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Acoustic Analysis of Underwater Vocalizations from Crabeater Seals (*Lobodon carcinophagus*): Not So Monotonous

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Abstract

Underwater vocalizations of pack-ice crabeater seals (*Lobodon carcinophagus*) were recorded by J. A. Thomas off the western side of the Antarctic Peninsula during the austral breeding season in November 1978. Data were collected by dropping an ANS 57 sonobuoy from the side of a ship to a depth of 15.3 m and recorded on a Nagra III reel-to-reel recorder (system frequency response linear from 20 Hz to 20 kHz ± 2 dB). The acoustic properties of 315 underwater vocalizations were analyzed using Spectrogram real time software. As previous investigators documented, all crabeater seal sounds during the breeding season were of one type, a long groan. D. Cothran recorded a solitary crabeater seal of unknown age and sex foraging during the non-breeding season in February 2007 in the same general area of the Antarctic Peninsula using a Sony TRV-900 digital underwater video camcorder. Twenty seconds of underwater acoustic data were spectrographically analyzed, and 18 vocalizations were identified and classified into four previously unreported sound types: (1) short groan, (2) whistle, (3) screech, and (4) grunt. For the first time, the acoustic characteristics of the common long groan and four previously undescribed underwater vocalizations by crabeater seals were examined spectrographically with parameters of frequency and time reported herein. The long groan showed little frequency or temporal variation and was repeated by other distant crabeater seals at about 20.0-s intervals. No long groans were recorded during the short February videotape. The four previously undocumented vocalizations were produced while a single crabeater seal foraged in shallow water. Hierarchical cluster analysis showed that the long groan was acoustically dissimilar to the four new vocalizations; however, only 18 sounds were available for analysis. Still, this videotape documents that this species does produce more than one sound type. Further research should be conducted to adequately document the underwater acoustic repertoire of the crabeater seal, especially outside the breeding season.

Key Words: vocalization, crabeater seal, *Lobodon carcinophagus*, Antarctica, predation, aggression, breed, forage

Introduction

The ice surrounding Antarctica provides three habitats to marine mammals: (1) the thick fast-ice attached to land, (2) the floating pack-ice, and (3) open water. The area between the stationary fast-ice and floating pack-ice is called the ice edge. Seasonal changes cause the ice edge to advance and retreat and, thus, provide an ideal feeding location for many species: minke whales (*Balaenoptera acutorostrata*), killer whales (*Orcinus orca*), crabeater seals (*Lobodon carcinophagus*), leopard seals (*Hydrurga leptonyx*), Adelie penguins (*Pygoscelis adeliae*), emperor penguins (*Aptenodytes forsteri*), rock hopper penguins (*Eudyptes crestatus*), chinstrap penguins (*P. antarctica*), and 43 genera in the Notothenid fish (Eastman & Eakin, 2000). In addition, humpback whales (*Megaptera novaeangliae*), fin whales (*B. physalus*), and blue whales (*B. musculus*) occupy the open water surrounding Antarctica throughout the year, feeding on krill (*Euphausia superba*) (Perrin et al., 2009).

There are four species of Antarctic pinnipeds (Perrin et al., 2009). Unlike Arctic seals who contend with predation by polar bears (*Ursus maritimus*), Antarctic seals do not have natural land predators, so they are relatively safe from predation when hauled-out on the ice. Weddell seals (*Leptonychotes weddellii*) occur in fast-ice areas and are a mid-level predator, which feeds on both large and small fish (Thomas & Rogers, 2009). Ross seals (*Ommatophoca rossii*) occur in fast-ice or dense pack-ice and have a varied diet consisting of small fish, cephalopods, and krill (Thomas & Terhune, 2009). The leopard seal is a pack-ice or ice-edge species and a top-level predator that feeds on penguins, fish, krill, and the pups of other seal species, mainly crabeater seals (Siniff et al., 1979; Golladay & Thomas, 1995).

Natural History of Crabeater Seals

Crabeater seals are the most abundant pinniped in the world, and their distribution is limited to pack-ice or ice-edge areas around Antarctica (Bengtson, 2009), where they feed almost exclusively on krill (Bengtson, 2002). Because of their pagophilic habits and the limited access by researchers to pack-ice habitat, little is known about their population dynamics, especially outside their austral breeding season (Bengtson, 2002, 2009). There is little basis to suggest that crabeater seals are migratory (Bertram, 1940). However, Rogers (2003) reported that crabeater seals do move frequently, but not in any set pattern. Stirling & Kooyman (1971) reported that during the winter, crabeater seals move northward to the edge of the pack-ice. Individual crabeater seals equipped with satellite transmitters travelled at least one-third of the distance around the Antarctic continent in as little as 11 mo (Stirling & Thomas, 2003). Their distribution and movements likely are tied to ice conditions and their need to access stable ice floes to haul out.

Crabeater seals are seasonally monogamous (Bengtson & Siniff, 1981); during the breeding season, a male remains hauled-out on an ice floe with a female and her pup (Bengtson & Stewart, 1997). The mating season ranges from early October to mid-November (Wall et al., 2007), with most of the pups born and weaned before the end of November. Although the male is unlikely to be the pup's father (more likely to be fathered by another male from the previous mating season), he guards the pup and female from predators, such as leopard seals and killer whales, and mates with the resident female when her pup weans (Shaughnessy & Kerry, 1989). According to Stirling & Thomas (2003), a male actively tries to prevent the female from leaving the ice floe after the pup is weaned for the purpose of immediate copulation. This mating strategy is a large time and energy investment for the male, but it reduces intra-male competition for a mate and increases a male's likelihood of mating.

