that, on average, 84.7 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 27 years and updates the long-term rate of growth for the population to 10.9% (95% CI 10.5 - 11.3%). Indeed this has barely changed since the 2007 survey (10.9% with 95% CI 10.5-11.4%). While this is remarkably consistent, we have to bear in mind that the 2010 survey is just one data point on the end of a 27 year period containing 18 survey results and it would take a result a long way from the trend-line to shift the curve significantly. Even so, if we shorten the period to make the rate of increase more contemporary, we can see that 1996 – 2010 gives a rate of increase of 10.7% (95% CI 9.4 – 12.1; n = 8 surveys) while 2001 – 2010 yields 11.0% (8.2 – 14.0; n = 5). The confidence intervals increase with reduction in numbers of surveys and time, but the central trend remains highly conserved.

If compared with the last survey in 2007, however, there has only been a 6.2% per annum increase to 2010. This could be explained either by 2007 having an abnormally high four week rate of passage, or by a reduction in the real rate of increase. The former seems more likely as (i) 2007 was above the long-term average (Figs. 11 and 12) and (ii) it is likely that in 2007 the migratory pattern was abnormally skewed to earlier in the season and much higher, particularly earlier in the season, than expected (Noad *et al.*, 2008). Although we initially thought there may be some evidence of the rate of growth slowing during the 2010, this impression was due to comparing with 2007 counts. With more analyses, however, there is no evidence at this stage of any slowing in the high rate of growth of the east Australian population.

The rate of increase is expected to slow soon, however. In Figure 13 the existing data are fitted to a simple logistic function (the point of inflection at 50% of carrying capacity K) as well as the previously modelled exponential curve. The fit of the exponential curve is slightly better than the logistical regression. The logistical regression suggests that we are at the point of inflection and that a slowing of the rate of growth should be evident in the next few years.

4.2 Absolute abundance estimate

Our absolute abundance estimate combines our 2004 absolute abundance estimate, a recalculated correction factor for whales available but missed f_m and our new long-term rate of population increase (together with their various SEs). The 2004 abundance estimate was sound although we knew at the time that the correction factor for whales available but missed f_m may have been underestimated. Additional funding from AMMC allowed us to re-examine the data through (i) a review of the matches obtained in the initial analysis of double count data, (ii) the implementation of a logistic regression approach (binomial GLM) as outlined by Buckland *et al.* (1993), (iii) the identification and removal of collinear variables, (iv) model selection using a backward step-wise approach with Akaike's Information Criterion (AIC), and (v) using the conditional probability estimates from the final iteration to calculate the correction factor and corresponding standard errors (Dunlop *et al.*, 2010; Dudgeon *et al.*, in prep.). The resultant absolute abundance estimate is the most robust possible until we undertake the next absolute abundance survey at Pt Lookout.

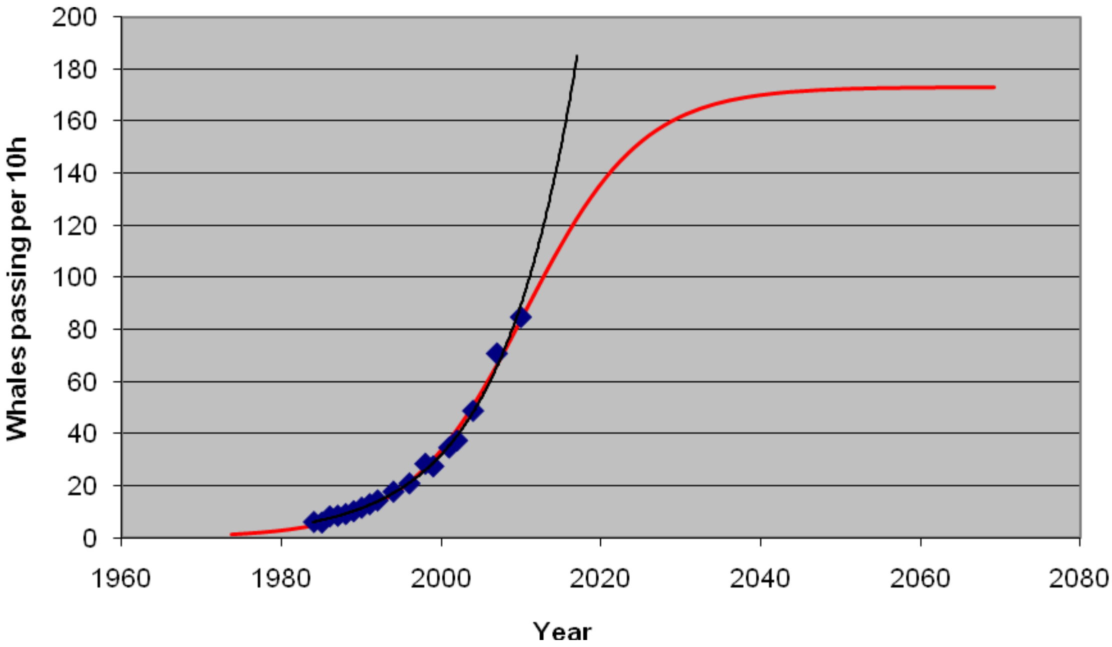

Figure 13. Whales passing per 10h over peak 4 weeks with best-fit projected exponential growth function (black) and simple logistic growth function (red). R^2 = 0.993 and 0.991, respectively.

