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# Acoustic Behavior of Antarctic Killer Whales (*Orcinus orca*) Recorded Near the Ice Edge of McMurdo Sound, Antarctica

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## Abstract

Underwater acoustic recordings of a group of seven to nine killer whales (*Orcinus orca*) were made opportunistically along a lead within the fast-ice in McMurdo Sound, Ross Sea, Antarctica in early December 1979. At the time of the recordings, the killer whale group was chasing Adélie penguins (*Pygoscelis adeliae*); however, no predation events were observed. A total of 87 min and 39 s were recorded and examined, with 506 sounds analyzed. The animals produced echolocation clicks, buzz sequences, pulsed signals, and whistles. Seven previously undocumented call types were described from these killer whales based on consistent aural and spectrographic analysis of signals. Acoustic measurements were made in the frequency and time domains using spectrographic and power spectrum analysis. This preliminary study is the first quantitative report on the acoustic features of underwater sounds produced by a specific group of killer whales in Antarctic waters. The acoustic characteristics are similar to sounds described from killer whale populations throughout the world, and the consistent repetition of call types suggests a pod-specific repertoire. Three different ecotypes of killer whales have been described in Antarctic waters based on their color pattern, habitat use, and prey preference. The group of animals recorded in this study is believed to be Type C killer whales based on photographs as well as behavioral observations at the surface. In order to compare vocal repertoires and acoustic behavior with analogous sympatric ecotypes from, for example, the Northeast Pacific, it will be necessary to analyze calls made from the other known Antarctic ecotypes. Acoustic analyses could very likely be a reliable diagnostic tool for identifying sympatric ecotypes in Antarctic waters.

**Key Words:** killer whale, *Orcinus orca*, acoustic behavior, Antarctica, penguin predation, foraging behavior

## Introduction

Long-term studies of recognizable groups of killer whales in the Northeast Pacific (Northern Puget Sound and British Columbia) have identified three killer whale ecotypes—(1) resident, (2) transient, and (3) offshore—that have different prey, seasonal movement patterns, morphology, genetics, and acoustic behavior (Bigg, 1982; Ford, 1984, 1989; Bigg et al., 1990; Ford et al., 1994; Barrett-Lennard et al., 1996; Deecke, 2003). Resident killer whales prey exclusively on fish, and transient killer whales are marine-mammal prey specialists (Bigg, 1982; Ford et al., 1994, 1998; Barrett-Lennard et al., 1996; Deecke, 2003). Offshore killer whales have been identified more recently as a third ecotype, but their prey preferences, group dynamics, distribution, and movement patterns are not as clearly understood (Bigg et al., 1987; Dahlheim et al., 2008).

The ecological divergence among the killer whale ecotypes in the Northeast Pacific explains much of the behavioral differences observed. None of the ecotypes found in the Northeast Pacific have natural predators, thus their acoustic behavior is not influenced by predator avoidance. Instead, the acoustic differences between resident and transient ecotypes reflect their foraging specializations (Guinet, 1992; Barrett-Lennard et al., 1996; Deecke, 2003; Deecke et al., 2005). Evidence exists explaining that the acoustic repertoires of the ecotypes in each population are learned, thus propagating ecotype-specific behavior (Deecke et al., 2000; Miller & Bain, 2000; Yurk et al., 2002).

Killer whales have high-frequency hearing, over 100.0 kHz (Bain & Dahlheim, 1994), and they echolocate on potential prey. Generally, fish have low-frequency hearing abilities, approximately up to 10.0 kHz (Fay & Popper, 1975), so they are unlikely to hear the echolocation clicks of killer whales. In contrast, pinniped studies to date indicate that their hearing abilities are as high as 60.0 to 80.0 kHz, depending on the species, and are likely to hear at least some portion of killer whales' echolocation clicks (Au et al., 2000).

Similarly, cetacean species that may also be susceptible to predation by marine-mammal-eating killer whales have hearing sensitivities within the frequency range of killer whale vocalizations and echolocation clicks (Au et al., 2000).

The purpose of the predominant silence of marine-mammal-eating killer whales in the Northeast Pacific is likely to avoid detection by their acoustically adept pinniped and cetacean prey. Fish-eating killer whales do not have the same constraints of announcing their presence to their prey and, thus, are free to be more soniferous. Sound rates and call complexity in transient, marine-mammal-eating killer whales are significantly reduced, and their repertoire is smaller (Ford, 1984). Consistent differences in the number of call types, the rate of calling, and the complexity of sound types have proven to be diagnostic in identifying ecotypes in the Northeast Pacific (Ford, 1984, 1989; Ford et al., 1994).

