

# Remote Antarctic feeding ground important for east Australian humpback whales

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**Abstract** Understanding the dynamics of population recovery is particularly complex when an organism has multiple, remote breeding and feeding grounds separated by one of the longest known migration routes. This study reports on the most comprehensive assessment of humpback whale (*Megaptera novaeangliae*) movements between remote Antarctic waters south of New Zealand and east Australia (EA), and the migratory corridors and breeding grounds of Australia and Oceania. A total of 112 individual whales were

identified; 57 from microsatellites and 61 by fluke with 23 % ( $n = 26$ ) matched to sites outside Antarctica. Despite large datasets from other southern regions being included in the comparison, the whales were predominantly linked to EA ( $n = 24$ ). Only two matches to the Oceania catalogues directly north was surprising; therefore the primary feeding grounds of these endangered whales still remain unknown. The confirmation of the Balleny Islands as an important feeding ground for EA whales could provide an insight into reasons behind the rapid recovery of this population. Determining the feeding grounds of Oceania's whales may explain whether prey energetics or migration length are limiting factors to their recovery and will allow an understanding of future ecosystem changes in these whales.

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## Introduction

Migrations are necessary for animals that require spatially separated habitats, such as breeding and feeding grounds, but few mammals undertake long periods of fasting as a consequence of differences in these habitats. For species of concern, understanding all ecological requirements is crucial when determining their recovery. Humpback whales (*Megaptera novaeangliae*) undertake annual migrations between polar feeding grounds and tropical breeding grounds and show population structuring, primarily due to maternal philopatry (Clapham 2009). Most humpback populations are recovering from depletion (Clapham and Baker 2002); however, adjacent populations in the southern hemisphere show highly variable recovery rates (Clapham 2009). The east Australia (EA) humpback whale population is growing at 10.6 % per annum (Noad et al. 2011), which is near the maximum growth rate for the species (Zerbini et al. 2010), whereas neighbouring Oceania subpopulations found on the breeding grounds between New Caledonia and French Polynesia (Fig. 1) are recovering considerably more slowly (Childerhouse et al. 2008; Constantine et al. 2012).

The Antarctic feeding grounds of southern hemisphere humpback whales are remote and largely unsurveyed; therefore, links between the breeding and feeding grounds

are poorly understood (Valsecchi et al. 2010; Schmitt et al. 2013). Discovery tags from whaling (Dawbin 1964), genotypes (Steel et al. 2008), satellite telemetry (Garrigue et al. 2010a; Hauser et al. 2010), acoustics (Garland et al. 2013) and photo-identification (Stevick et al. 2010; Robbins et al. 2011) show single movements between defined breeding grounds and feeding areas (International Whaling Commission (IWC) Areas IV–I; Fig. 1) but large feeding aggregations of whales south of NZ have yet to be described.

Determining the Antarctic feeding grounds of southern hemisphere whales may provide important insights into causes behind the different population recovery rates. Previous opportunistic surveys have resulted in six fluke matches between EA and Area V (Fig. 1) feeding grounds (Kaufman et al. 1990; Rock et al. 2006; Franklin et al. 2012). Until now, there has been no comprehensive comparison of whales from Antarctic feeding grounds south of Oceania and EA and links to their migration routes and breeding grounds. We expected Antarctic Area V, spanning the Antarctic waters 130°E–170°W directly south of EA and east of NZ (Fig. 1), to be an important feeding ground for whales breeding in western Oceania as it was an area of historical abundance. Here we conduct the first large-scale research effort using fluke photographs and genotyping to determine the identity of humpback whales on the productive Area V Antarctic feeding grounds south of Oceania.

