# Killer whales preying on a blue whale calf on the Costa Rica Dome: genetics, morphometrics, vocalisations and composition of the group

ROBERT L. PITMAN*, HOLLY FEARNBACH+, RICHARD LEDUC*, JAMES W. GILPATRICK, JR.*, JOHN K.B. FORD# AND LISA T. BALLANCE*

*Contact e-mail: robert.pitman@noaa.gov*

ABSTRACT

Killer whale (*Orcinus orca*) populations in high latitude, nearshore areas appear to regularly exhibit prey specialisation among two or more sympatric ecotypes, but nearly nothing is known about populations that inhabit open ocean areas or tropical latitudes. On 26 September 2003, during a cetacean survey in the eastern tropical Pacific Ocean, a group of an estimated 19 killer whales was encountered feeding on a calf of a blue whale (*Balaenoptera musculus*); the location was 10°58'N, 88°40'W, 230km west of Nicaragua. The whales were studied for 2.5 hours and during this time skin biopsy samples were collected, acoustic recordings made, aerial and lateral photographs taken and behavioural observations recorded. The 19 individuals identified included 4 males (3 adults, 1 subadult), 5 cow-calf pairs and 5 other females/subadult males. Using aerial photogrammetry, body lengths of 17 different animals were measured: the largest male (who carried the carcass most of the time) was 8.0m long; and the largest female (with a calf) was 6.1m. From 10 biopsy samples, two distinct haplotypes were identified that differed from *resident* (i.e. fish-eating ecotype) killer whales in the northeastern Pacific by one and two base pairs, respectively. The single discrete call recorded was a typical killer whale call but it had a two-part pitch contour that was structurally distinct from calls recorded to date in the North Pacific. These observations reaffirm that calves of even the largest whale species are vulnerable to predation, although by migrating to calving areas in the tropics, where killer whale densities are lower, baleen whales should be able to increase their overall reproductive fitness, as suggested by Corkeron and Connor (1999).

KEYWORDS: KILLER WHALE; PREDATION; GENETICS; MORPHOMETRICS; VOCALISATION; BLUE WHALE; MIGRATION; PACIFIC OCEAN; NORTHERN HEMISPHERE

## INTRODUCTION

Killer whales (*Orcinus orca*) are distributed throughout the world's oceans and are generally considered to comprise a single species (Rice, 1998). Recent research, however, has revealed considerable population sub-structuring within regional communities, with up to three ecotypes occurring sympatrically. For example, in the continental shelf waters of the eastern and central North Pacific, three distinct forms of killer whales have been identified: *residents* are neritic fish-eaters; *transients* are neritic mammal-eaters; and *offshores* are an outer coastal form with largely unknown diet preferences but evidence suggests that they feed on fish, including perhaps sharks (Barrett-Lennard and Heise, 2006; Heise *et al*., 2003; Jones, 2006). Three morphologically distinct forms of killer whales have also been described from Antarctica (types A, B, and C), which appear to prey mainly on Antarctic minke whales (*Balaenoptera bonaerensis*), pinnipeds, and fish, respectively (Pitman and Ensor, 2003).

Prey specialisation among different killer whale ecotypes also appears to have contributed to morphological divergences, including significant differences in body size. For example, fish-eating ecotypes in Antarctica are 2-3m smaller than the ecotype that preys on minke whales (Pitman *et al*., 2007). Furthermore, a comparison of body length data and prey preferences from killer whale communities in the western North Pacific, North Atlantic and Antarctic waters, suggests that high latitude populations may regularly comprise a nearshore, diminutive, fish-eating form living in close proximity to a larger, offshore, mammal-eating form (Pitman *et al*., 2007).

High latitude killer whale communities typically seem to include habitat partitioning, prey specialisation, morphological divergence and perhaps ultimately, reproductive isolation among sympatric forms. To date, however, there have been few detailed observations of killer whales that inhabit either deep ocean waters or live in low latitudes to consider how they might fit into this evolutionary scenario. Baird *et al*. (2006) summarised recent killer whale encounters around the Hawaiian Islands, including a group feeding on a humpback whale, and a live-stranded individual that had squid beaks in its stomach. From two tissue samples they collected from two separate encounters they identified two different haplotypes – one identical to 'Gulf of Alaska 2' *transients*; the other differed by one DNA base pair from mammal-eating killer whales in Alaskan coastal waters. Whether these 'island-associated' killer whales were year-round residents or part of a wider-ranging population could not be determined.

In September 2003, while conducting a cetacean survey in the eastern tropical Pacific Ocean, a group of killer whales was encountered feeding on a blue whale calf (*Balaenoptera musculus*). During the encounter, vocalisations were recorded, skin biopsy samples collected and a series of aerial and lateral photographs of nearly all of the whales present were obtained. In this paper, analyses of these acoustic, genetic and photogrammetric data are

* *NOAA Fisheries, Southwest Fisheries Science Center, 8604 La Jolla Shores Dr., La Jolla, CA 92037, USA.*
+ *NOAA Fisheries, National Marine Mammal Laboratory, Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115, USA.*
# *Cetacean Research Program, Pacific Biological Station, Fisheries and Oceans Canada, Nanaimo, BC V9T 6N7, Canada.*

presented and for the first time a group of open-ocean, tropical killer whales of known feeding habits are characterised. Finally, some preliminary comparisons are made with ecotypes described from the northeastern Pacific.