Photographs of recognizable dorsal fins and saddle patches of Northeast Pacific killer whales have allowed researchers to identify individual animals and their associations and to document interactions over long time periods and among regions. However, in contrast with the Northeast Pacific populations, where morphological differences are less apparent, Antarctic killer whale types are readily distinguishable in the field by their distinctive color patterns (Pitman & Ensor, 2003). Jehl et al. (1980) first reported that color patterns of Antarctic killer whales were distinctly different from killer whales in the North Pacific and North Atlantic, but they did not report different color patterns among Antarctic killer whales. Since that time, photographic and observational data have indicated that three distinct killer whale forms exist in Antarctic waters. These different forms vary greatly in body length, size and angle of their eye-patch, and whether or not they have a dorsal cape (Pitman & Ensor, 2003; Pitman et al., 2007). Type A killer whales have a medium-sized eye-patch and no dorsal cape; Type B killer whales have a conspicuously large eye-patch and a dorsal cape color pattern; and Type C killer whales have a small forward slanting eye-patch and a dorsal cape pattern (Pitman & Ensor, 2003). Type C killer whales were photographed at the same general location, as the underwater recordings described herein, around December in three subsequent years (Jehl et al., 1980; Thomas et al., 1981; Awbrey et al., 1982). More recent reports by Pitman et al. (2007), Ballard & Ainley (2005), and Lauriano et al. (2007) stated that Type C killer whales are the most common ecotype in the McMurdo Sound area during the late austral spring.

In addition to phenotypic differentiation, Antarctic killer whales ecotypes also appear to have divergent prey preferences and habitat specificity. Type A killer whales inhabit offshore waters and are believed to prey on pelagic marine mammal species, particularly Antarctic minke whales (*Balaenoptera bonaerensis*). Minke whales have a circumpolar Antarctic distribution; however, they are usually seen in ice-free waters and commonly around the Antarctic Peninsula, which is the furthest north land mass on the continent and has open-water areas most of the year (Pitman & Ensor, 2003).

Type B killer whales are found in more inshore pack-ice areas. Although these animals might also prey on minke whales, and possibly humpback whales (*Megaptera novaeangliae*), their predominant prey choice appears to be pinnipeds such as Weddell seals (*Leptonychotes weddellii*), crab-eater seals (*Lobodon carcinophagus*), leopard seals (*Hydrurga leptonyx*), and possibly Ross seals (*Ommatophoca rossii*) (Pitman & Ensor, 2003). Lauriano et al. (2007) have documented a possible Adélie penguin predation by Type B killer whales at Terra Nova Bay, Antarctica.

Type C killer whales are inhabitants of inshore waters along the pack/fast-ice edge. These whales travel into the fast-ice leads and thus far have only been documented foraging on fish, such as Antarctic toothfish (*Dissostichus mawsoni*). It is likely that Type C killer whales are the same as those described by Berzin & Vladimirov (1983)—*O. glacialis*.

Since these forms are morphologically distinct and largely sympatric throughout their range, Pitman & Ensor (2003) and LeDuc et al. (2008) discussed whether, under the Biological Species Concept (Mayr & Ashlock, 1991), these killer whale types warrant separate species designation.

The underwater sounds of killer whales in the Ross Sea area of Antarctica have been briefly described and compared to killer whale sounds in other oceans (Thomas et al., 1981; Awbrey et al., 1982). These cursory reports indicated qualitative acoustic differences when compared to the Northeast Pacific killer whale populations. However, there have been no investigations considering acoustic differences among Antarctic killer whales in various regions. Since both signal attributes and acoustic behavior likely differ among foraging specialists (Deecke et al., 2005), the analysis of Antarctic killer whale sounds could be a useful tool for examining potential ecotype and species divergence among these animals.

The objective of this study was to complete a quantitative acoustic analysis of underwater sounds from one pod of Antarctic killer whales, probably Type C, observed along the ice edge in McMurdo Sound, Antarctica, in early December 1979. A detailed description of the acoustic characteristics is necessary for speculating the uses of sound, as well as for establishing a basis for comparison of the acoustics of other killer whale populations. Consistent patterns in signal structure could indicate discrete call types and signify the existence of distinctive repertoires.

## Materials and Methods

### *Photographs of Killer Whales During Recordings*

Although the existence of at least three distinct ecotypes of killer whales in Antarctica had not been documented at the time of our study (Pitman & Ensor, 2003), 35-mm, dated photographs taken of the animals present at the time of the recordings, were recently reviewed to determine if the ecotype of the whales could be determined.