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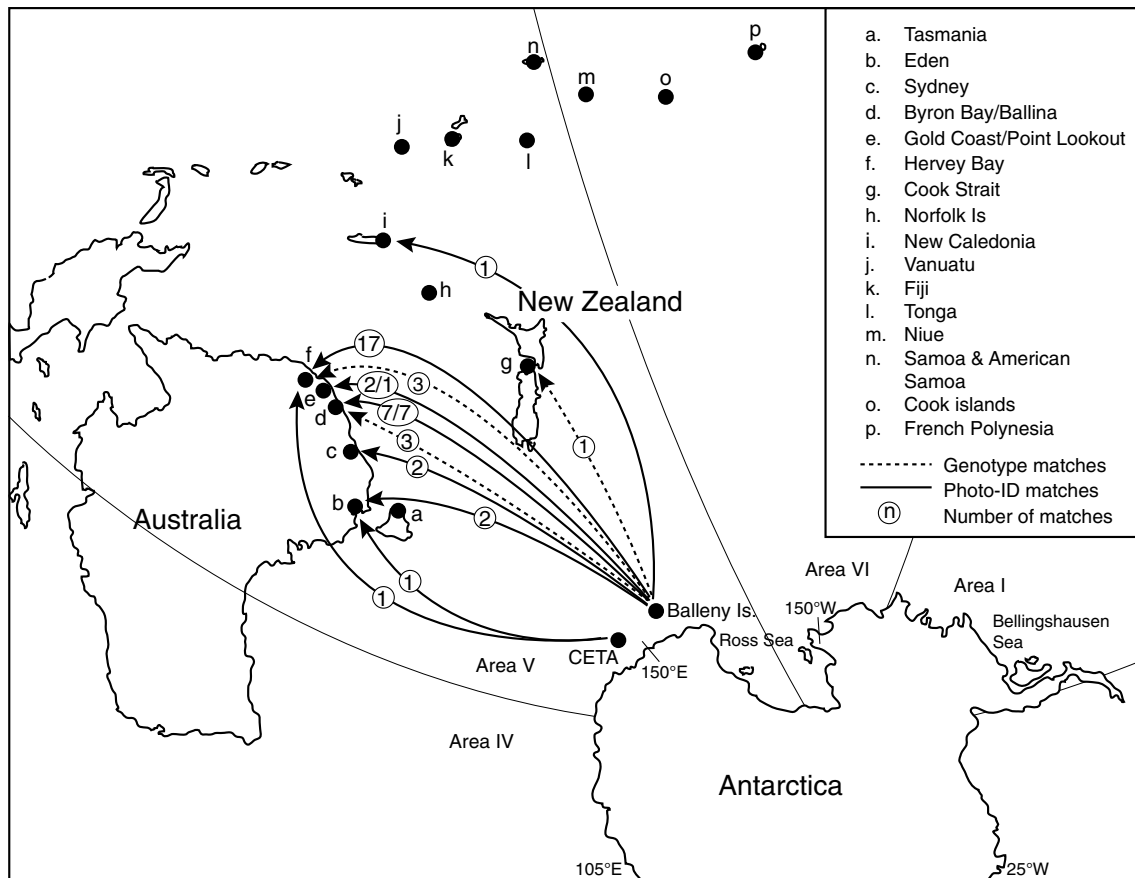
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## Methods

### Photo-identification

Humpback whales were identified from photographs of natural markings on the underside of their flukes (Katona et al. 1979). Photographs were collected during two Antarctic voyages; (1) the Antarctic Whale Expedition (AWE), a dedicated Antarctic cetacean research voyage, from 2 February to 15 March 2010, that surveyed 5,800 nm south of 60° between 150°W and 150°E (Gales 2010). (2) The French Cetacés en Terre Adélie (CETA) programme, with opportunistic cetacean sightings from 10 to 22 January 2010 on the Adélie Land continental shelf between 140 and 146°E (Garrigue et al. 2010b). Images from these two expeditions were combined to make a single catalogue (AWE/CETA) of the best image of each whale and curated on a website at the Australian Antarctic Division. The AWE/CETA catalogue was then matched to existing fluke catalogues from Australia, Oceania and Antarctica resulting in broad coverage of migratory corridors, breeding grounds and other Antarctic waters (Table 1). These catalogues, curated by different researchers, had been internally reconciled so only a single image of each whale existed in the respective catalogues, but many of the catalogues from different



**Fig. 1** Location and number of genotype (*dashed line*) and photo-identification (*solid line*) matches of humpback whales from Antarctica to the migratory corridors and breeding grounds of Australia, New Zealand and Oceania. The Antarctic Whale Expedition survey

boundaries of 150°E and 150°W which provided the majority of the data are demarcated. The location of the two matched photographs taken on the French Cetacés en Terre Adélie expedition are noted as CETA