## METHODS

Observations were made while conducting a marine mammal sightings survey aboard the NOAA Research Vessel *David Starr Jordan* in the eastern tropical Pacific Ocean (ETP); additional details of the study area and overall survey methods can be found in Jackson *et al*. (2004). Four pairs of 25 × 150mm mounted spotting binoculars were used for detecting and observing cetaceans. After initially sighting the killer whales, they were closed in on and observed for 2.5h. During that time a 5m inflatable launch was deployed to collect biopsy samples and take photographs; a helicopter was launched to take aerial photographs for photogrammetric analysis; and acoustic recordings were obtained from a hydrophone mounted on the bow of the ship. Additional details on each of these activities are presented below.

Biopsy samples were collected for molecular genetics analyses using a crossbow and floating bolts. On returning to the vessel, blubber samples were sectioned from the skin and frozen at −80°C. The skin samples were then split: one half was preserved in a saturated salt solution and dimethyl sulfoxide (DMSO), the other half was flash-frozen in liquid nitrogen. Both halves were then stored at −80°C until they could be analysed at the end of the cruise.

DNA was extracted from the biopsy samples using a Qiagen *DNeasy* extraction kit. The entire mitochondrial control region was amplified in two overlapping segments and sequenced in both directions: the 5' end with the primers 5'-CCTCCCTAAGACTCAAGGAAG-3' (designed at Southwest Fisheries Science Center [SWFSC]) and 5'-CCTGAAGTAAGAACCAGATG-3' (Rosel *et al*., 1995), and the 3' end with the primers 5'-GTGAAACCAGCAACCCGC-3' and 5'-AAGGCTGGGACCAAACCTT-3' (both designed at SWFSC). Sequencing was done using *Big Dye Terminator* reagents and protocols from Applied Biosystems (ABI), with the PCR primers serving as sequencing primers. The products of the sequencing reactions were run on an *ABI 3100* automated genetic analyser, with the sequences edited using *Sequencher* (Gene Codes v.4.1) and aligned by eye.

Underwater vocalisations were recorded during the event using three closely spaced hydrophones mounted in the bow of the ship. The hydrophones had an effective frequency response from 500Hz to 25kHz (± 10dB). The signals were recorded on a Marantz *PMD700* DAT recorder. Acoustic signals were analysed using *Audition* 1.5 (Adobe Corporation) and *Raven* 1.2.1 (Cornell Lab of Ornithology) software.

From the launch, 163 images were taken using a Canon digital 35mm single lense reflex (SLR) camera equipped with an 85-300mm lens; from the helicopter an additional 83 images were taken using a 400mm lens. These images were used to estimate the number of whales present, identify associated animals (defined as animals less than one body length apart in the photos), assign sexes and ages and to match (to the extent possible) biopsy samples with individual animals. The photographs also allowed a qualitative assessment of morphological features (colour patterning, scarring etc.) and presence of barnacles on the dorsal fin. The original photographs are permanently archived at SWFSC, La Jolla, CA.

In order to obtain morphometric measurements, the killer whales and the blue whale calf were photographed from a helicopter equipped with a belly-mounted, large format (126mm) camera (for details of photogrammetric methods see Gilpatrick, 1997; Perryman and Lynn, 1993; Pitman *et al*., 2007). A high resolution, motion-compensating, KA-76 military reconnaissance camera was used that was mounted below the fuselage of a *McDonald-Douglas 500D* helicopter. The photos were taken at a ground speed of 166km $h^{-1}$, at a height above sea level ranging between 62.6-137.0m. A data acquisition system simultaneously recorded the time and a radar altimeter reading as each photograph was taken. A total of 338 images were taken using this system.

Animals were measured using a computer-based video imaging system (Gilpatrick and Lynn, 1994). Total body length (TL: tip of rostrum to edge of fluke notch), and fluke width were determined only for whales photographed swimming parallel to, and at or near the surface of the water. It has been suggested that, at least for Antarctic killer whale populations, relative fluke width may be a useful taxonomic character (Berzin and Vladimirov, 1983), so fluke-width-to-body-length ratios were calculated whenever possible.

To estimate the precision of our body length measurements, the same methods were used to estimate the length of the 4.9m launch in the water during the event. The launch was photographed six times at altitudes ranging from 130-140m. Estimated lengths averaged 4.9m (range: 4.8-5.0m); the coefficient of variation (CV) was 0.020% and 95% confidence limits of the means (CL) were ± 0.076m. Thus, for a 4.9m target at the sea surface, the variance in the aerial photogrammetric method translated to an estimated error of ± 7.6cm (or ± 1.6%) with a 95% confidence interval.

## RESULTS

The event took place on 26 September 2003, at 10°58'N, 88°40'W, 230km off the Pacific coast of Nicaragua (Fig. 1). The water depth was approximately 3,000m, the sea surface temperature was 28°C, the wind speed was 5kt and sighting conditions were excellent. The animals were initially sighted at 11:26 Local Mean Time. They were closed in on and at 11:45 a launch was deployed. The next 2h 25min were spent recording their vocalisations, collecting biopsy samples and photographing individual whales. The launch returned to the vessel at 14:10. A helicopter onboard the ship was launched at 12:02 to take aerial photographs and observe from the air; it returned to the ship at 13:29.

