Antarctic waters (Area V) near the Balleny Islands are a summer feeding area for some eastern Australian Breeding Stock E(i) Humpback Whales (*Megaptera Novaeangliae*)

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ABSTRACT

Discovery mark tagging provided the first evidence of linkages between eastern Australian and Oceania Humpback whale breeding grounds and the Antarctic Area V feeding areas. Early investigation of movements of humpback whales in the Western Pacific led to the view that the Balleny Islands and the Ross Sea were the summer destinations for humpback whales from eastern Australia and the Oceania breeding grounds. Recent photo-identification (ID) studies provided further evidence of low levels of migratory interchange and complex linkages within Oceania and between eastern Australia and Oceania. We report here the migratory movement of three humpback whales *(Megaptera novaeangliae)* between Eastern Australia (E(i) breeding stock) and the Area V Antarctic feeding area in the vicinity of the Balleny Islands. Using photo-ID techniques, comparisons between a Balleny Island fluke catalogue (n = 11 individuals) and existing fluke catalogues from eastern Australia (n = 3,120 individuals) and Oceania (n = 725 individuals), yielded three matches to Hervey Bay, Byron Bay and Ballina in eastern Australia and no matches to Oceania. The eastern Australia catalogue (n = 3,120) was made up of Hervey Bay (n = 1,556), Byron Bay, (n = 916) and Ballina (n = 648). The Oceania catalogue (n = 725) is made up of Tonga (n = 282); New Caledonia (n = 160); French Polynesia (n = 159); New Zealand (n = 41); Cook Islands (n = 36); American Samoa (n = 31); Vanuatu, Niue, Samoa and Fiji (n = 11) and Norfolk Island (n = 5). Only three previous individual photo-ID matches have been reported between eastern Australia Breeding Stock E(i) and Antarctic Area V feeding areas in the vicinity of the Balleny Islands and the Ross Sea. Only one genotype match has been reported between Antarctic Area V feeding areas and Oceania breeding grounds. An analysis of the frequencies of whales seen and not seen in the Balleny Islands, Oceania and eastern Australia, relative to the expected frequencies, based on the estimated population sizes and the sizes of the catalogues, supports the hypothesis that Antarctic Area V waters, in the vicinity of the Balleny islands, is a summer feeding area for some eastern Australian humpback whales.

KEYWORDS: HUMPBACK WHALE; PHOTO-ID; MIGRATION; SITE FIDELITY; EASTERN AUSTRALIA; OCEANIA; ANTARCTIC WATERS; BREEDING GROUNDS; FEEDING AREAS; SURVEY-VESSEL; SOUTHERN HEMISPHERE; PACIFIC OCEAN

INTRODUCTION

'Discovery' mark tagging (Brown, 1977) provided the first evidence of migratory interchange of humpback whales between the breeding grounds of eastern Australia and Oceania, and also linkages between the feeding and breeding areas within the IWC Areas IV, V and VI (Chittleborough, 1959; Dawbin, 1964; International Whaling Commission, 2011; Paton and Clapham, 2006). Investigation of migratory movement of humpback whales in the Western Pacific led Dawbin (1956; 1949) to consider that the Balleny Islands and the Ross Sea were the summer destination for humpback whales that travel along the coasts of eastern Australia and other parts of the Pacific and through New Zealand waters. Further evidence of the complexity of migratory interactions amongst Oceania breeding grounds (including New Caledonia, Vanuatu, Tonga, Samoa, American Samoa, Cook Islands, Fiji, Niue and French Polynesia) and the New Zealand and Norfolk Island migratory corridors has been obtained from long term photo-identification (hereafter photo-ID) studies of humpback whales undertaken by members of the South Pacific Whale Research Consortium (SPWRC) and the Southern Cross University Whale

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Research Centre (Abernethy *et al.*, 1992; Donoghue, 2008; Franklin *et al.*, 2008; Garrigue *et al.*, 2002; Garrigue *et al.*, 2007; Gibbs and Childerhouse, 2004; Hauser *et al.*, 2000; Poole, 2002; 2006).