**Table 1** Summary of the regional photo-identification catalogues matched to AWE/CETA

Location	Breeding, migration, feeding	Total
West Australia	M; B	1,664
East Australia	M; B	9,994
AHWC (assorted)	B	2,403
AHWC (Antarctic)	F	1,270
New Zealand	M	100
Norfolk Island	M	6
Oceania	B	1,806
Overall total		17,243

The Antarctic humpback whale catalogue (AHWC, curated by JA) contains images from the breeding and feeding grounds and hence the delineation of this catalogue into two categories

areas had not been reconciled with each other. While the AWE/CETA catalogue only contains the best image of each whale, the sum of individuals across the other catalogues

is likely to include duplicate images of some individuals. Therefore, the total number of images matched to the AWE/CETA catalogue exceeds the actual number of individual whales. This refers primarily to EA where several catalogues of over 1,000 whales exist and to date have not been reconciled.

#### Genetic identification

Tissue samples were collected during the AWE using a biopsy rifle system. Total cellular DNA was isolated using an automated Promega Maxwell<sup>®</sup>16 System. Ten microsatellite loci were amplified for each sample (GT211, GT575 (Bérubé et al. 2000), GATA417 (Palsbøll et al. 1997), EV1, EV14, EV37, EV94, EV96 (Valsecchi and Amos 1996) and rw4-10 (Waldick et al. 1999). For each locus, one of the primers within each pair was labelled fluorescently at the 5' end to allow for visualisation of alleles on an automated ABI 3130 sequencer (Applied Biosystems). Sex was determined using a fluorescent 5' exonuclease assay producing

**Table 2** Unique genotypes (individual whales) sampled on breeding grounds and migratory routes (details in electronic supplementary material, Table 4)

Region	No. loci	No. loci shared with AWE	Dataset	Years	No. unique genotypes
Oceania breeding grounds					
New Caledonia	17	10	SPWRC	1995–2005	388
Tonga	17	10	SPWRC	1991–2009	371
Samoa/American Samoa	17	10	SPWRC	2001–2009	88
Cook Islands	17	10	SPWRC	1996–2005	108
French Polynesia	17	10	SPWRC	1997–2007	230
Niue	17	10	SPWRC	2008	3
Total Oceania					1,188 (1,140)
Northbound migration					
Byron Bay, EA	13	8	SCU	1996–2004	337
Eden, EA	10	10	AMMC	2008	43
Tasmania, EA	10	10	AMMC	2006–2008	1
Cook Strait, NZ	17	10	SPWRC	2003–2009	65
Total northbound					446
Southbound migration					
Hervey Bay, EA	13	8	SCU	1997–2003	365
Ballina, EA	13	8	SCU	2003–2004	63
Eden, EA	10	10	AMMC	2008	18
Tasmania, EA	10	10	AMMC	2006–2008	69
Exmouth, WA	10	10	AMMC	2007	204
Total southbound					719
Total breeding and migration					2,353 (2,272)

The number of unique genotypes across the entire region (i.e. between-region matches removed) shown in parentheses

EA east Australia, NZ New Zealand, WA west Australia

Dataset curators are *SPWRC* South Pacific Whale Research Consortium, *SCU* Southern Cross University, Australia, *AMMC* Australian Marine Mammal Centre, Australia

PCR product from the ZFX and ZFY orthologous gene sequences (Morin et al. 2005). Sequencing of 700 bp of the mitochondrial (mt)DNA control region followed Olavarría et al. (2007).

Replicates were identified and removed from within the dataset using GenAlEx (Peakall and Smouse 2012). Genotypes of the remaining individuals were then compared to 2,272 previously typed individuals from Australia and Oceania (Table 2), some of which had been compared previously (Anderson et al. 2010). All datasets included mtDNA control region sequence and sex information (supplementary material, tables 1–3). Initial genotype matching between the datasets was conducted using Cervus (Kalinowski et al. 2007) using ‘relaxed’ conditions to avoid false exclusion of true matches due to genotyping or standardisation errors. The relaxed conditions required a minimum of six matching loci to confirm identity (Waits and Leberg 2000; Waits et al. 2001; Hoffman and Amos 2005; Morin et al. 2010).