The initial sighting was a series of large blows over the horizon. Due to the close proximity to the Costa Rica Dome (see Discussion), an area where blue whales have been regularly encountered over the years (e.g. Reilly and Thayer, 1990), see also Fig.1, it was immediately suspected they were indeed blue whales. The ship was turned to approach the animals, but found only killer whales and the carcass of a blue whale calf. It was therefore inferred that at least one adult blue whale had been present but had left the area after the calf had been killed.

When closing in, it was immediately clear that a kill had just taken place: the whales were milling and diving in an area of a large and widening oil slick at the surface and scavenging seabirds were just starting to gather. (Over the course of the observations, the birds that came to feed in the slick ultimately included an estimated 100 Galapagos storm-petrels (*Oceanodroma tethys*), 7 Markham's storm-petrels (*O. markhami*) and 10 Tahiti petrels (*Pseudobulweria*

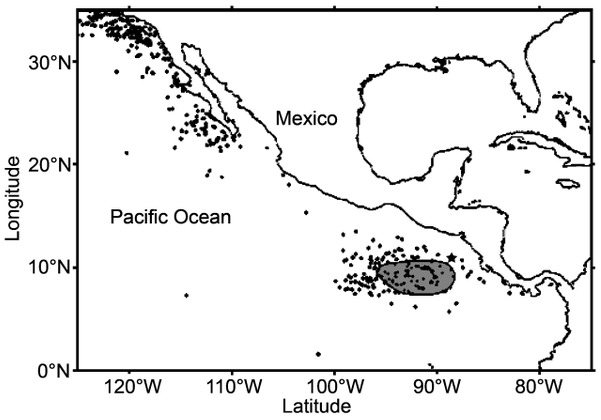


Fig. 1. The eastern tropical Pacific Ocean showing the nominal location of the Costa Rica Dome (shaded area) during the month of September (from Fiedler, 2002; see text). Also shown are sightings of blue whales from research vessels and fisheries observers on tuna purse seine vessels (diamonds, from Ballance *et al*., 2006), and the location where killer whales were observed preying upon a blue whale calf in September 2003 (star).

*rostrata*)). When the launch was deployed, it went directly to the slick where personnel onboard retrieved a 2.5cm cube of cetacean skin and blubber dropped by a foraging storm-petrel. The sample appeared (and was later genetically confirmed) to be from a blue whale. It was very fresh and still seeping blood.

During the first 10min of the launch, two different killer whales swam by at different times within 5m; they both rolled over on their side underwater and appeared to investigate the launch. Throughout the remainder of the sighting however, all of the killer whales were less inquisitive and increasingly evasive, apparently in response to the launch moving back and forth between subgroups for photographs and biopsy samples. The presence of the helicopter may have also altered the behaviour and groupings of the animals and these factors must be considered in the behavioural descriptions presented below.

From the water surface, other than the oil slick, bird flock and the small chunk of flesh retrieved, there was little evidence that a predation event had taken place. People in the launch did not actually see the blue whale carcass during the first 2h on the water, and observers on the research vessel did not see it at all even though they were less than 1km away and observing through the high-powered binoculars the entire time. Personnel in the helicopter, however, radioed back almost immediately after they were airborne that one of the adult male killer whales was carrying what appeared to be an intact, freshly-killed blue whale calf and that other whales were attempting to feed on it.

Two adult male killer whales took turns in carrying the carcass, but the larger of the two (and the largest animal photographed; see below), carried it most of the time, using his mouth and flippers. A young calf consistently observed with the larger male was often seen trying to feed on the carcass as they travelled together. The larger male released the carcass on several occasions apparently when the launch got too close and each time, after the carcass sank out of sight, another animal that appeared to be an adult female used its rostrum to push it back to the surface where the other whales sometimes took turns feeding on it. On one occasion, at a location where a group had just been at the surface with the carcass, the launch passed over a long piece of blue whale skin and blubber, approximately 2m long and 1m wide that had been stripped off the carcass.

There was evidence of recent aggressive interactions among the killer whales present. At least three photographed individuals had very fresh killer whale tooth rake marks on them. For example, a sub-adult male with the group that was carrying the carcass had tooth rake marks on both his flanks behind the dorsal fin that showed exposed, red flesh; the large male carrying the carcass also had fresh red rake marks on his head and flanks and another female also had red rake marks (Fig. 2d). In addition to fresh rake marks, almost all of the animals had old rake marks (quite heavy on two calves), suggesting that agonistic interactions occurred regularly.

It was not until after about 2h of observation that personnel in the launch finally saw the carcass at the surface, when the blue whale's flukes and, shortly afterward, its head were lifted out of the water. Several minutes later as the carcass was being dragged along the surface, the full length of the blue whale's belly was exposed; there were no visible signs of damage to the animal at either time. Shortly afterwards, observations were terminated and the launch returned to the ship.

**Group size, composition and associations**

Although the sighting conditions were excellent, it was difficult to estimate the number of killer whales present. They were in separate groups, diving for up to 5min at a time and being evasive. Based on an analysis of all the photographs taken from both the launch and the helicopter, it was estimated that there were 19 individuals present including 4 males (3 adults, 1 subadult [a 'sprouter']), 5 adult females with 5 calves, and 5 other females/subadult males. Photographs of eight of the biopsied animals were matched to photographically-identified individuals (one additional biopsy sample was a duplicate), and the gender of each was genetically determined. From this it was established that two individuals in the 'females/subadult males' category were in fact females.