### *Recordings*

An underwater recording session of killer whales was made opportunistically near the ice edge of McMurdo Sound, Ross Sea, Antarctica, by Jeanette Thomas and Larry Kuechle on 11 December 1979 as part of a larger research project on population dynamics of Weddell seals by Dr. Donald Siniff of the University of Minnesota. The recordings were made using a battery-operated Nagra III reel-to-reel recorder (7.5 cm/s, with a frequency response 20.0 Hz to 20.0 kHz ± 2 dB) and an Ithaco 605 hydrophone (frequency response 50.0 Hz to 75.0 kHz ± 3 dB) powered by a 24-V battery. Therefore, the recorder limited analysis to signals below 20.0 kHz.

Upon arrival at the recording site, a group of seven to nine killer whales was observed chasing five to 10 Adélie penguins (*Pygoscelis adeliae*) that were swimming in a 20- to 30-m wide lead in the fast-ice, which ran perpendicular to the fast-ice edge. A hydrophone was lowered to a depth of 6 to 7 m in the ice lead, and recording equipment and researchers were located at the edge of the ice lead. The killer whale group appeared to be actively chasing Adélie penguins at the time of the recordings; however, no predation events were documented.

### *Sound Analysis*

Recordings were digitized to a computer hard drive from the Nagra III recorder using *Sound Forge* software. Once digitized, the sounds were analyzed using *SpectraPLUS* software, with the upper analysis frequency limit set at 24.0 kHz.

Clicks, whistles, pulsed signals, and buzzes were recorded. Individual clicks were not analyzed because of the frequency limits of the recordings (upper limit of 20.0 kHz from the Nagra III reel-to-reel recorder clipped the upper frequencies). Whistles (the high-frequency components – HFC) were defined as tonal signals with or without harmonics and could be correctly identified by examining spectrograms and waveforms. Pulsed signals (the low-frequency components – LFC) had an audible tonal quality because of a high pulse repetition rate and typically were very rich in harmonics. The presence or absence of harmonic structure was confirmed by power spectrum analysis. Buzzes were identified spectrographically as a rapid succession of click bursts. Some of the acoustic signals had overlapping parts or components that graded into another component.

Spectrographic analysis was used to measure the acoustic variables. Power spectrum analysis was used to determine the peak frequencies of buzzes at the beginning, middle, and end of the sound. For nonpulsatile sounds, the portion of the sound with the highest amplitude was designated as the dominant part of the sound, and the following frequency-domain measurements were collected: beginning frequency, ending frequency, maximum frequency, minimum frequency, beginning harmonic interval, ending harmonic interval, beginning subharmonic interval, and ending subharmonic interval. The number of inflection points, or frequency modulations, in the dominant part of each component was scored.

Time-domain variables included duration of each component and the total duration of the sound. Not all the variables were clearly measurable for all sounds, which are reflected by unequal sample sizes for each parameter.

Each buzz sequence was analyzed—whether or not a component of another call type. The measurements taken for each buzz sequence included the duration and the peak frequency at the beginning, middle, and end of each sequence.

Each call type was identified by listening to and watching real-time spectral analysis and noting distinct signal structures, repeated patterns of components, and patterns of grading or overlapping of components. Call types contained individual buzzes, whistles, and pulsed signal types or any combination of the three. The naming of call types signified the location of the recordings (e.g., AM – Antarctic, McMurdo) followed by an arbitrary call type number. Many of the signals could not be identified as specific call types; these signals were designated as *aberrant*. Aberrant sounds included both whistles and pulsatile signals, and no distinction was made between the two.

### *Statistical Analysis*

Data were entered into an *Excel* spreadsheet and imported into *SYSTAT*, Version 10.2, for statistical analysis. Basic summary statistics for each documented acoustic variable were generated by call type. All statistical tests were at $\alpha = 0.05$ level of significance.

Principle component analysis (PCA) was used to determine which set of acoustic variables best described the variability in the underwater repertoire of Antarctic killer whales. For this study, the criteria for determining whether component loadings from the PCA were significant was a component loading > the absolute value of 0.45. Three factors were analyzed. The variables included in the PCA were beginning frequency, ending frequency, maximum frequency, minimum frequency, number of inflection points, beginning harmonic interval, ending harmonic interval, beginning subharmonic interval, ending subharmonic interval, and component duration. No particular rotation provided an improved spatial display among the three factors.