## Results

We identified 112 individual humpback whales (fluke  $n = 61$ ; genotype  $n = 57$ ; of these, both methods  $n = 6$ ). Despite extensive but non-systematic coverage near the humpback whales’ preferred habitat near the sea-ice edge, sightings were unevenly distributed even when taking sighting conditions into consideration (Gales 2010). The greatest number of whales was sighted near the Balleny Islands compared to other areas along the survey route (Gales 2010). Subsequently, the majority of whales were photographed ( $n = 57$ ) or biopsied ( $n = 56$ ) near the Balleny Islands (66°55’S 163°45’E) (Gales 2010; Garrigue et al. 2010b) (Fig. 1).

Sixty-one individual whales included in the AWE/CETA catalogue were matched to 17,243 other catalogued images (Table 1). Twenty-five (41 %) whales matched other catalogues (EA = 24, New Caledonia = 1) (Fig. 1) with matches dating back to 1984. Sixteen whales were sighted

more than once. Of these, individuals were sighted on average 2.2 times with an average of 6.7 years between the initial sighting and their AWE/CETA sighting when each whale was counted once per location per annum.

Analysis of the mtDNA control region resolved 26 previously described haplotypes (Olavarría et al. 2007) and two new haplotypes. There was a 1:1 sex ratio (28 females/29 males) of genotyped whales. Comparison of the 57 AWE whales to 2,272 unique individuals from other areas (Table 2) resulted in seven matches (EA = 6, NZ = 1) (Fig. 1). Six to ten matching microsatellite loci were considered sufficient to establish a match (pID,  $2.3 \times 10^{-7}$ , supplementary material, table 4), given the small number of pairwise matches ( $57 \times 2,272 = 1.3 \times 10^5$ ).

## Discussion

Our research unequivocally shows the importance of the Balleny Islands region as a feeding ground for EA humpback whales as surprisingly; with the exception of two matches (to the New Caledonia breeding ground and NZ migratory corridor), all matches were to EA whales. The Antarctic feeding areas for whales from the Oceania breeding grounds remain unknown despite the majority of the data being collected at the Balleny Islands, a likely feeding ground south of western Oceania (Fig. 1). We present the most comprehensive matching of individually identified humpback whales undertaken in this poorly surveyed Antarctic region, which provides insight into the ecology of humpback whales.

The Balleny Islands represent a productive part of eastern Antarctica (Atkinson et al. 2009), and this humpback whale feeding ground may provide valuable insights into why the EA subpopulation is recovering rapidly (Noad et al. 2011), in contrast to the endangered Oceania whales (Constantine et al. 2012). Whales are likely to have similar energetic requirements to survive irrespective of the Antarctic feeding ground location (Reilly et al. 2004), and it is possible that regional productivity and the length of migration path may play a role in population recovery. EA whales feed at Eden, south-eastern Australia, on their southern migration before reaching the Antarctic feeding grounds (Stamation et al. 2007). Satellite-tagged humpbacks on their southern migration past east Australia stopped for periods of days to weeks (Gales et al. 2009) at the productive subtropical front passing the south-west coast of the South Island, NZ (Murphy et al. 2001). It has been suggested that they may opportunistically feed on prey patches before they arrive in Antarctic waters. Telemetry could help determine the relationship between whale foraging behaviour on their migratory path and on the feeding grounds by measuring chlorophyll *a* productivity (e.g. Laidre et al. 2010) and niche preferences within the water column (e.g. Friedlaender et al. 2006).

Understanding the role of opportunistic feeding grounds to the energetics of humpback whales may provide insights into the different recovery rates of this species.

Despite the essential role of Antarctic waters as the summer feeding grounds for all southern hemisphere whales (de la Mare 1997; Reilly et al. 2004; Nicol et al. 2008), most recent research on humpback whale feeding grounds has been conducted around the Antarctic Peninsula (Thiele et al. 2004; Friedlaender et al. 2006). The potential Antarctic feeding grounds available to Oceania's humpback whales cover a broad and largely inaccessible expanse of the Southern Ocean (Fig. 1). Throughout these waters, there is variation in productivity and sea-ice edge dynamics; both factors are important for humpback whales in Antarctica (de la Mare 1997; Murphy et al. 1998; Holland and Kwok 2012; Bintanja et al. 2013). It would be valuable in the future if researchers working in the poorly studied area between the eastern Ross Sea and Bellinghousen Sea, located west of the Antarctic Peninsula (Fig. 1), could photo-identify whales in these waters. This information may reveal the Oceania whales' feeding grounds. There are a few records of humpback whales from eastern Oceania matching to the waters west of the Antarctic Peninsula (Steel et al. 2008; Robbins et al. 2011), and we suggest that the highly productive waters of the western Antarctic Peninsula may provide the feeding grounds for some of Oceania's humpback whales. Satellite tag deployments and comparing photo-ID and genetic data from Oceania to the Antarctic Peninsula may determine the strength of these linkages.