Throughout most of the sighting the killer whales formed two main groups: a smaller group immediately associated with the blue whale carcass, and a larger group that was usually separated by 200-300m, but moving with the other group. The larger group comprised about eleven individuals, including five cow-calf pairs, and one subadult male or female.

The carcass group comprised approximately seven animals, including 3 males (2 adults and 1 sub-adult), 2 adult (or near adult) females and 2 subadult males/females. This group included the largest male, who was carrying the carcass throughout most of the sighting. These two groups were fairly fluid however and did not appear to represent stable associations during the 2.5h of observations. For example, at least one cow-calf pair initially photographed with the larger group, later joined the carcass group and the calf was photographed from the air several times attempting to feed on the carcass.

There was also a lone adult male that briefly associated with each of the groups during the observation period, but most of the time was by himself on the periphery of both groups.

The distribution of the different haplotypes among the killer whales also indicated that there was probably mixing between the two groups. Two different haplotypes (A and B) were identified among the biopsy samples (see below) and both were present in both groups. For example, the large

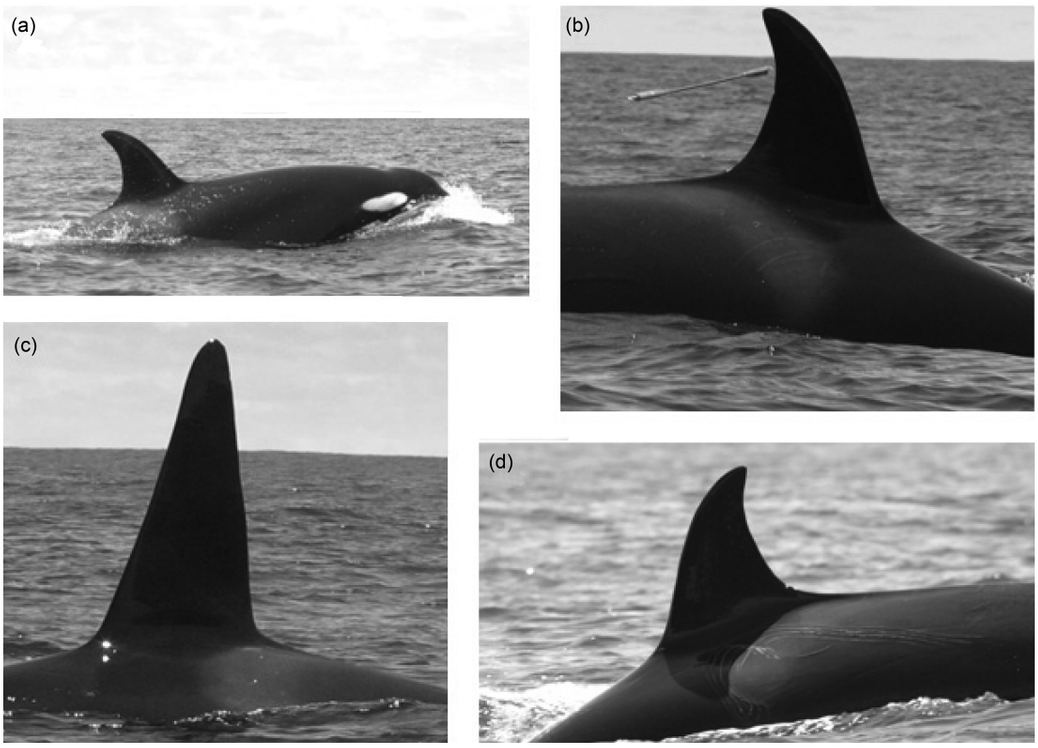


Fig. 2. Killer whales photographed on 26 September 2003, at 10°58'N, 88°40'W, 230km west of the Pacific coast of Nicaragua. (a) Adult female showing eyepatch similar to North Pacific killer whales along with no evident cape pattern; (b) same adult female as in 2a. showing inconspicuous saddle patch and dorsal fin without nicks; biopsy sample was just taken from saddle area; (c) adult male with inconspicuous saddle patch; (d) female showing nick at the base of the dorsal fin, inconspicuous saddle patch and fresh rake marks (with exposed red flesh in colour photographs). Genders were all confirmed genetically; photographs by H. Fearnbach.

male that carried the carcass during the sighting was Haplotype B, while the adult male that accompanied him and also carried the carcass on occasion was Haplotype A. The larger group included an adult female (with a calf) that was Haplotype A, and another female (also with a calf) that was Haplotype B. In addition, the female (with a calf) that moved between the two groups was Haplotype A, as was the adult male that stayed on the periphery throughout most of the sighting.

**Morphometrics and morphology**

From the photogrammetry, total length (TL) measurements were obtained for 17 different animals. TL for two adult males were 6.9 and 8.0m, respectively, the latter being the largest animal in the group. TL for 10 animals of unidentified sex and age (i.e. females or young males) averaged 5.9m (range: 5.4-6.3m); TL for 5 adult females (i.e. with calves) averaged 5.8m (range: 5.4- 6.1m); TL for 5 calves averaged 3.8m (range: 3.2-4.7m).

Fluke width (FW) could be determined for only two females (TL=5.8 and 6.0m); these measured 1.5m and 1.7m, respectively, which gave FW/TL ratios of 0.26 and 0.28, respectively.