## Results

Currently, there are three known ecotypes of Antarctic killer whales (Types A, B, and C; Pitman & Ensor, 2003). Photographs of the animals present when the acoustic recordings were made and clearly showed that the animals had a conspicuous dorsal cape, indicating that they were one of the ice-inhabiting types: B or C. No other diagnostic morphologies were evident from the photographs (Figure 1).

A total of 87 min and 39 s of underwater acoustic recordings were examined, and 506 total sounds were analyzed during this opportunistic encounter with a pod of killer whales near the ice edge.

Throughout most of the recordings, spectrograms demonstrated a delayed and attenuated reverberation of the killer whale sounds (Figure 2). The signals were likely reflecting and echoing off the walls of the ice lead. These multipath reflections were evident, but they did not preclude accurate measurements of acoustic variables on the first or primary sound.

**Figure 1.** Photograph of underwater acoustic recording of Antarctic killer whales near the ice edge of McMurdo Sound in December 1979; notice the killer whale's head is not visible to properly identify the ecotype. (Photo: J. A. Thomas)

Seven killer whale call types were identified and designated AM1 to AM7. Summary statistics for the acoustic variables for each call type are listed in Table 1; a spectrogram of each call type is given in Figure 2. The Call Type AM1 sound (18.8% of the sounds) contained three types of signals—(1) buzzes, (2) whistles, and (3) pulsed signals. A buzz sequence graded into a pulsed signal (LFC) and contained an overlapping whistle (HFC). Call Type AM2 (10.3% of the sounds) was a short duration whistle with harmonics. The whistle was preceded by a short pulsed signal; however, the inability to accurately measure this pulse precluded its inclusion in the analysis. Call Type AM3 (1.2% of the sounds) was a short duration whistle with harmonics. Call Type AM4 (8.1% of the sounds) was a frequency-modulated, upsweeping narrowband signal that was rich in harmonics. The high number of inflection points indicated the sound was highly frequency-modulated. Call Type AM5 (0.02% of the sounds) was a buzz sequence which graded into a downsweeping frequency-modulated signal rich in harmonics. Call Type AM6 (2.6% of the sounds) was a short duration whistle with harmonics; no subharmonics were evident. Call Type AM7 (2.8% of the recording) had overlapping whistles and pulsed signals. The LFCs were highly frequency-modulated and downsweeping. There was only one sound in which the HFC had harmonics. There were a total of 137 different aberrant sounds of the 506 analyzed (27.1%).

Buzz sequences graded into whistles, other pulsed signals, or other buzz sequences. The measurements taken for each buzz sequence included the duration and the peak frequency at the beginning, middle, and end of each sequence. The summary statistics for acoustic variables of buzz sequences are in Table 2.

The PCA indicated beginning, ending, maximum, and minimum frequencies of the dominant part of a call as significant variables in Factor 1 for describing the sounds of these Antarctic killer whales. Factor 2 variables were related to harmonic structure and included presence/absence of harmonics and subharmonic intervals. Factor 3 variables were related to time and included the number of inflections and the component duration. The PCA also calculated the percent of total variance explained by each factor. The sum of the total variance explained by PCA, over all three factors, was 75.4%. The component loadings plot of the PCA test can be seen in Figure 3.