With regards to where we are in terms of full recovery, the logistic function fitted to the data (Fig. 13) has an asymptote of 173 whales per 10h, 2.04 times the 2010 rate. Extrapolating from our absolute abundance estimate yields a *K* of 29,660 by around 2065. This, of course, also suggests that the population in 2010 is 50% recovered.

Another estimate can be made using Jackson *et al.* (2008) who, using recently reported illegal Soviet catches of humpback whales in the Southern Ocean as well as previously recorded catches, calculated median posterior estimates of pre-exploitation carrying capacity for east Australia at 22,000-25,700 humpback whales. Using this and our revised absolute abundance estimate of 12,777 – 16,504 (95% CI) suggests that the population may be 50 – 75% recovered. As discussed previously, the pre-exploitation value of *K*, however, may be not necessarily be the new post-exploitation *K* and the difference in the estimated degree of 'recovery' may be due to whether it is defined prospectively (as in our model) or retrospectively (as in Jackson *et al.*'s model). Of course, the other main difference is that our model is very simple, driven only by post-exploitation survey data, while Jackson *et al.* present a much more sophisticated model including many more variables. On the one hand, given these quite different approaches it is remarkable that they are in the same 'ball-park', both even having the time of growth inflection between 2010 and 2015. On the other hand, it also has to be acknowledged that an important variable in the Jackson *et al.* model is rate of population growth which is provided by the Pt Lookout surveys.

Although at first glance our estimate of *K* is not much greater than that of Jackson *et al.* (2008), unfortunately this does not take into account the outstanding question regarding whether or not our absolute abundance estimates are capturing the entire population. 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 absolute abundance estimates would be underestimates but the estimates of Jackson *et al.* should not be affected. The difference between the estimates would therefore be exacerbated. However, as we have argued previously, it would seem unlikely 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 and we would recommend convening a small planning meeting to determine how best to measure this, probably as an additional component to the next absolute abundance survey at Pt Lookout which we would recommend be undertaken in 2013. The planning meeting should include us as well as statisticians and modellers: the advice of David Peel and Mark Bravington would be particularly useful.

4.3 Shape and timing of the peak of migration

The shape of the migration in 2010 was much more ‘traditional’ than that of 2007 and similar to that of 2004 (Fig. 8). The daily variability in numbers of groups seen appeared to be less than in previous years, with a relatively long plateau lacking the large daily fluctuations of previous surveys. Statistically, however, this is not supported. The coefficients of variation for the peak four week counts in 2004, 2007 and 2010 are 0.20, 0.40 and 0.20, respectively. So although there is less variation than 2007, there is no difference to 2004. Again it appears that 2007 was an abnormal migration in terms of the distribution of whales during the peak.

The timing of the peak four weeks, starting 26 June, was the latest in the last nine surveys using the peak four week counts (Table 1; Paterson *et al.*, 2004; Noad *et al.*, 2006a, 2008). The start of the peak four weeks appears to range from 13 June to 26 June, or over a period of approximately two weeks. The mean and median dates are both 19 June. Future relative abundance surveys should therefore be conducted for 8 weeks starting around 4 June. This provides a few days for training and a small buffer against peaks starting earlier than the 13th. If the peak is late, it should also provide around a week at the end of the survey beyond the peak. It should be noted that ideally there is around one week of observations before and after the peak so that the peak itself can be confidently identified.

The change in primary survey position from Norm’s Seat to the ridge above Frenchman’s Beach was successful and useful. The additional height and more easterly and southerly views provided much better survey conditions than Norm’s

Seat. The tower built by the Redland City Council was excellent. The calibration study showed that there was no significant difference in the numbers of whales seen from both platforms during simultaneous surveys. We have not performed a group-by-group analysis of these data, however, and it is possible that there may have been differences between the sites in terms of double-counting or missing groups. We feel that both of these are innately more likely from Norm's Seat (hence our desire to change to the Frenchman's site) but, if both occur, they appear to have corrected for each other. In any case, with regards to the relative abundance survey, the important metric of whales passing per 10-h day required no correction between the sites.

Table 1: Peak timing of northward migration at Pt Lookout.