The overall colour patterning and body shape was similar to that of killer whales in the North Pacific, but with at least one noticeable difference. The eyepatch was similar to other North Pacific killer whales and Type A Antarctic killer whales (Pitman and Ensor, 2003), i.e. medium-sized and oriented parallel to the body axis and no dorsal cape was evident (Fig. 2a). There were relatively few nicks on the trailing edge of the dorsal fins of any of the animals photographed: nine had small nicks; two animals had moderate to large notches; and the remaining eight were unmarked (Fig. 2b-d).

A distinctive feature of these animals was the inconspicuousness of the saddle (the pale area on the back, behind the dorsal fin); it was faint in most individuals (Fig. 2b-d) and almost absent in others. No 'open' saddles were seen (i.e. showing a dark incursion into the saddle), characteristic of resident killer whales in the eastern and central North Pacific (Baird and Stacey, 1988). Although this feature could have been overlooked in some cases because of the faintness of the saddle. At least four individuals had barnacles (presumably *Xenobalanus globicipitis*; Kane *et al*., 2006) attached to the trailing edges of their dorsal fins, however the majority did not.

Aerial photogrammetry was also used to estimate that the length of the blue whale calf was approximately 6m. This estimate was less precise than for the killer whales because the carcass was usually at least 1-2m underwater and was never photographed parallel to the surface (the tail or head was usually hanging down).

**Population identity and genetics**

The mitochondrial control region sequences were 989bp long. The 10 different individuals sampled represented two distinct haplotypes: one (A) being present in eight samples and the other (B) in two (GenBank accession numbers: DQ851147 and DQ851148, respectively). These haplotypes differed from each other by a single transitional base substitution and have not been previously published for killer whales. These sequences are most similar to published

northern and southern *resident* and *offshore* haplotypes (Hoelzel *et al*., 2002; Zerbini *et al*., 2007); (GenBank accession numbers: DQ399077-DQ399079). Although this is the first time we have recorded Haplotype B anywhere, we have recorded Haplotype A from other killer whales sampled off Mexico and Panama (SWFSC, unpublished data).

**Acoustics**

A total of 194 social signals were analysed from the 31.5min of recording. Of these, 189 were pulsed signals and 5 were whistles. Pulsed signals were dominated by a single highly-repetitive discrete (or stereotyped) call, which comprised 68% of the total signals. The remaining 60 pulsed signals were variable in structure and non-repetitive (19%), or could not be identified due to poor signal-to-noise ratio (13%). The single discrete call, shown in Fig. 3, was a two-part signal with a total average duration of 0.88s. (±SE 0.02, *n*=34 calls). The first of the two parts was typically slightly shorter than the second (mean duration 0.37s (±SE 0.02) versus 0.51 (±SE 0.02)). The first part of the signal had a gradually increasing pitch that peaked at a mean sideband interval of 1779Hz (±SE 18.2), before sharply dropping prior to the start of the second part, which had a relatively constant but lower pitch (mean sideband interval 876Hz, ±SE 10.3). The frequency structure of the five whistles analysed was generally similar to narrow-band whistles described for killer whales elsewhere (e.g. Reisch *et al*., 2005). Too few whistles were recorded to determine if these were stereotyped in structure.

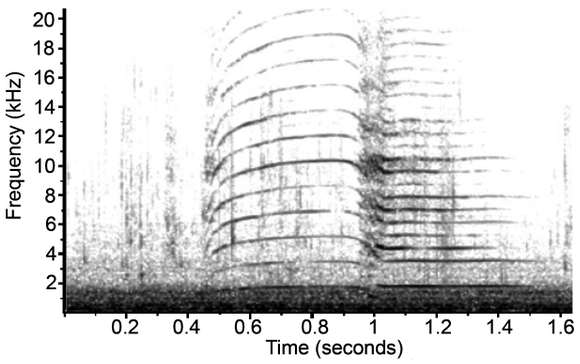


Fig. 3. Spectrogram of discrete call type recorded from killer whales encountered on 26 September 2003, at 10°58'N, 88°40'W, 230km west of the Pacific coast of Nicaragua. The call was digitised at a 44.1kHz sampling rate, and the spectrogram was created with a 512 point FFT, 50% frame overlap and hamming filter.

## DISCUSSION

Although killer whales are found in all of the world's oceans, they are relatively uncommon in the tropics (Dahlheim and Heyning, 1999; Forney and Wade, 2006), including the ETP (Wade and Gerrodette, 1993); (Pitman, pers. obs.). Group size in the ETP is also generally small. For example, mean school size for killer whales during the surveys reported here (Wade and Gerrodette, 1993) was 5.4 (CV=0.09, *n*=57); which is similar to Hawaiian waters (Baird *et al*., 2006) where mean group size was 4.2 (SD=2.1, *n*=21). The fact that there were an estimated 19 whales present in the event witnessed, suggests that two or more groups were almost certainly involved. Separate groups may have temporarily associated to assist in the killing of the calf, or possibly another group (or groups) may have appeared after the kill. The presence of fresh tooth rake marks on several individuals, young and adults alike, suggests that there may have been some aggressive, perhaps inter-group, interactions occurring.

