Abundance estimate of Australian east coast humpback whales (Group E1) in 2005 using multi year photo-identification data and capture-recapture analysis.

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Abstract
Vessel based surveys were conducted between 1999 and 2005 during the annual humpback whale northern migration off Byron Bay on the east coast of Australia. A multi-year photo-identification sampling and capture-recapture analysis was undertaken for this 7 year period. This analysis resulted in a population estimate for the number of humpback whales that migrated north past Byron Bay in 2005 of 7390 (95% CI: 4040-10739). This estimate is consistent with other capture-recapture and land based estimates for Group E(1) and supports the growing body of data that indicates a high rate of increase for this population of humpback whales.

Introduction
In the Southern Hemisphere, humpback whales (*Megaptera novaeangliae*) undertake an annual migration during the austral winter months from their high-latitude summer feeding areas in the Antarctic to their low-latitude winter tropical breeding areas (Chittleborough 1965; Dawbin 1966). This northern annual migration is not random in structure, with clear temporal segregation of different classes of whales being recorded from whaling data. The first animals to leave the feeding grounds on the annual migration are lactating females and yearlings, followed by immature whales of both sexes, mature males and resting females at the peak of the season, and finally pregnant females (Dawbin 1966, 1997).

Humpback whale populations in the South west Pacific Ocean are made up of two populations (E and F). Group E has now been divided into three subgroups known as E(1) those wintering off the Australian east coast, E(2) those wintering around New Caledonia, an E(3) those wintering around Tonga (IWC 2005; Olavarria et al. 2006).

Following intensive over-exploitation of Southern Hemisphere humpback whale populations last century, including illegal whaling operations in the Southern Ocean (Clapham et al. 2009), Group E collapsed in 1962 to less than 5% of the original estimated pre-exploitation abundance (potentially in range of 30,000 to 40,000 humpback whales (Jackson et al. 2006)). Ongoing research over the last 27 years, monitoring the abundance of this humpback whale population has measured a high but steady rate of increase of 10.9% per annum (95% CI 10.5 – 11.4%) (Noad et al.

2008). This rate of increase is close to or at the estimated maximum biological rate of increase for this species (Clapham & Zerbini 2006). Other breeding stocks in the south west Pacific Ocean are showing limited or no signs of recovery (Gibbs and Childerhouse 2004; Garrigue et al., 2000, 2002; Paton et al. 2009; Paton et al. in review).

Recent estimates of adult survival rate for humpback whales include figures of 0.95 for the Gulf of Maine population (Buckland 1990, Clapham et al. 2003) and 0.96 for populations in the North Pacific Ocean (Calambokidis & Barlow 2004, Mizroch et al. 2004).

Research activities to monitor the abundance of the Group E(1) humpback whales have primarily relied on land based counts and distance sampling methodology (Bryden et al. 1988, 1996; Paterson et al. 1989, 1994, 2001, 2004; Brown, 1996, Brown et al. 2003Noad et al. 2004, 2008). Noad et al. (2008) estimated absolute abundance of this stock based on land based counts for 2007 at 9,683 whales (95% CI: 8,556 – 10,959). Paton et al. (in press) undertook a single-season, multi-point sampling and capture–recapture analysis using photo-identification data for the population of migrating whales in 2005. These data were analysed using a variety of closed population models with a model-averaged estimate of 7,041 (95% CI: 4075 – 10,008) whales migrating along the east Australian coast in 2005. Although each of these abundance estimates relies on different assumptions and is subject to different inherent biases, both methods produced a similar population estimate (taking into consideration the reported annual population recovery rate of 10.9% (Noad et al. 2008)).

By using a number of techniques to assess the current abundance of the Group E(1) population, a more robust population estimate can be obtained. Here, we present a further estimate for the abundance of the humpback whales migrating along the Australian east coast in 2005 using a multi-year sampling and capture-recapture analysis.