Recent photo-ID matching between eastern Australian fluke catalogues (i.e. Hervey Bay and Byron Bay) and ten regional Oceania fluke catalogues for the period 1999 to 2004 (Garrigue *et al.*, 2011) provides further evidence of the low levels of migratory interchange and illustrates the complexity of linkages between eastern Australia and Oceania (Donoghue, 2008; Franklin *et al.*, 2008). To date, only three individual photo-ID matches (Fig. 1) have been reported between humpback whales that migrate along the eastern Australian coast (E(i) Breeding Stock) and Antarctic Area V feeding areas in the vicinity of the Balleny Islands and the Ross Sea (Kaufman *et al.*, 1990; Rock *et al.*, 2006). No photo-ID matches have been reported between any of the Oceania breeding grounds and Area V or Area VI Antarctic feeding areas. However, one recent genotype match was reported between New Caledonia and the Antarctic Area V feeding area, and a small number of genotype matches have been reported between Oceania breeding grounds and Antarctic Area I and VI feeding areas (Steel *et al.*, 2008).

The Balleny Islands are located in the Ross Sea at 67°S, 163°E, and are included within the Southern Ocean Whale Sanctuary that was declared at the 46th meeting of the International Whaling Commission (IWC) in 1994 (Fig. 1).

In this study, photo-ID matches are used to document the migratory movements of individual humpback whales between the Balleny Islands (Antarctic Area V feeding area) and Hervey Bay, Byron Bay and Ballina on the eastern coast of Australia (Breeding Stock (E (i)). The data are used to investigate whether Antarctic waters near the Balleny Islands are a summer feeding area for some eastern Australian humpback whales and/or Oceania humpback whales.

METHODS

Photo-ID data

Observations of humpback whales were undertaken in close proximity to the Balleny Islands (67°S, 163°E), from the 14 to the 25 February 2006 during a marine biodiversity research cruise organised by the New Zealand Ministry of Fisheries. Sightings of humpback whales ranged between latitudes 66°10'260''S and 67°34'771''S and longitudes 162°20'005''E and 164°49'663''E. The Balleny Islands (BI) humpback fluke catalogue consists of $n = 11$ individuals.

Vessel-based photo-ID of humpback whales in Hervey Bay, Queensland (25°S, 153°E) was undertaken between 1999 and 2005 as part of a long-term study of the behaviour and ecology of humpback whales by two of the authors (TF and WF). Photo-ID studies of humpback whales were undertaken on their northern migration at Byron Bay (BB) (28°38'S, 153°38'E) between 1999 and 2005; and during the southern migration at Ballina (BA) (28°52'S, 153°36'E) between 2003 and 2005. The combined and reconciled eastern Australian fluke catalogues consists of $n = 3{,}120$.

Dedicated surveys of humpback whales in Oceania were conducted between 1999 and 2004 during the austral winter in four primary sites: New Caledonia; Tonga; the Cook Islands; and French Polynesia. Surveys were conducted in only one or two seasons in other South Pacific sites: Vanuatu, Fiji, Samoa, and Niue. Surveys at American Samoa began in