The colour patterning of these killer whales was similar to North Pacific killer whales except for their relatively inconspicuous saddle patch. Hawaiian killer whales also show faint saddle patches (Baird *et al*., 2006), and this seems to be typical for tropical killer whales in general, including the tropical Atlantic and Indian oceans (Pitman, pers. obs.). Hawaiian killer whales also had oval scars visible mainly on their saddle patches, which were presumably the healed bites of cookiecutter sharks (*Isistius* sp.; Baird *et al*., 2006), whereas among the numerous photographs of the ETP killer whales, there were few or no bites present. ETP cetaceans in general have relatively few cookiecutter shark bites on them compared, for example, to those in the western Atlantic and western Pacific ocean basins (Pitman, pers. obs.).

The single, discrete call recorded during this encounter was typical of killer whale calls in other regions, i.e. it had a pulsed structure, was less than 1s in duration and was subdivided into distinct parts or segments (Deecke *et al*., 2005; Ford, 1987; Ford, 1991; Strager, 1995; Yurk *et al*., 2002). Groups of killer whales generally produce repertoires of 5-15 different call types, each of which is aurally and spectrographically distinct. These repertoires are often specific to particular matrilineal groups (Ford, 1991; Strager, 1995), although mammal-eating killer whales in British Columbia and southeastern Alaska tend to have population-specific call repertoires (Deecke *et al*., 2005). Although consistent in general structure to killer whale calls elsewhere, the single call type recorded during this encounter had a two-part pitch contour that appears distinct in fine-scale time and frequency structure from killer whale calls recorded and catalogued in other areas of the eastern North Pacific (Deecke *et al*., 2005; Ford, 1987; Yurk *et al*., 2002) and elsewhere (e.g. north Atlantic, Moore *et al*., 1988; Strager, 1995). It is highly likely that the whales recorded during this encounter had additional calls in their repertoire, but did not produce these during the short recording session.

To date, there have been no recorded long-term associations between two different haplotypes within a single group of killer whales among well-studied matrilineal pods in the Northeast Pacific (Barrett-Lennard, 2000; Hoelzel *et al*., 1998). However, short-term associations between different haplotypes have been recorded; for example, groups of killer whales with both Northern and Southern *resident* haplotypes are regularly encountered in Prince William Sound and the fjords of Kenai Peninsula, Alaska (Yurk *et al*., 2002). However, genetic sampling of entire pods of killer whales in other areas of the world is rare, so it is not known how prevalent haplotype mixing is for this species as a whole. In the event described, it is likely that at least two (and perhaps more) separate groups of killer whales temporarily came together for feeding and perhaps socialising. If so, and if the different haplotypes represent animals from different groups, it is unclear what, if anything could prevent interbreeding between the groups we sampled because individuals of both haplotypes freely associated during the episode.

Outside of the northeast Pacific, haplotype similarity is not necessarily a consistent indicator of ecotypic prey specialisation in killer whales. For example, the haplotype of an apparent mammal-eating killer whale in Hawaii was most similar to *transient* (mammal-eating) killer whales in

Alaska (Baird *et al*., 2006), while the two different haplotypes from the event described here differed by one and two base pairs, respectively, from *resident* (fish-eating) killer whales in the Northeast Pacific. More sampling is necessary to determine the relationship between ecotypic and haplotypic variation among killer whale populations and how these relate to killer whale evolution and, perhaps, speciation on a global scale.

Although killer whales are known predators of blue whales (Tarpy, 1979), this is the first reported incidence of a calf taken in the tropics, which raises some interesting questions. The event described here occurred within an oceanographic area known as the Costa Rica Dome (CRD, Fig. 1). The CRD is a 300-500km$^2$, semi-permanent, hydrographic (vs topographic) feature in the far eastern ETP, with markedly enhanced productivity due to wind- and current-induced upwelling (Fiedler, 2002). It is also the only area in the ETP south of Baja California, Mexico, and north of the Peru Current where blue whales regularly occur (Fig. 1), and it has been suggested that individuals from either Northern or Southern Hemisphere populations may migrate there to feed, to breed or both (Reilly and Thayer, 1990). Blue whale calves measure 6-7m at birth (Sears, 2002); with an estimated length of 6m, it is therefore thought that the blue whale calf seen was born at the CRD. Although it has been shown that at least some Californian blue whales migrate to the CRD during their calving/breeding season (Mate *et al*., 1999), this observation is the first record, to our knowledge, of a neonatal blue whale at the CRD. If blue whales do regularly migrate to the CRD for calving, it could be a predictable feeding area for mammal-eating killer whales in the ETP.

Many baleen whale species undertake extensive seasonal migrations to lower latitudes to mate and give birth, but to date there has been no widely accepted explanation for this behaviour. Corkeron and Connor (1999) postulated that this migration could reduce the risk of killer whale predation on calves (Jones and Swartz, 1984; Pitman *et al*., 2001). They noted that killer whales occur much more commonly in higher latitudes than in the tropics (Forney and Wade, 2006), and that they are the main (and perhaps only) predators of large whale calves. This idea has met with some pointed criticism (Clapham, 2001) and it is also clear from our observation and those of others (e.g. Flórez-González *et al*., 1994), that even in the tropics, calves of large whales are not completely safe from killer whales. However, as an anti-predator strategy, migration does not have to be effective *all* of the time in order to confer evolutionary benefits (Connor and Corkeron, 2001). Migrations that produce even a modest reduction in the number of killer whale encounters (and, therefore, calf mortalities) could significantly increase reproductive success and individual fitness. This is especially true for large baleen whales with their very low reproductive output.