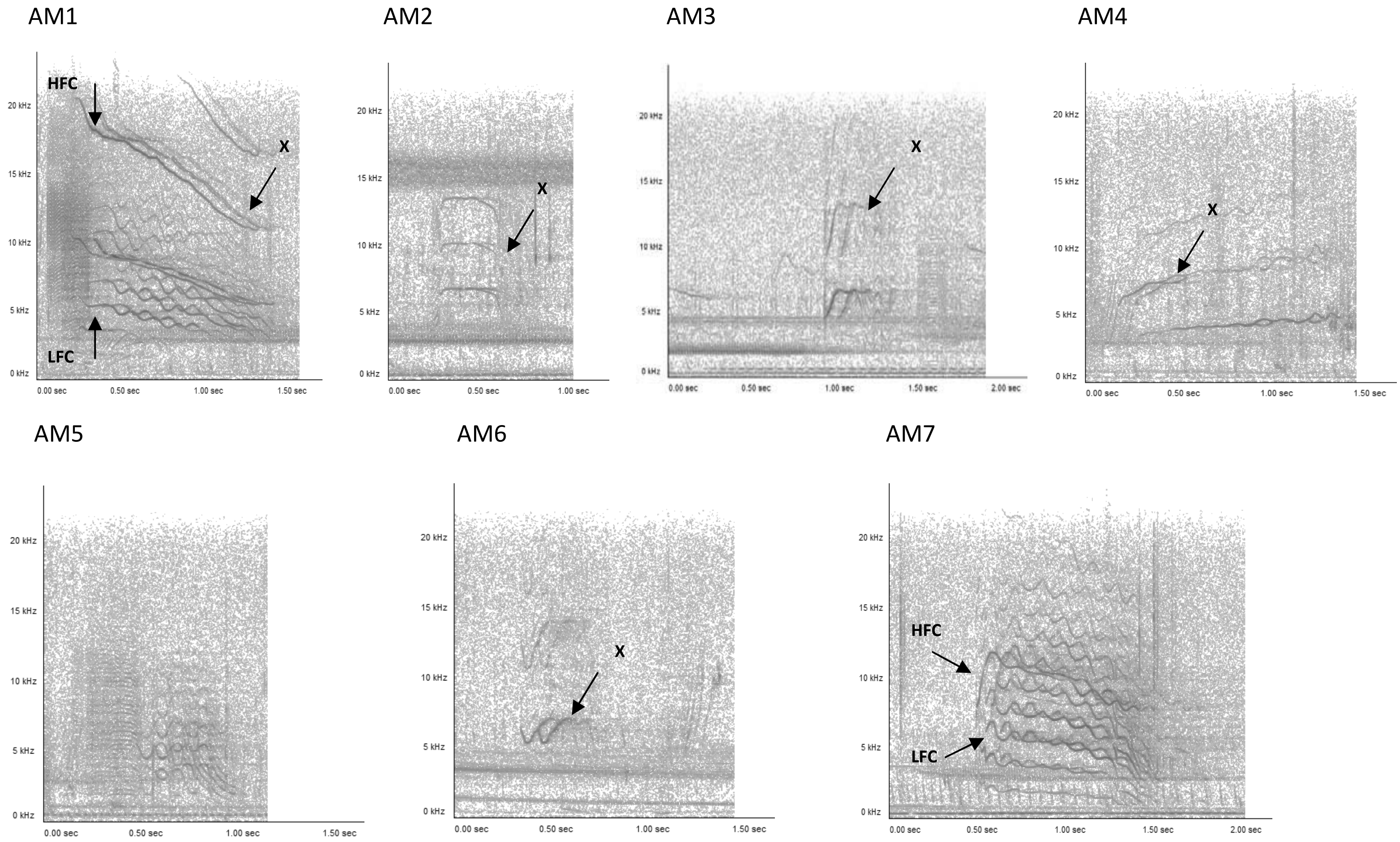

**Figure 2.** Spectrogram of Antarctic killer whale underwater call types near the ice edge of McMurdo Sound in December 1979; arrows for high- (HFC) and low-frequency (LFC) components are indicated for calls AM1 and AM7. Arrows below each "X" indicate examples of the reverberation of the killer whale sounds that were evident throughout the recordings (the reverberations did not affect the ability to accurately make measurements of the killer whale signals).

**Table 1.** Summary statistics for typical and aberrant underwater killer whale sounds recorded at the ice edge near McMurdo Sound in December 1979, including the HFC and LFC components for Call Types AM1 and AM7