Our research has shown that the Balleny Islands are important for EA humpback whales. Unfortunately, the feeding grounds of Oceania's humpback whales remain unresolved, and the waters between their breeding grounds and Antarctica remain poorly surveyed. Further investigation of linkages between feeding grounds and migratory paths is vital to resolve whether Oceania's whales are recovering slowly due to resource limitations, migration distance and/or if population declines from historical whaling remains a driving factor.

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## References

- Anderson M, Steel D, Franklin W, Franklin T, Paton D, Burns D, Harrison P, Baverstock P, Garrigue C, Olavarría C, Poole MM, Hauser N, Constantine R, Thiele D, Clapham P, Donoghue M,

- Baker CS (2010) Microsatellite genotype matches of eastern Australian humpback whales to Area V feeding and breeding grounds. Paper SC/62/SH7 presented to the IWC scientific committee. Morocco, Agadir, p 11
- Atkinson A, Siegel V, Pakhomov EA, Jessopp MJ, Loeb V (2009) A re-appraisal of the total biomass and annual production of Antarctic krill. *Deep-Sea Res I* 56:727–740
- Bérubé M, Jørgensen H, McEwing R, Palsbøll PJ (2000) Polymorphic di-nucleotide microsatellite loci isolated from the humpback whale, *Megaptera novaeangliae*. *Mol Ecol* 9:2181–2183
- Bintanja R, van Oldenborgh GJ, Drijfhout SS, Wouters B, Katsman CA (2013) Important role for ocean warming and increased ice-shelf melt in Antarctic sea-ice expansion. *Nat Geosci* 6:376–379
- Childerhouse S, Jackson J, Baker CS, Gales N, Clapham PJ, Brownell RL (2008) *Megaptera novaeangliae*, Oceania subpopulation. IUCN Red List of Threatened Species. (<http://www.iucnredlist.org/>)
- Clapham P (2009) Humpback whale *Megaptera novaeangliae*. In: Perrin WF, Würsig B, Thewissen JGM (eds) Encyclopedia of marine mammals. Academic Press, San Diego, pp 582–585
- Clapham P, Baker CS (2002) Whaling, modern. In: Perrin WF, Würsig B, Thewissen JGM (eds) Encyclopedia of marine mammals. Academic Press, San Diego, pp 1328–1332
- Constantine R, Jackson JA, Steel D, Baker CS, Brooks L, Burns D, Clapham P, Hauser N, Madon B, Mattila D, Oremus M, Poole M, Robbins J, Thompson K, Garrigue C (2012) Abundance of humpback whales in Oceania using photo-identification and microsatellite genotyping. *Mar Ecol Prog Ser* 453:249–261
- Dawbin WH (1964) Movements of whales marked in the south west Pacific ocean 1952 to 1962. *Norsk Hvalfangst Tid* 53:68–78
- de la Mare WK (1997) Abrupt mid-twentieth-century decline in Antarctic sea-ice extent from whaling records. *Nature* 389:57–60
- Franklin W, Franklin T, Brooks L, Gibbs N, Childerhouse S, Smith F, Burns D, Paton D, Garrigue C, Constantine R, Poole MM, Hauser N, Donoghue M, Russell K, Mattila DK, Robbins J, Oosterman A, Leaper R, Harrison P, Baker S, Clapham P (2012) 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*). *J Cetacean Res Manag* 12:321–327
- Friedlaender AS, Halpin PN, Qian SS, Lawson GL, Wiebe PH, Thiele D, Read AJ (2006) Whale distribution in relation to prey abundance and oceanographic processes in shelf waters of the western Antarctic Peninsula. *Mar Ecol Prog Ser* 317:297–310
- Gales N (2010) Antarctic whale expedition: preliminary science field report and summary. Unpublished Report, Australian Marine Mammal Centre, Australian Antarctic Division, Hobart, Australia, p 21
- Gales N, Double M, Robinson S, Jenner C, Jenner M, King E, Gedamke J, Paton D, Raymond B (2009) Satellite tracking of southbound East Australian humpback whales (*Megaptera novaeangliae*): challenging the feast or famine model for migrating whales. Paper SC61/SH/17 presented to the IWC scientific committee. Portugal, Madeira, p 11
- Garland EC, Gedamke J, Rekdahl ML, Noad MJ, Garrigue C, Gales N (2013) Humpback whale song on the Southern Ocean feeding grounds: implications for cultural transmission. *PLoS ONE* 8:e79422