## ACKNOWLEDGMENTS

We thank the officers and crew of the RV *David Starr Jordan* for their support. S. Rankin installed the bow hydrophone, which allowed us to make the acoustic recordings. K. Cramer, M. Force, M. Richlen and J. C. Salinas assisted in the field; D. Ellifrit and J. Durban provided opinions on the sex and age classes of killer whales in our photographs. Marine mammal research was conducted under MMPA Permit No. 774-1437-05 issued to SWFSC.

## REFERENCES

Baird, R.W., McSweeney, D., Bane, C., Barlow, J., Salden, D., Antoine, L.K., LeDuc, R.G. and Webster, D.L. 2006. Killer whales in Hawaiian waters: information on population identity and feeding habits. *Pac. Sci*. 60: 523-30.

Baird, R.W. and Stacey, P.J. 1988. Variation in saddle patch pigmentation in populations of killer whales (*Orcinus orca*) from British Columbia, Alaska and Washington State. *Can. J. Zool*. 66(11): 2582-85.

Ballance, L.T., Pitman, R.L., Hewitt, R.P., Siniff, D., Trivelpiece, W.Z., Clapham, P.J. and Brownell Jr, R.L. 2006. pp.215-30. *In*: Estes, J.A., DeMaster, D.P., Doak, D.F., Williams, T.M. and Brownell, R.L. (eds). *Whales, Whaling and Ocean Ecosystems*. University of California Press, Berkeley, California. 402pp.

Barrett-Lennard, L. and Heise, K. 2006. The natural history and ecology of killer whales. pp.163-73. *In*: Estes, J.A., DeMaster, D.P., Doak, D.F., Williams, T.M. and Brownell Jr, R.L. (eds). *Whales, Whaling and Ocean Ecosystems*. University of California, Berkeley, California. 402pp.

Barrett-Lennard, L.G. 2000. Population stucture and mating patterns of killer whales as revealed by DNA analysis. Thesis University of British Columbia, Vancouver, BC. 97pp.

Berzin, A.A. and Vladimirov, V.L. 1983. Novyi vid kosatki (Cetacea, Delphinidae) iz vod Antarktiki. *Zool. Zh*. 62(2): 287-95. [Translated in 1984 as "A new species of killer whale (Cetacea, Delphinidae) from Antarctic waters" by S. Pearson, National Marine Mammal Laboratory, Seattle, WA 98115, USA].

Clapham, P.J. 2001. Why do baleen whales migrate? A response to Corkeron and Connor. *Mar. Mammal Sci*. 17: 432-36.

Connor, R.S. and Corkeron, P. 2001. Predation past and present: killer whales and baleen whale migration. *Mar. Mammal Sci*. 17: 436-39.

Corkeron, P. and Connor, R.S. 1999. Why do baleen whales migrate? *Mar. Mammal Sci*. 15: 1228-45.

Dahlheim, M.E. and Heyning, J.E. 1999. Killer whale *Orcinus orca* (Linnaeus, 1758). pp.281-322. *In*: Ridgway, S.H. and Harrison, R.J. (eds). *Handbook of Marine Mammals*. Academic Press, London. v-xix+486pp.

Deecke, V., Ford, J.K.B. and Slater, P.J.B. 2005. The vocal bevaiour of mammal-eating killer whales: communicating with costly calls. *Anim. Behav*. 69: 395-405.

Fiedler, P.C. 2002. The annual cycle and biological effects of the Costa Rica Dome. *Deep Sea Research* 49: 321-38.

Flórez-González, L., Capella, J.J. and Rosenbaum, H.C. 1994. Attack of killer whales (*Orcinus orca*) on humpback whales (*Megaptera novaeangliae*) on a South American Pacific breeding ground. *Mar. Mammal Sci*. 10(2): 218-22.

Ford, J.K.B. 1987. A catalogue of underwater calls produced by killer whales (*Orcinus orca*) in British Columbia. *Can. Data Rept. Fish. Aquatic Sci*. 633: 165pp.

Ford, J.K.B. 1991. Vocal traditions among resident killer whales (*Orcinus orca*) in coastal waters of British Columbia. *Can. J. Zool*. 69(6): 1454-83.

Forney, K.A. and Wade, P.R. 2006. Worldwide distribution and abundance of killer whales. pp.145-62. *In*: Estes, J.A., Brownell, R.L., DeMaster, D.P., Doak, D.F. and Williams, T.M. (eds). *Whales, Whaling and Ocean Ecosystems*. University of California Press. 418pp.

Gilpatrick, J.W., Jr. 1997. Calibration of radar altimeter readings used in aerial photogrammetry of eastern tropical Pacific dolphins, 1992 and 1993. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-226 [Available from *swfsc.noaa.gov/publications*].

Gilpatrick, J.W. and Lynn, M.S. 1994. A test of two photogrammetric measuring instruments used to determine dolphin lengths from vertical aerial photographs. NOAA Tech. Memo. NOAA-NMFS-SWFSC-196. [Available from *swfsc.noaa.gov/publications*].

Heise, K., Barrett-Lennard, L., Saulitis, E., Matkin, C. and Bain, D. 2003. Examining the evidence for killer whale predation on Steller sea lions in British Columbia. *Aquat. Mamm*. 29: 325-34.

Hoelzel, A.R., Dahlheim, M.E. and Stern, S.J. 1998. Low genetic variability among killer whales (*Orcinus orca*) in the eastern North Pacific and genetic differentiation between foraging specialists. *J. Hered*. 89: 121-28.