Methods

Survey methods

Vessel based photo-identification surveys were undertaken annually at Byron Bay, (Latitude 28^0 37'S, Longitude 153^0 38'E) between 1999 and 2005. Byron Bay, located in northern New South Wales, is the most easterly point on the Australian mainland and is located on the edge of the migratory corridor of humpback whale population E1 (Figure 1). At this location the bulk of the migrating humpback whales migrate within 10km of the coast (Bryden 1985). The width of the humpback whale migration corridor was re-assessed in 1991 (Brown 1996) and 2007 (Noad and Dunlop 2007) at Point Lookout (135km north of Byron Bay), and found to be consistent with the results of Bryden (1985). Humpback whales travel past the eastern point of Australia at Byron Bay, in both a northerly and southerly direction, en-route between the Antarctic feeding grounds and the Great Barrier Reef breeding grounds (Paterson 1991).

Surveys were undertaken as whales migrated north past Cape Byron during the austral winter months (May – August). Survey effort was not consistent for each field season between 1999 and 2005, and while the annual surveys were timed to include what was anticipated to be the peak of the northern migration passing Byron Bay, based on historical and recent data (Paterson 1991; Dawbin 1997; Paton and Kniest 2006), most annual surveys covered only a short part of the migration period.

The research vessel was assisted in finding pods of whales by a team of land-based observers working from Cape Byron lighthouse using the "Cyclopes" (theodolite/ computer) whale tracking system (Kniest and Paton 2001). Survey effort, timing and equipment used during each annual survey are summarised in Table 1.

Photography of ventral fluke surfaces was obtained using a standard sampling protocol throughout the duration of the project. Ventral fluke photographs were obtained during a maximum of ten terminal dives and/or a maximum of 45 minutes with each pod (as per Smith et al. 1999). Photographs of the ventral fluke surfaces of calves were not included in this study.

Photo-Identification
The single best photograph for each individual whale for each field season was selected. Non digital images were scanned using a Nikon Coolscan III at maximum resolution. All images were cropped to a common 3 x 2 pixel ratio as high quality jpeg digital files. Composites of multiple images of a single fluke were constructed if these provided sufficient information to accurately identify the whale (Figure 2). All images for each field season were assessed for within-season resights to eliminate duplicates.

To address potential bias associated with photo quality, an independent cetacean researcher experienced in humpback whale fluke photograph matching, reviewed the fluke catalogue using a protocol developed in the Northern Hemisphere for grading humpback whale fluke identification photograph quality (Calambokidis *et al*. 2001). This included scoring all flukes according to five different characteristics of photo quality: (1) exposure / contrast / lighting; (2) fluke angle; (3) photographer / lateral angle; (4) focus / sharpness; and (5) proportion of fluke visible. Each photograph was given a score from 1 to 5 (highest quality to lowest) for each characteristic, and all flukes with at least one score of 4 or lower (5) were excluded from the dataset.

Matching
A stratified matching system developed by one of the authors (DB) was used in this analysis. This system is based on stratifying flukes by different characteristics including percentage black, characteristics of the centre and characteristics of the trailing edge of the fluke for each identification photograph. This system was used to reduce the number of comparisons required in the matching process. All matches found were reviewed and confirmed by at least two of the authors (DP and DB).

Statistical model
Only the 2005 sample, which extended over a large part of the total migration (a 10 week survey period), might be considered to be a random sample from the migrating population. The samples in the years 1999 to 2004 would have been selected from the classes of whales passing Byron Bay in the relatively short periods of the surveys in those years. This is unlikely to have been the same part of the population each year because a) the peak of the migration can change by up to five weeks from year to year

(Dawbin 1956), and b) some whales are likely to have changed age class or pregnancy status between years, and therefore the timing of their migration.

The series of surveys describes an open population with births, mortality, potential immigration and emigration occurring between years. However, no open population model was available that was appropriate for the data analysis.