- Garrigue C, Zerbini AN, Geyer Y, Heide-Jørgensen M-P, Hanaoka W, Clapham P (2010a) Movements of satellite-monitored humpback whales from New Caledonia. *J Mamm* 9:109–115
- Garrigue C, Peltier H, Ridoux V, Franklin T, Charrassin J-B (2010b) CETA: a new cetacean observation program in East Antarctica. Paper SC/62/SH3 presented to the IWC scientific committee. Morocco, Agadir, p 5
- Hauser N, Zerbini AN, Geyer Y, Heide-Jørgensen M-P, Clapham P (2010) Movements of satellite-monitored humpback whales, *Megaptera novaeangliae*, from the Cook Islands. *Mar Mamm Sci* 26:679–685
- Hoffman JJ, Amos W (2005) Microsatellite genotyping errors: detection approaches, common sources and consequences for paternal exclusion. *Mol Ecol* 14:599–612
- Holland PR, Kwok R (2012) Wind-driven trends in Antarctic sea-ice drift. *Nat Geosci* 5:872–875
- Kalinowski ST, Taper ML, Marshall TC (2007) Revising how the computer program Cervus accommodates genotyping error increases success in paternity assignment. *Mol Ecol* 16:1099–1106
- Katona S, Baxter B, Brazier O, Kraus S, Perkins J, Whitehead H (1979) Identification of humpback whales by fluke photographs. In: Winn HE, Olla BL (eds) Behavior of marine animals. Plenum Press, New York
- Kaufman GD, Osmond MG, Ward AJ, Forestell PH (1990) Photographic documentation of the migratory movement of humpback whale (*Megaptera novaeangliae*) between east Australia and Antarctic Area V. *Rep Int Whal Comn Special Issue* 12:265–267
- Laidre KL, Heide-Jørgensen MP, Logsdin ML, Delwiche L, Nielsen TG (2010) A whale of an opportunity: examining the vertical structure of chlorophyll-*a* in high Arctic waters using instrumented marine predators. *Mar Biol Res* 6:519–529
- Morin PA, Nestler A, Rubio-Cisneros NT, Robertson KM, Mesnick SL (2005) Interfamilial characterization of a region of the ZFX and ZFY genes facilitates sex determination in cetaceans and other mammals. *Mol Ecol* 14:3275–3286
- Morin PA, Martien KK, Archer FI, Cipriano F, Steel D, Jackson J, Taylor BL (2010) Applied conservation genetics and the need for quality control and reporting of genetic data used in fisheries and wildlife management. *J Hered* 101:1–10
- Murphy EJ, Boyd PW, Leakey RJG, Atkinson A, Edwards ES, Robinson C, Priddle J, Bury SJ, Robins DB, Burkill PH, Savidge G, Owens NJP, Turner D (1998) Carbon flux in ice-ocean-plankton systems of the Bellingshausen Sea during a period of ice retreat. *J Mar Syst* 17:207–227
- Murphy RJ, Pinkerton MH, Richardson KM, Bradford-Grieve JM, Boyd W (2001) Phytoplankton distributions around New Zealand derived from SeaWiFS remotely sensed ocean colour data. *NZ J Mar Freshw Res* 35:343–362
- Nicol S, Worby A, Leaper R (2008) Changes in the Antarctic sea ice ecosystem: potential effects on krill and baleen whales. *Mar Freshw Res* 59:361–382
- Noad MJ, Dunlop RA, Paton D, Cato DH (2011) Absolute and relative abundance estimates of Australian east coast humpback whales (*Megaptera novaeangliae*). *J Cetacean Res Manag* 3:243–252
- Olavarría C, Baker CS, Garrigue C, Poole M, Hauser N, Caballero S, Flórez-González L, Brasseur M, Bannister J, Capella J, Clapham P, Dodemont R, Donoghue M, Jenner C, Jenner M-N, Moro D, Oremus M, Paton D, Rosenbaum H, Russell K (2007) Population structure of South Pacific humpback whales and the origin of the Eastern Polynesian breeding grounds. *Mar Ecol Prog Ser* 330:257–268
- Palsbøll PJ, Bérubé M, Larsen AH, Jørgensen H (1997) Primers for the amplification of tri- and tetramer microsatellite loci in baleen whales. *Mol Ecol* 6:893–895
- Peakall R, Smouse PE (2012) GenAlEx 6.5: genetic analysis in Excel—an update. *Population genetic software for teaching and research. Bioinformatics* 28:2537–2539
- Reilly S, Hedley S, Borberg J, Hewitt R, Thiele D, Watkins J, Naganobu M (2004) Biomass and energy transfer to baleen whales in the South Atlantic sector of the southern ocean. *Deep-Sea Res II* 51:1397–1409
- Robbins J, Dalla Rosa L, Allen JM, Mattila DK, Secchi ER, Friedlaender AS, Stevick PT, Nowacek DP, Steel D (2011) Return