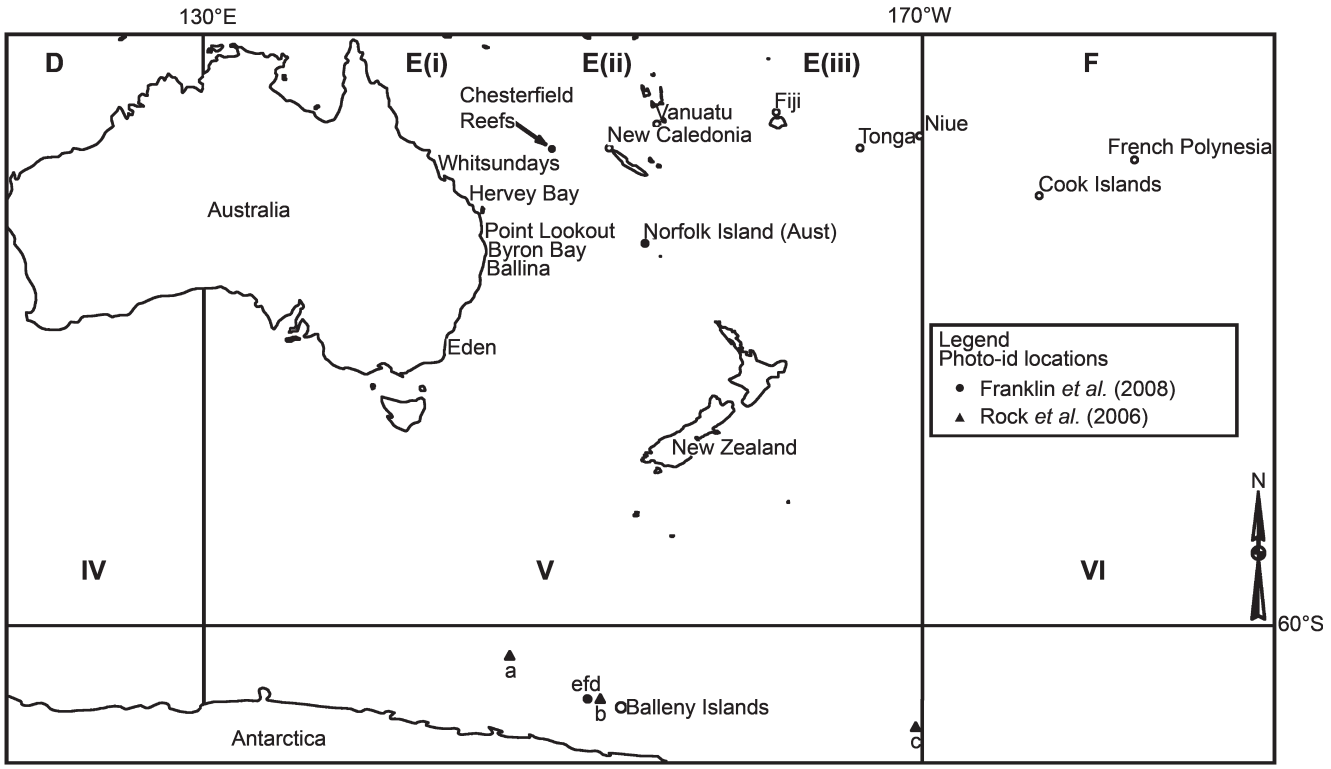

Fig. 1. Locations of the Balleny Islands; the Eastern Australian and Oceania photo-ID survey sites; Eastern Australia and Oceania Breeding Stocks E(i), (ii), (iii); Antarctic feeding areas IV, V, VI and I (International Whaling Commission, 2011). The symbols marked (a), (b) and (c) show the location of individual whales reported in Rock *et al.* (2006) and the symbols marked (d), (e) and (f) show the location of the matches reported herein. Whale (a) was sighted at Point Lookout and Eden; whale (b) was sighted in the Whitsundays, Hervey Bay and Eden; whale (c) in Hervey Bay and Eden (Rock *et al.*, 2006). Whale (d) was sighted in Ballina; whales (e) and (f) were sighted in both Byron Bay and Hervey Bay but in different years (see photo-ID details in Fig. 2)

Table 1
Eastern Australia (EA), Oceania (OC) and Balleny Islands (BI) population and site Fluke catalogues.

Eastern Australia (EA)		Oceania (OC)		Balleny Islands (BI)	
Site	Flukes (*n*)	Site	Flukes (*n*)	Site	Flukes (*n*)
Hervey Bay	1,556	New Caledonia	160	Balleny Islands	11
Byron Bay	916	Vanuatu	6		
Ballina	648	Norfolk Island	5		
		New Zealand	41		
		Fiji	2		
		Tonga	282		
		Samoa	1		
		American Samoa	31		
		Niue	2		
		Cook Islands	36		
		French Polynesia	159		
Total EA	3,120	Total OC	725	Total BI	11

2003; New Zealand surveys began in 2004 and surveys at Norfolk Island began in 2003. The reconciled and combined Oceania fluke catalogue consists of $n = 735$.

The site sampling effort and methods used to compare the Oceania and eastern Australian catalogues, both within and between regions, is fully reported in SPWRC *et al.* (2007) and Garrigue *et al.* (2011). Comparisons of each of the 11 individual flukes from the Balleny Islands were made to each of the 3120 individuals in the eastern Australian Fluke Catalogues, and to each of the 725 individuals in the Oceania Fluke Catalogues.

The population and site catalogues used in this analysis are summarised in Table 1 and site locations are shown in Fig. 1.

Statistical analysis

Two separate analyses were conducted, one investigating the matches found between the Balleny Islands (BI) and eastern Australian (EA) catalogues, and one investigating the lack of matches between the Balleny Islands and Oceania (OC) catalogues.

Each tested the question: are these data consistent with the hypothesis that the whales sighted in the vicinity of the Balleny Islands are from a single population? (Single population hypotheses)

The following rationale was used to design the analysis.