| Call type | Statistic | Beginning frequency (Hz) | Ending frequency (Hz) | Maximum frequency (Hz) | Minimum frequency (Hz) | Beginning harmonic interval (Hz) | Ending harmonic interval (Hz) | Beginning subharmonic interval (Hz) | Ending subharmonic interval (Hz) | Number of inflections | Component duration (s) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AM1 (HFC) | *n* | 49 | 49 | 49 | 49 | 32 | 33 | 5 | 5 | 49.0 | 49.0 |
| | Mean | 9,773 | 5,859 | 9,854 | 5,714 | 7,627 | 5,324 | 1,998 | 2,274 | 3.5 | 0.8 |
| | SD | 2,849 | 1,584 | 2,783 | 1,524 | 3,021 | 2,104 | 560 | 2,298 | 3.3 | 0.2 |
| AM1 (LFC) | *n* | 46 | 46 | 46 | 46 | 38 | 37 | 31 | 31 | 46.0 | 46.0 |
| | Mean | 6,614 | 4,161 | 6,748 | 3,862 | 1,666 | 982 | 1,972 | 1,121 | 7.8 | 0.7 |
| | SD | 2,377 | 1,595 | 2,320 | 1,360 | 789 | 797 | 1,539 | 934 | 4.0 | 0.2 |
| AM2 | *n* | 52 | 52 | 52 | 52 | 38 | 38 | 12 | 12 | 52.0 | 52.0 |
| | Mean | 5,726 | 6,038 | 7,037 | 5,558 | 3,088 | 3,319 | 2,084 | 1,741 | 1.3 | 0.4 |
| | SD | 1,533 | 1,640 | 1,638 | 1,619 | 1,262 | 1,722 | 1,014 | 1,143 | 1.2 | 0.2 |
| AM3 | *n* | 6 | 6 | 6 | 6 | 6 | 6 | 1 | 1 | 6.0 | 6.0 |
| | Mean | 5,943 | 6,986 | 7,324 | 5,943 | 3,558 | 4,417 | 3,285 | 3,507 | 0.8 | 0.4 |
| | SD | 1,777 | 1,619 | 1,463 | 1,777 | 907 | 1,633 | 0 | 0 | 0.4 | 0.2 |
| AM4 | *n* | 41 | 41 | 41 | 41 | 23 | 22 | 16 | 15 | 41 | 41.0 |
| | Mean | 4,753 | 5,413 | 7,006 | 3,829 | 1,537 | 2,387 | 1,669 | 1,566 | 7.6 | 0.8 |
| | SD | 2,248 | 2,831 | 2,695 | 2,115 | 877 | 1,593 | 736 | 1,005 | 5.8 | 0.3 |
| AM5 | *n* | 10 | 10 | 10 | 10 | 9 | 9 | 8 | 7 | 10 | 10.0 |
| | Mean | 6,645 | 3,981 | 6,805 | 3,713 | 1,540 | 832 | 1,672 | 964 | 6.5 | 0.6 |
| | SD | 2,124 | 3,043 | 2,344 | 2,844 | 483 | 693 | 394 | 514 | 4.3 | 0.2 |
| AM6 | *n* | 13 | 13 | 13 | 13 | 6 | 6 | 0 | 0 | 13.0 | 13.0 |
| | Mean | 5,581 | 6,457 | 6,838 | 4,877 | 5,800 | 6,238 | NA | NA | 2.2 | 0.3 |
| | SD | 510 | 919 | 813 | 427 | 357 | 742 | NA | NA | 0.7 | 0.1 |
| AM7 (HFC) | *n* | 7 | 7 | 7 | 7 | 1 | 1 | 1 | 1 | 7.0 | 7.0 |
| | Mean | 9,311 | 6,092 | 11,253 | 5,898 | 519 | 563 | 659 | 278 | 6.6 | 0.7 |
| | SD | 3,638 | 2,674 | 2,592 | 2,574 | 0 | 0 | 0 | 0 | 4.5 | 0.4 |
| AM7 (LFC) | *n* | 7 | 7 | 7 | 7 | 5 | 5 | 5 | 5 | 7.0 | 7.0 |
| | Mean | 6,553 | 3,305 | 7,047 | 3,305 | 1,765 | 665 | 1,757 | 1,110 | 5.3 | 0.5 |
| | SD | 2,172 | 1,206 | 1,973 | 1,206 | 172 | 337 | 249 | 487 | 3.7 | 0.2 |
| Aberrant | *n* | 137 | 137 | 137 | 137 | 43 | 43 | 26 | 26 | 137 | 137.0 |
| | Mean | 6,720 | 6,360 | 8,107 | 5,464 | 2,943 | 2,719 | 1,628 | 1,557 | 3.9 | 0.6 |
| | SD | 2,682 | 2,004 | 2,463 | 1,879 | 2,608 | 2,558 | 985 | 1,047 | 3.9 | 0.4 |

## Discussion

The underwater sounds of killer whales near McMurdo Sound of the Ross Sea area of Antarctica have been briefly described and compared to sounds from killer whales in other oceans (Jehl et al., 1980; Thomas et al., 1981; Awbrey et al., 1982). These cursory reports provided spectrograms and depicted some basic signal structure characteristics, although they also indicated qualitative geographic differences between Antarctic, North Pacific, and Icelandic killer whale sounds. There have been no investigations regarding acoustic differences between sympatric Antarctic killer whale types. Since both signal attributes and acoustic behavior are indicative of foraging specialists (Ford et al., 1998), the analysis of Antarctic killer whale sounds could be a useful method for examining ecotype and possible species divergence among these animals.

Killer whales swimming within fast-ice leads provided an ideal platform for safely recording their underwater sounds; however, the recordings provided evidence of significant reflection of killer whale sounds off the ice channel. The reverberation of the killer whale sounds were evident from the recordings. So, killer whales must be able to navigate or even hunt in this reverberant environment. It is interesting to note that underwater recordings made with the same equipment from breathing holes of Weddell seals in the fast-ice do not produce such reflections.