We used the Chapman small sample modification to the Lincoln-Petersen two sample estimator for N (see e.g., Chao and Huggins 2005) based on a sample pooled over the years 1999 to 2004, and compared with the 2005 sample. This is a consistent estimator of the population size when either or both of the samples are a simple random sample as we assumed for the 2005 sample (see e.g., Schwarz 2005). We adjusted the number marked in the pooled sample (n_1) to the number expected to have been alive and available for resighting in 2005 (n_{1A}) by reducing the count from the year last sighted assuming a true survival rate of 0.95 pa. This procedure adjusted for the mortality between marking and recapture. Births and permanent immigrants in the interval 1999 to 2005 would have been represented in the 2005 sample. There was no basis on which to make any adjustment for permanent emigrants.

The Chapman estimator of population size ($\hat{N}$):

$$\hat{N} = \frac{(n_1+1)(n_2+1)}{(m_2+1)} - 1$$

$$Var(\hat{N}) = \frac{(n_1+1)(n_2+1)(n_1-m_2)(n_2-m_2)}{(m_2+1)^2(m_2+2)}$$

where,
n_1 = number identified in first sample,
n_2 = number identified in second sample,
m_2 = number common to both samples.

Results
Table 1 describes the survey dates for the years 1999 to 2005. As may be seen there only the 2005 survey extended over a relative large part of approximately 12 weeks of the migration period.

A total of 1008 fluke photographs were assessed for inclusion in the analysis. Following independent assessment against photograph quality protocols, 243 fluke photographs were excluded from the data set based on photographic quality. The final data set comprised a total of 765 fluke identification photographs. Table 2 reports the matches and frequencies of capture histories. Table 3 reports the number of whales sighted between 1999 and 2004 (n_1) and the number of those expected to have been alive and available for capture in 2005 (n_{1A}) based on an assumed mortality rate of 5%.

Three hundred and thirty seven (337) whales were sighted in 2005 (n_2) of which 15 had been previously sighted at least once in the period 1999-2004 (m_2).The Chapman estimate of the population size in 2005 ($\hat{N} \mid n_1, n_2, m_2$) was 8,850 (95% CI: 4823-12878) whales.

The mortality-adjusted Chapman estimate of the population size in 2005 ($\hat{N} \mid n_{1A}, n_2, m_2$) was 7390 (95% CI: 4040-10739) whales.

Discussion

This study represents a multi-year sampling and capture-recapture abundance estimate using photo-identification for Group E(1) humpback whales migrating north past Byron Bay on the east coast of Australia during 2005. This estimate of 7,390 (95% CI: 4040-10739) humpback whales is consistent with the Paton et al. (in press) multi-point sampling and capture-recapture estimate for 2005 of 7,041 (95% CI: 4075 - 10,008) and Noad et al. (2008) land based distance sampling estimate of 9,683 whales (95% CI: 8,556:10,959) for 2007 for this same population. The Noad et al. (2008) estimate, when extrapolated backwards using an annual increase rate of 10.9%, would give an estimate for 2005 of 7,873 (95% CI: 6,597-8,911).

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Table 1 Summary of survey effort and equipment used.

Year	1999	2000	2001	2002	2003	2004	2005
Dates of survey	19- 20 June, 30 June – 11 July	25 June – 9 July	23 June – 8 July	17 June – 20 July	21 June – 6 July	26 June – 11 July	4 June – 12 Aug
Survey period (days)	14	14	16	34	16	16	69
Research vessel	5.8 metre centre console	5.8 metre centre console	5.8 metre centre console	5.8 metre centre console	5.8 metre centre console	5.8 metre centre console	5.5 metre centre console
Photographic equipment	Canon EOS 1, 300mm lens F2.8	Canon EOS 1, 300mm lens F2.8	Canon EOS 10D, 100-400mm lens F3.5-5.6IS	Canon EOS 10D, 100-400mm lens F3.5-5.6IS	Canon EOS 10D, 100-400mm lens F3.5-5.6IS	Nikon D100, 70-200mm lens F2.8 VR and 1.4x converter	Canon EOS 20D, 100-400mm lens F3.5-5.6IS

Table 2 Matches and frequencies for capture histories of humpback whales recorded near Byron Bay, Australia.