(a) If the whales sighted near the Balleny Islands were members of the eastern Australian population, the proportion of the BI catalogue expected to be matched to the EA catalogue would be equal to the proportion of the eastern Australian population that were in the EA catalogue and alive and available for capture near the Balleny Islands. For example, if one third of the eastern Australian population were in the EA catalogue and alive at the time the Balleny Islands was sampled, a third of the BI catalogue would be expected to be matched to the EA catalogue (single population hypothesis).

(b) Alternatively, if the whales sighted near the Balleny Islands were not members of the eastern Australian population, the proportion of the BI catalogue expected to be matched to the EA catalogue would be less than the proportion of the eastern Australian population alive and in the EA catalogue (separate population hypothesis).

The same rationale can be applied in the Oceania – Balleny Islands case.

Given the above rationale and the estimates described below, each of the analyses may be based on a test of association in a 2 × 2 cross-table of frequencies constructed as 'not seen' or 'seen' near the Balleny Islands by 'not seen' or 'seen' in eastern Australia/Oceania (Table 2).

Given these data and estimates, the expected numbers of matches in the case of eastern Australia and the Balleny Islands, $\hat{m}_{EA–BI}$ and $\hat{m}_{OC–BI}$, may be derived from the equal proportions rationale presented above, $m_{EA–BI}/n_{BI} = n_{EA}/N_{EA}$ and $m_{OC–BI}/n_{BI} = n_{OC}/N_{OC}$, and calculated as $\hat{m}_{EA–BI} = (n_{EA} \times n_{BI})/N_{EA}$ and $\hat{m}_{OC–BI} = (n_{OC} \times n_{BI})/N_{OC}$ respectively. This is both the standard way of calculating the expected frequencies under a null hypothesis of independence in a cross-table (row total by column total over grand total) and a simple transformation of the Lincoln-Peterson estimator,

Table 2
Scheme for the cross-tables: Eastern Australia (EA)/Oceania (OC) – Balleny Islands matches.

	Eastern Australia/Oceania		
Balleny Islands	Not seen	Seen	Total
Not seen	$N_{EA/OC} - n_{BI} - n_{EA/OC} + m_{EA/OC–BI}$	$n_{EA/OC} - m_{EA/OC–BI}$	$N_{EA/OC} - n_{BI}$
Seen	$n_{BI} - m_{EA/OC–BI}$	$m_{EA/OC–BI}$	n_{BI}
Total	$N_{EA/OC} - n_{EA}$	$n_{EA/OC}$	$N_{EA/OC}$

$N_{EA/OC}$ = Population estimate at 2006 for Eastern Australian (EA)/Oceania (OC).
$n_{EA/OC}$ = Estimate of number of living whales in 2006 from the EA/OC catalogues.
$m_{EA/OC–BI}$ = Number of whales matched between EA/OC and Balleny Islands.
n_{BI} = Number of whales identified at Balleny Islands.

$\hat{N} = (n_1 \times n_2)/m_2$. The expected frequencies for each of the other cells were obtained in the standard way. Note that the null hypothesis of independence in the table corresponds to the single population hypothesis described above.

A one-tailed test of association is appropriate because the alternative hypothesis is that the observed frequency of whales seen at both locations will be fewer (and never more) than the expected frequency under the null hypothesis. A one-tailed *p*-values from Fisher's Exact Test was used. This test is preferred over the asymptotic Pearson Chi-Square test when expected frequencies are small.

The analysis required estimates of the eastern Australian and Oceania populations (N_{EA}, N_{OC}) for 2006 and estimates of the number of individuals in the EA and OC catalogues that were alive in 2006 and potentially available for capture near the Balleny Islands (n_{EA}, n_{OC}). The estimate of the eastern Australian population in 2006 was based on the Noad *et al.* (2011) estimate of 7,090 in 2004 with an expected rate of increase of 10.6% (Noad *et al.*, 2011). The estimate of the number of individuals in the EA catalogue that were alive in 2006 and potentially available for capture near the Balleny Islands was based on the number of individuals catalogued between 1999 and 2005, with an expected mortality rate of 4% per annum (Clapham *et al.*, 2003; 2001; Zerbini *et al.*, 2010). The estimate of the Oceania population in 2006 was based on the Baker *et al.* (2006) estimate of 3,827 between 1999 and 2004. The estimate of the number of individuals in the OC catalogue that were alive in 2006 and potentially available for capture near the Balleny Islands was based on the number of individuals catalogued between 1999 and 2004 with an assumed mortality rate (= birth rate) of 4% per annum (Baker *et al.*, 2006).