- movement of a humpback whale between the Antarctic Peninsula and American Samoa: a seasonal migration record. *Endang Species Res* 13:117–121
- Rock J, Pastene LA, Kaufman G, Forestell P, Matsuoka K, Allen J (2006) A note on east Australia group V stock humpback whale movement between feeding and breeding areas based on photo-identification. *J Cetacean Res Manag* 8:301–305
- Schmitt NT, Double MC, Jarman SN, Gales N, Marthick JR, Polanowski AM, Baker CS, Steel D, Jenner KCS, Jenner M-NM, Gales R, Paton D, Peakall R (2013) Low levels of genetic differentiation characterize Australian humpback whale (*Megaptera novaeangliae*) populations. *Mar Mamm Sci*. doi:10.1111/mms.12045
- Stamation KA, Croft DB, Shaughnessy PD, Waples KA (2007) Observations of humpback whales (*Megaptera novaeangliae*) feeding during their southward migration along the coast of southeastern New South Wales, Australia: identification of a possible supplemental feeding ground. *Aquat Mamm* 33:165–174
- Steel D, Garrigue C, Poole M, Hauser N, Olavarría C, Flórez-González L, Constantine R, Caballero S, Thiele D, Paton D, Clapham P, Donoghue M, Baker CS (2008) Migratory connections between humpback whales from south Pacific breeding grounds and Antarctic feeding areas based on genotype matching. In: Paper SC/60/SH13 presented to the IWC scientific committee. Santiago, Chile, p 9
- Stevick PT, Neves MC, Johansen F, Engel MH, Allen J, Marcondes MC, Carlson C (2010) A quarter of a world away: female humpback whale moves 10000 km between breeding areas. *Biol Lett* 7:299–302
- Thiele DC, Chester ET, Moore SE, Sirovic A, Hildebrand JA, Friedlaender AS (2004) Seasonal variability in whale encounters in the western Antarctic Peninsula. *Deep-Sea Res II* 5:2311–2325
- Valsecchi E, Amos W (1996) Microsatellite markers for the study of cetacean populations. *Mol Ecol* 5:151–156
- Valsecchi E, Corkeron PJ, Galli P, Sherwin W, Bertorelle G (2010) Genetic evidence for sex-specific migratory behaviour in western South Pacific humpback whales. *Mar Ecol Prog Ser* 398:275–286
- Waits JL, Leberg PL (2000) Biases associated with population estimation using molecular tagging. *Anim Conserv* 3:191–199
- Waits LP, Luikart G, Taberlet P (2001) Estimating the probability of identity among genotypes in natural populations: cautions and guidelines. *Mol Ecol* 10:249–256
- Waldick RC, Brown MW, White BN (1999) Characterization and isolation of microsatellite loci from the endangered North Atlantic right whale. *Mol Ecol* 8:1763–1765
- Zerbini AN, Clapham PJ, Wade PR (2010) Assessing plausible rates of population growth in humpback whales from life-history data. *Mar Biol* 157:1225–1236