Year	Start of peak
1994	18/06/1994
1996	22/06/1996
1998	13/06/1998
1999	19/06/1999
2001	16/06/2001
2002	15/06/2002
2004	22/06/2004
2007	20/06/2007
2010	26/06/2010

4.4 Change in survey site and future surveys

For future surveys at Pt Lookout, we recommend the continued use of Frenchman's over Norm's Seat. The one disadvantage of Frenchman's is that the effective use of the site requires a tower to be assembled, and this in turn requires the permission of the Redland City Council, more organisational effort prior to the survey and possibly additional funding. (Although the council kindly funded the building of the tower in 2010, they may not do so in the future. The cost of this was approximately $8000.)

While the extra height and improved angle of view of Frenchman's helps, there is still a problem coping with the high numbers of whales passing during the peak. We routinely have days with more than 100 groups or an average of a new group every six minutes for 10 hours. While we have attempted to cope with this by increasing observer numbers over the years, it would be difficult to have teams greater than the current size of five. Sightings would be called over the top of each other and just physical space constraints may make it difficult for all observers to maintain good communication with the computer operator. Instead of increasing observer group size, it would be preferable to make more use of double counts to attempt to quantify the proportion of whales missed and correct for this. It is likely that this will increase with time and increasing whale numbers. This in itself will be a logistical challenge as it may require two towers to be erected on the ridge above Frenchman's Beach.
In terms of future surveys, we recommend that the next survey be in 2013 and be an extended absolute abundance survey similar to that undertaken in 2004. The 2013 date maintains the triennial timing of the recent surveys which is a good compromise between avoiding the high cost and statistical over-sampling of annual or biennial

surveys on the one hand, and maintaining the relatively high resolution of the Pt Lookout series of surveys on the other. The current survey frequency allows us to measure rates of increase with narrow confidence intervals, and this should allow us to detect a real slow down in the rate of increase quickly with good temporal resolution. The other important factor to consider is that were the surveys less frequent than three years, there would probably be some loss of ‘corporate memory’ with inevitable loss of experienced personal able to run the surveys, loss of relationships with the Redland City Council, and generally reduced organisational efficiency especially with regards to organising accommodation, equipment and volunteers.

The remarkable consistency of the relative abundance estimate as a function of time and the small confidence interval in rate of increase is unique for whale populations. 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 Pt Lookout survey data provides a very sensitive diagnostic indicator 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.

4.5 Acoustic survey

The 2010 acoustic survey was much more successful that our failed 2007 attempt. We are indebted to Ms Ann Allen of the Woods Hole Oceanographic Institution for providing us with a copy of her data collected as part of her PhD studies. (This was provided in return for field accommodation and maintenance, and logistical support.) while the recordings have net been analysed in detail, they certainly contain many humpback song recordings and will be useful in developing acoustic survey methodology in the future. This is part of a long-term acoustic monitoring program and the results of the 2010 acoustic survey will be seen in context of the longer term data sets available.

4.6 Summary and recommendations

The 2010 survey has provided an updated estimate of the rate of growth of the population and, together with a revised estimate of f_m, an updated estimate of absolute abundance. By fitting a logistic regression curve to the data, we also estimated that we are at the point of inflection with the rate of growth expected to slow over the coming years. The resultant logistic function has also allowed us to estimate K at approximately 30,000 whales.

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 continue to be conducted every three years with two shorter relative abundance estimates to every one longer absolute abundance survey.

3. The next survey should be in 2013 and should be an extended 14 week absolute abundance survey with extensive periods of double counts.
4. Double count data should be assessed using a logistic regression approach rather than a simple Lincoln-Petersen approach.
5. The primary survey site should henceforth be on the ridge above Frenchman's Beach.
6. Relative abundance surveys should be conducted for eight weeks starting around 4 June. This will provide the best possible chance of capturing and confidently identifying the peak four weeks of the migration.
7. A short planning workshop should be held to plan a methodological approach to addressing the question of sex bias in the migration. Additional fieldwork may be required to address this during the 2013 absolute abundance estimate.
8. The deployment of autonomous recorders should continue at Pt Lookout in conjunction with land-based surveys.

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The 2010 east Australian humpback whale survey would not have been possible without a great number volunteers who gave their time to spot whales, often in uncomfortable conditions, from Pt Lookout. These included Amy James (USA), Kylie Owen (Aus), Michael Williamson (UK), Jane Gardner (UK), Emma Gates (UK), Sabrina Buongiovanni (Italy), Michael Johns (USA), Jessie Stoneman (USA), Paul Causon (UK), Rebecca Wood (UK), Linda Garlepp (Aus), Angela Recalde Salas (Columbia), Laura Bussolini (US), Michael Hitchcock (Aus) and Saras Sharma (Fiji). We also thank our other survey coordinators for all their great work – Louise Bennet (Aus), Melinda Rekdahl (Aus) and Ailbhe Kavanagh (Ireland). We would also like to thank the staff of the Redland City Council, particularly Mr Daniel Carter, for taking the time to meet with us in planning the survey, and for organising and providing the excellent scaffolding platform for our use. The acoustic recordings were kindly provided to us by Ms Ann Allen from the Woods Hole Oceanographic Institution.

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