As the population size and mortality data are estimates, *p*-values were calculated for variation of ±10% in the estimated numbers of whales in the EA and OC catalogues that were alive and available for capture near the Balleny Islands.

RESULTS

Comparison of the Balleny Islands Catalogue to the eastern Australian Catalogue found three matches of individual whales, whereas no matches were found from a comparison of the Balleny Islands Catalogue to the Oceania Catalogues. One of the individual whales sighted in the Balleny Islands was sighted in Ballina three years earlier and two of the individual whales sighted in the Balleny Islands were sighted in both Byron Bay and Hervey Bay but in different years (Fig. 2).

Eastern Australia – Balleny Islands matches

Assuming a 10.6% annual increase from 7,090 whales in 2004, an estimated eastern Australian population of 8,673 whales in 2006 was obtained.

The 3,120 individuals recorded in the EA catalogue between 1999 and 2005 were assumed to have been captured at a constant rate of 446 whales per annum. Application of an estimated mortality rate of 4% per annum yielded an estimated 2,772 whales in the catalogue that were alive and available for capture near the Balleny islands in early 2006.

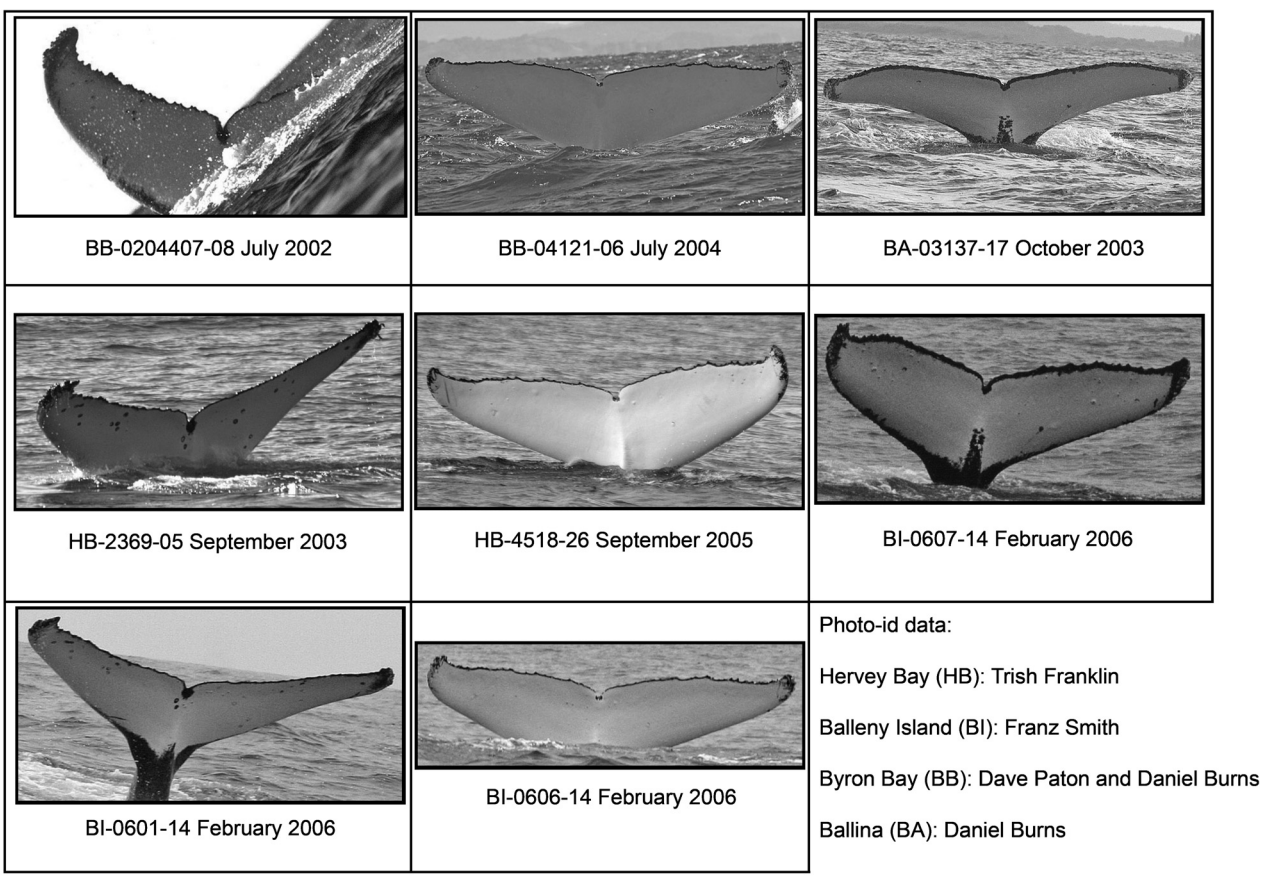

Fig. 2. Photographs and dates of the confirmed individual photo-ID matches between the Balleny Islands (BI), Hervey Bay (HB), Byron Bay (BB) and Ballina (BA). Left column: Individual e in Fig. 1; seen in BB, HB and BI. Central column: Individual f in Fig. 1; seen in BB, HB and BI. Right column: Individual d in Fig. 1; seen in BA and BI.

Table 3

Observed and expected frequencies of whales Not seen and Seen near the Balleny Islands by Not seen and Seen in Eastern Australia.

		Eastern Australia		
Balleny Islands	Frequency	Not seen	Seen	Total
Not seen	Observed	5,893	2,769	8,662
	Expected	5,893.5	2,768.5	8,662
Seen	Observed	8	3	11
	Expected	7.5	3.5	11
Total		5,901	2,772	8,673

Table 4

Observed and expected frequencies of whales Not seen and Seen near the Balleny Islands by Not seen and Seen in Oceania.

		Oceania		
Balleny Islands	Frequency	Not seen	Seen	Total
Not seen	Observed	3,177	639	3,816
	Expected	3,178.8	637.2	3,816
Seen	Observed	11	0	11
	Expected	9.2	1.8	11
Total		3,188	639	3,727

Table 3 reports the frequencies of whales 'not seen' and 'seen' near the Balleny Islands by 'not seen' and 'seen' in eastern Australia based on these estimates together with the size of the Balleny Islands catalogue (n = 11) and the number of Balleny Islands to eastern Australia matches (n = 3). The expected frequencies shown there were derived on the assumption of independence corresponding to an hypothesis that the whales seen in both places were members of the same population.