Row	1999	2000	2001	2002	2003	2004	2005	n_row
1	1	0	0	0	0	0	0	32
2	0	1	0	0	0	0	0	32
3	0	0	1	0	0	0	0	64
4	0	0	0	1	0	0	0	103
5	0	0	0	0	1	0	0	61
6	0	0	0	0	0	1	0	101
7	0	0	0	0	0	0	1	322
8	1	0	0	1	0	0	0	1
9	1	0	0	0	0	1	0	1
10	1	0	0	0	0	0	1	1
11	0	1	0	1	0	0	0	1
12	0	0	1	1	0	0	0	1
13	0	0	1	0	1	0	0	1
14	0	0	0	1	1	0	0	1
15	0	0	0	1	0	1	0	1
16	0	0	0	1	0	0	1	7
17	0	0	0	0	1	1	0	3
18	0	0	0	0	1	0	1	2
19	0	0	0	0	0	1	1	5

Table 3 Number of sampled humpback whales estimated to be alive in 2005 based on an estimated 0.95 population survival rate.

Year	n-last sighted	Estimated n-alive in 2005[1]
1999	32	23.52
2000	32	24.76
2001	64	52.13
2002	106	90.88
2003	63	56.86
2004	106	100.70
1999-2004	$n_1 = 403$	$n_{1A} = 348.85$

[1] Calculated as (n-last sighted)*$(0.95)^{(2005\text{-Year})}$

Figure 1 Study Area

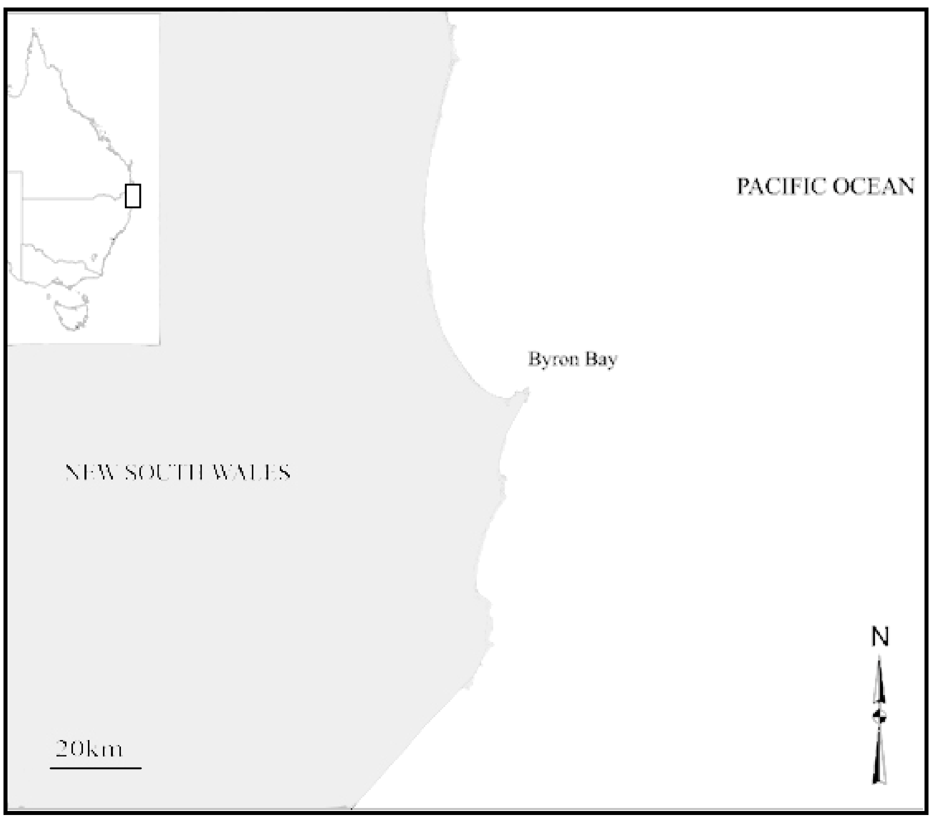

Figure 2. Example of a composite image used in the analysis.