**Table 2.** Summary statistics for killer whale underwater buzz sequences near the ice edge of McMurdo Sound in December 1979

| Variables | *n* | Minimum | Maximum | Mean | SD |
|---|---|---|---|---|---|
| Peak beginning (Hz) | 97 | 5,945.0 | 17,380.0 | 11,645.0 | 2,462.0 |
| Peak middle (Hz) | 97 | 957.0 | 17,115.0 | 1,306.0 | 2,904.0 |
| Peak end (Hz) | 82 | 4,829.0 | 17,286.0 | 11,114.0 | 2,841.0 |
| Total duration (s) | 137 | 0.1 | 1.0 | 0.2 | 0.2 |

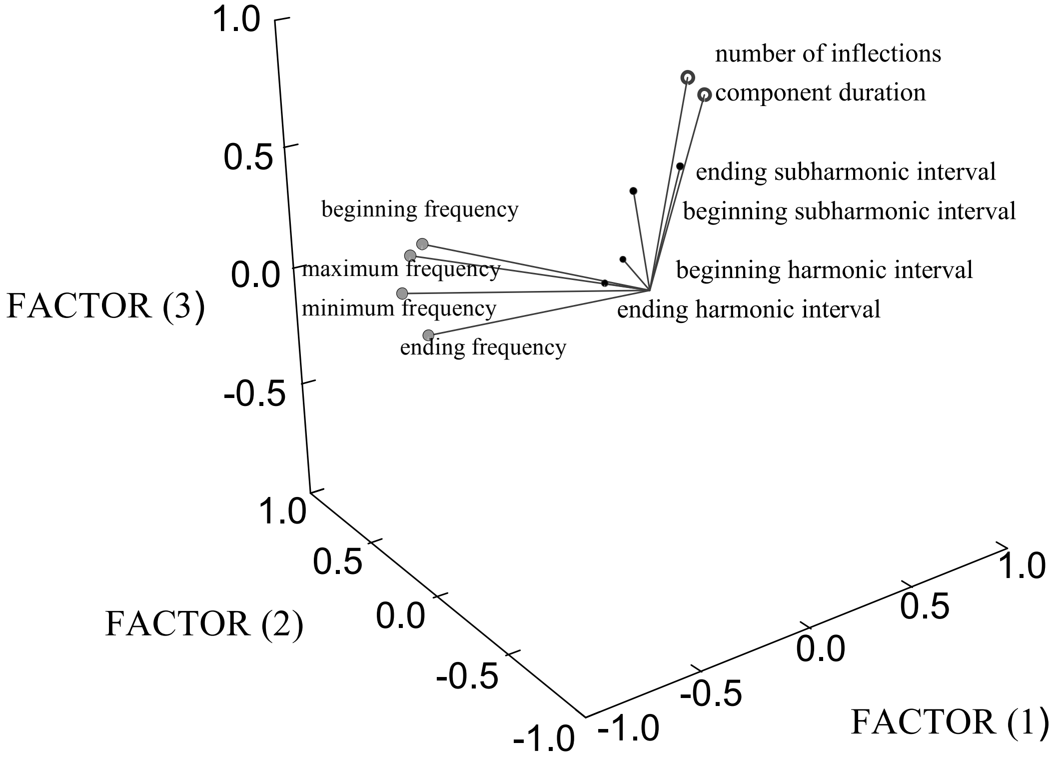

**Figure 3.** Component loadings plot for the important variables from principle component analysis of killer whale sounds recorded near the ice edge of McMurdo Sound in December 1979

The Antarctic killer whale sounds analyzed in this study demonstrated a repertoire of whistles, buzzes, pulsed sounds, and echolocation clicks as reported from killer whales in other regions. Seven discrete call types were clearly evident and repeated throughout the recording. Call Types AM1 and AM7 demonstrated buzz sequences, which graded into tonal pulsed signals with overlapping whistles. Call Types AM2 and AM3 had a brief pulsed signal that graded into short duration whistles. Call Type AM5 was a buzz sequence that graded into a frequency-modulated downsweeping, then a tonal signal. Miller (2002) examined the directionality of killer whale sounds that contained overlapping whistles and pulsatile signals. The whistles (HFCs) were found to be directional, while the tonal pulsed signals were omnidirectional. Miller hypothesized that such composite sounds relay orientation cues of the sender to conspecifics. These sounds are likely communicative in function and are common among resident killer whales in the Northeast Pacific (Miller, 2002; Rehn et al., 2007). The same function of overlapping sounds is plausible for this recording of Antarctic killer whales.