The one-tailed p-value from Fisher's exact test for the data in Table 3 was 0.512, indicating no evidence of dependency. Indeed, the observed and expected frequencies could not have been closer with 3 (or 4) whales seen at both sites. Thus there was no evidence to reject the null hypothesis that the whales seen near the Balleny Islands were from the eastern Australian population.

By way of context for this result, the null hypothesis (at $p < 0.05$) would have been rejected were no matches to have been found (p = 0.014), but not if as few as one match had been found (p = 0.089). Alternatively, if 3 matches were to have been found then the number of Balleny Islands flukes would have had to exceed 21 for the null hypothesis to have been rejected (for 22 Balleny Islands flukes, p = 0.046).

With a 10% lower estimate of the number of whales alive and in the EA catalogue, the expected number of matches was 3.1 and the p-value was 0.614; with 10% higher estimate, the expected number of matches was 3.8 and the p-value was 0.431.

Oceania – Balleny Islands matches

It was assumed that there was no increase in the Oceania population from the 2004 estimate of 3,827 whales (Baker *et al.*, 2006).

The 735 individuals recorded in the Oceania catalogue between 1999 and 2004, were assumed to have been captured at a constant rate of 122.5 whales per annum. Application of an estimated mortality rate of 4% per annum yielded an estimated 639 whales in the Oceania catalogue that were alive and available for capture near the Balleny islands in early 2006.

Table 4 reports the frequencies of whales 'not seen' and 'seen' near the Balleny Islands by 'not seen' and 'seen' in Oceania based on these estimates together with the size of the Balleny Islands catalogue (n = 11) and the number of Balleny Islands to Pacific matches (n = 0). The expected frequencies shown there were derived on the assumption of independence corresponding to an hypothesis that the whales seen in both places were members of the same population.

The one-tailed p-value from Fisher's exact test for the data in Table 4 was 0.134. Thus, although the data provide weak evidence to reject the null hypothesis that the whales seen near the Balleny Islands were members of the Oceania population, the samples were not large enough to provide a level of significance sufficient to conclude that they were not.