Hoelzel, A.R., Natoli, A., Dahlheim, M.E., Olavarría, C., Baird, R.W. and Black, N.A. 2002. Low worldwide genetic diversity in the killer whale (*Orcinus orca*): implications for demographic history. *Proc. R. Soc. Lond. Ser. B*. 269: 1467-73.

Jackson, A., Gerrodette, T., Chivers, S., Lynn, M., Olson, P. and Rankin, S. 2004. Marine mammal data collected during a survey in the eastern tropical Pacific Ocean aboard the NOAA ships *McArthur* and *David Starr Jordan*, July 29-December 10, 2003. *NOAA Technical Memorandum NMFS* NOAA-TM-NMFS-SWFSC-366. [Available

from *http://swfsc.noaa.gov/publications/TM/SWFSC/NOAA-TM-NMFS-SWFSC-366.pdf*].

Jones, I.M. 2006. A northeast Pacific offshore killer whale (*Orcinus orca*) feeding on a Pacific halibut (*Hippoglossus stenolepis*). *Mar. Mammal Sci*. 22: 198-200.

Jones, M.L. and Swartz, S.L. 1984. Demography and phenology of gray whales and evaluation of whale-watching activities in Laguna San Ignacio, Baja California Sur, Mexico. pp.309-74. *In*: Jones, M.L., Swartz, S.L. and Leatherwood, S. (eds). *The Gray Whale, Eschrichtius robustus*. Academic Press, Inc., Orlando, Florida. xxiv+600pp.

Kane, E., Olson, P. and Gerrodette, T. 2006. The commensal barnacle *Xenobalanus globicipitis* Steenstrup, 1851 (Crustacea: Cirripedia) and its relationship to cetaceans in the eastern tropical Pacific. *NOAA NMFS Admin Report* LJ-06-03. Available from NOAA/NMFS Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, California 92037, USA.

Mate, B.R., Lagerquist, B.A. and Calambokidis, J. 1999. Movements of North Pacific blue whales during the feeding season off Southern California and their southern fall migration. *Mar. Mammal Sci*. 15(4): 1246-57.

Moore, S.E., Francine, J.K., Bowles, A.E. and Ford, J.K.B. 1988. Analysis of calls of killer whales, *Orcinus orca,* from Iceland and Norway. *Rit Fisk*. 11: 225-50.

Perryman, W.L. and Lynn, M.S. 1993. Identification of geographic forms of common dolphin (*Delphinus delphis*) from aerial photogrammetry. *Mar. Mammal Sci*. 9(2): 119-37.

Pitman, R., Balance, L.T., Mesnick, M.L. and Chivers, S. 2001. Killer whale predation on sperm whales: observations and implications. *Mar. Mammal Sci*. 17: 494-507.

Pitman, R.L. and Ensor, P. 2003. Three forms of killer whales (*Orcinus orca*) in Antarctic waters. *J. Cetacean Res. Manage*. 5(2): 131-39.

Pitman, R.L., Perryman, W.L., LeRoi, D. and Eilers, E. 2007. A dwarf form of killer whale in Antarctica. *J. Mammal*. 88(1): 43-48.

Reilly, S.B. and Thayer, V.G. 1990. Blue whale (*Balaenoptera musculus*) distribution in the eastern tropical Pacific. *Mar. Mammal Sci*. 6(4): 265-77.

Reisch, R.L., Ford, J.K.B. and Thomsen, F. 2005. Stability and group-specificity of stereotyped whistles in resident killer whales, *Orcinus orca*, off British Columbia. *Anim. Behav*. 71: 79-93.

Rice, D.W. 1998. *Marine Mammals of the World. Systematics and Distribution. Special Publication No. 4*. The Society for Marine Mammalogy, Allen Press Inc., Lawrence, Kansas. v-ix+231pp.

Rosel, P.E., Haygood, M.G. and Perrin, W.F. 1995. Phylogenetic relationships among true porpoises (Cetacea:Phocoenidae). *Mol. Phylogenet. Evol*. 4: 463-74.

Sears, R. 2002. Blue whale (*Balaenoptera musculus*). pp.112-16. *In*: Perrin, W.F., Wursig, B. and Thewissen, G.M. (eds). *Encyclopedia of Marine Mammals*. Academic Press, New York. 1414pp.

Strager, H. 1995. Pod-specific call repertoires and compound calls of killer whales, *Orcinus orca* Linnaeus, 1758, in the waters of northern Norway. *Can. J. Zool*. 73: 1037-47.

Tarpy, C. 1979. Killer whale attack! *Natl. Geogr*. 155: 542-45.

Wade, P.R. and Gerrodette, T. 1993. Estimates of cetacean abundance and distribution in the eastern tropical Pacific. *Rep. int. Whal. Commn* 43: 477-93.

Yurk, H., Barrett-Lennard, L., Ford, J.K.B. and Matkin, C. 2002. Cultural transmission with maternal lineages: vocal clans in resident killer whales in southern Alaska. *Anim. Behav*. 63: 1103-19.

Zerbini, A.N., Waite, J.M., Durban, J.W., LeDuc, R.G., Dahlheim, M. and Wade, P.R. 2007. Estimating abundance of killer whales in the nearshore waters of Alaska and Aleutian Islands using line transect sampling. *Mar. Biol*. 150(5): 1033-48.

Date received: July 2006
Date accepted: April 2007