The presence of discrete call types indicates conspecific communication and, based on killer whale studies from other oceans, likely denotes the presence of a pod-specific repertoire (Ford, 1989). Unfortunately, recordings of killer whales in other areas of Antarctica have not been examined and reported to date. It is very likely that dialectic differences occur among Antarctic killer whale types as well as among different pods of the same killer whale type. Type C killer whales have traditionally been encountered near the fast-ice edge of McMurdo Sound (Thomas et al., 1981; Pitman & Ensor, 2003; Ballard & Ainley, 2005) and have been documented as preying on Antarctic toothfish. However, recent observations have been made of Type B killer whales in fast-ice habitats, including one instance of predation on a Weddell seal in the lead formed by an icebreaker off of Cape Royd's, near McMurdo Sound (Ballard & Ainley, 2005; Andrews et al., 2008).

The recordings presented and discussed in this paper were of a single pod of killer whales. We believe that the killer whales recorded during the study were Type C for two reasons. First, Type C killer whales are by far the most abundant form observed and photographed in the fast-ice leads of McMurdo Sound, although Type B are occasionally observed as well (Pitman & Ensor, 2003; Ballard & Ainley, 2005; Lauriano et al., 2007; Pitman et al., 2007). Second, the sound structure and signal characteristics examined in this study were similar to sounds from fish-eating killer whales described in other oceans (i.e., the repertoire was large, sounds were abundant, and call types had variable structure). In contrast, the marine-mammal-eating killer whales of the Northeast Pacific produce fewer call types, less frequently, and with little structural variation (Deecke, 2003; Rehn et al., 2007).

At the time of the recordings in this analysis, the killer whales were actively pursuing Adélie penguins. Photographic evidence eliminated the possibility of Type A killer whales, largely supported Type C killer whales, but could not conclusively eliminate the possibility of Type B killer whales.

The consistent sound production by the killer whales throughout this short recording indicates that there was no apparent attempt to limit acoustic behavior while chasing penguins. Little is known about the underwater hearing of birds (including penguins). The in-air hearing of penguins is sensitive between 100.0 Hz and 15.0 kHz (Wever et al., 1969), and the bird audiograms reported by Fay & Popper (1975) showed little variation among species, so penguin hearing is suspected to be lower in frequency than most killer whale echolocation signals. The soniferous behavior of the killer whales chasing penguins at the time of the recordings promotes conjecture that the killer whales did not need to reduce their acoustic behavior while pursuing penguins.

According to Ballard & Ainley (2005), Type C killer whales commonly occur with Adélie penguins. They speculated that chasing events might have been "training" opportunities for young killer whales. Curiously, the Adélie penguins could have easily hopped onto the ice to avoid being chased. In contrast, Adélie penguins quickly leap out of the water onto the fast-ice when a leopard seal is nearby (J. Thomas, pers. obs., 1976-1980). Despite the lack of documented penguin predation, the coordinated chasing behavior is likely facilitated by underwater sounds produced by the killer whales. The observations of this pod chasing Adélie penguins might suggest that Antarctic killer whales are more catholic in their diet and are perhaps opportunistic feeders on multiple prey types. Similarly, Estes et al. (1998) reported that killer whales in the Northeast Pacific opportunistically fed on sea otters (*Enhydra lutris*), a species previously thought to be infrequently encountered or too small to be part of the killer whale's diet.

This recording was made when fast-ice was beginning to break up, allowing killer whales access to fast-ice areas near Weddell seal breeding colonies. In early December 1979, Weddell seals had completed mating, and adults and pups were starting to disperse from the colony (Thomas & DeMaster, 1983a, 1983b). Also, in early December 1979, leopard seals were seen patrolling the fast-ice edge, and their sounds were recorded in the same area as the killer whales.

Minke whales were also seen swimming in the same ice-edge area and fast-ice leads as killer whales and Adélie penguins (J. Thomas, pers. obs., 1979). However, photographs taken during the recording were definitely not of Type A killer whales. Furthermore, Type A killer whales have not been reported in the McMurdo Sound area, even though minke whales seem relatively common there.

Acoustic analysis in this study leads us to speculate that, like the fish-eating killer whales in the Northeast Pacific, the high number of call types, high calling rate, and distinct acoustic variability in call types accord well with our overall conjecture that the killer whales described herein are Type C killer whales, although we cannot be certain. The killer whale phenotypic variants in Antarctic waters are appreciably divergent from one another, as well as to other global populations. Eventual analysis of the acoustic attributes of all three Antarctic killer whale ecotypes might determine acoustic differences and geographic variations associated with different foraging strategies.

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