With no matches being found, the null hypothesis (at $p<0.05$) would have been rejected and the alternative hypothesis of two separate populations accepted only if there were at least 900 whales in the OC catalogue that were alive and available for capture near the Balleny islands in early 2006.

With a 10% lower estimate of the number of whales alive and in the OC catalogue, the expected number of matches was 1.7 and the p-value was 0.166; with 10% higher estimate, the expected number of matches was 2.0 and the p-value was 0.107.

DISCUSSION

Only six photo-ID matches have been reported between the eastern Australia (E(i) breeding stock) and Southern Ocean Antarctic Area V feeding areas. These comprise of the three matches reported here, between the Balleny Islands and Hervey Bay, Byron Bay and Ballina, and the three previously reported matches in Rock et al. (2006). All six individual humpbacks photographed in the Area V feeding area and/or around the Balleny Islands show long-term site-fidelity to either the eastern Australian migratory corridor utilised by the E(i) breeding stock or to locations within or near the putative terminus of the E(i) breeding stock within the Great Barrier Reef lagoon (Kaufman *et al.*, 1990; Trish Franklin unpublished data; Rock *et al.*, 2006) (Fig. 1 and Fig. 2).

While based on limited data from the Balleny Islands, these results are consistent with the hypothesis that the whales seen near the Balleny Islands were members of the population that migrates up the east coast of Australia. It would have been necessary, given the present sizes of the catalogues, to have found no matches between the Balleny Islands and the eastern Australian catalogues, or given the three matches that were found, for the Balleny Islands catalogue to have exceeded 21 individuals to reject this hypothesis.

While weak evidence was found against the hypothesis that the whales seen near the Balleny Islands were members of the population that migrates into Oceania, there were insufficient data to confidently conclude that they were not members of that population. Given that no matches were found between the Balleny Islands and Oceania catalogues,

the null hypothesis (at $p < 0.05$) would have been rejected in favour of the two separate populations hypothesis only if there had been at least 900 whales in the Oceania catalogue that were alive and available for capture near the Balleny Islands in early 2006.

Sampling in the Balleny Islands for this study was only conducted for a short period in February 2006 within a specified area. If whales that migrate from eastern Australia or Oceania arrive within the area around the Balleny Islands at different times during the season, or if the movements of humpbacks whales within and around the Balleny Islands area vary from year to year due to prey availability or other factors, a short sampling period within a specific area may result in a sampling bias. Although a small sample of humpback whale flukes obtained in the vicinity of the Balleny Islands was used in this study the data have provided evidence that some humpback whales from eastern Australia feed in the vicinity of these islands. Expanded temporal and spatial sampling of humpback whale flukes in the area of the Balleny Islands may yield further evidence of whether humpbacks from other populations feed in the vicinity of the Balleny Islands.

Previous research (Olavarría *et al.*, 2007) has concluded that, although some migratory interchange has been observed, the eastern Australian and Oceania humpback whales are discrete populations, (Franklin *et al.*, 2008; Garrigue *et al.*, 2007). Franklin *et al*. (2008) suggest that humpback whales with site-fidelity to eastern Australia may use the New Zealand migratory corridor to the south of the South Island and/or pass through the Foveaux Straits or Cook Straits when travelling to and from the Antarctic Area V feeding areas in the vicinity of the Balleny Islands or the Ross Sea.

If it is assumed that the data presented here indicate that the whales seen both in eastern Australia and near the Balleny Islands were very likely to have been members of the same population, then the whales observed near the Balleny Islands were unlikely to also be members of the Oceania population. While the finding of no matches between the Oceania and Balleny Islands catalogues is consistent with this argument, the small Balleny Islands catalogue and the location, duration and timing of sampling make it difficult to completely rule out some potential interaction with Oceania.

Given that eastern Australian and Oceania populations are discrete breeding stocks, the most parsimonious explanation is that the individuals at the Balleny Islands are likely to be part of the eastern Australian population based on the limited data available from the Balleny Islands.

Consequently further collection of humpback whale photo-ID fluke data, either in the vicinity of the Balleny Islands, the Ross Sea and/or from across the Area V feeding areas, will be important in clarifying the migratory linkages between Antarctic feeding areas and Oceania and eastern Australian breeding grounds.

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