Several studies suggest there is variation in crabeater seal behavior between the breeding and nonbreeding periods (Bengtson, 2002, 2009). During the breeding season, crabeater seals are closely associated with pack-ice and make shallow dives (4 to 10 m), while most crabeater seals spend their post-breeding season in open water, with most dives less than 100 m (Bengtson & Stewart, 1992; Wall et al., 2007). Nordøy et al. (1995) attached temperature depth recorders to eight crabeater seals and collected data for 5 mo. With the onset of autumn, crabeater seals stayed close to the continental shelf within the pack-ice and moved north as the sea ice expanded. They made about 150 dives/d, and the maximum depth recorded was 528 m. However, Kooyman & Kooyman (this issue) reported that Australian researchers in the late 1990s attached satellite tags to 23 crabeater seals in eastern Antarctica and dives were primarily shallow:

> The tagging was done from September to December, and the tags last < 3 months. The seals traveled about 400 to 600 km from the place of release in a meandering track. They were off the continental shelf and in pack-ice 86% of the time. From 92 to 98% of the time dives were to depths of < 20 m. Overall, they were probably grazing on krill, and in regard to diving, it is perhaps the most boring natural history of any pinniped. (p. 552)

Most adult crabeater seals typically have long, parallel scars running the length of their bodies. The distance between these scars matches the dentition pattern of leopard seals, suggesting crabeater seals are highly preyed upon by leopard seals but often escape (Jefferson et al., 1993). The main cause of crabeater seal mortality is attributed to killer whale predation (Rogers, 2003); killer whales are highly successful in capturing crabeater seal pups, thereby leaving no scars.

An acoustic study on crabeater seals by Thomas & DeMaster (1982) showed this species has a distinct diel activity pattern during the breeding season—hauling out at midday and entering the water at night; thus, more sounds are heard under water at night. They forage primarily at night on krill, continuously diving for periods of up to 16 h. Their daytime activities include hauling out on ice floes during the middle of the day to rest, tend their pups, and avoid predation by leopard seals and killer whales (Bengtson, 2002).

Crabeater seals, like most pinnipeds, have specially adapted sensory abilities for living in both air and water. The auditory abilities are unknown for the crabeater seal, or for any other Antarctic seal. However, the range for underwater hearing in other phocids, such as harbor seals (*Phoca vitulina*) and ringed seals (*Ph. hispida*), is from 1 to 80 kHz, with the best frequency between 17 and 25 kHz, depending on the species (Feldhamer et al., 2003). Because underwater hearing is sensitive and broadband in phocids, vocalizations likely play an important role in underwater communication.

Acoustic Repertoire

There are limited data on crabeater seal aerial or underwater vocalizations because of limited access by researchers to the constantly changing pack-ice habitat and difficulty with accessing the species during the dark austral winter. Crabeater seals have no natural land predators and typically are not aggressive while on land; however, a common response to humans on their ice floe includes teeth-baring and snorting loudly by expelling air through the nostrils before rapidly escaping into the water (Stirling & Kooyman, 1971).

Previous studies conducted during the austral spring breeding season led researchers to conclude that crabeater seals have only a single underwater vocalization, a long groan (Stirling & Siniff, 1978; Thomas & DeMaster, 1982). These acoustic displays are believed to be used during male-male interactions in the breeding season, although inter-male aggression has not been observed. Underwater video is needed to document male crabeater seal behavior to verify whether the long groan is produced exclusively by males. There has been no detailed spectrographic, acoustic analysis of the long groan. In addition, there are no previous reports on crabeater seal sounds made outside the breeding season.

Several underwater recordings of crabeater seal sounds were made remotely by J. A. Thomas using sonobuoys during the November 1978 breeding season on the western side of the Antarctic Peninsula. More recently, in February 2007, D. Cothran, a naturalist on a tourist cruise, opportunistically made underwater video/audio recordings of a single crabeater seal of unknown age and sex foraging in shallow water. These two sets of recordings serve as the basis for this study.

The goals of this study were to document the number and types of vocalizations by crabeater seals during the breeding and nonbreeding season and to document the acoustic properties of the sound types. Because other phocids have more than one underwater vocalization, it was likely that crabeater seals also have more than one vocalization, perhaps used outside the breeding season.

Materials and Methods

Study Site and Subjects

During the austral spring of 1978, several underwater recordings were collected by J. A. Thomas at Ezcurra Inlet, along the western side of the Antarctic Peninsula, and samples from the 18, 19, 25, and 28 November 1978 recordings were spectrographically examined. This location is a known breeding site for crabeater seals, and about 50 breeding and pupping crabeater seals were hauling in and out from icebergs in the area.

In February 2007, D. Cothran, an undersea specialist and naturalist onboard the tourist cruise ship *Lindblad Explorer*, opportunistically made underwater video/audio recordings of a single encounter with a solitary crabeater seal of unknown age or sex. The seal was exploring the rocky bottom and presumably foraging, but no fish or krill were videotaped. (See video footage at www.aquaticmammalsjournal.org.) Both sets of recordings were in the same general area west of Palmer Peninsula (Figure 1).

Recording Equipment and Methods

The November 1978 recordings were made using an ANS 57 sonobuoy (frequency response linear from 0.03 to 10.00 kHz + 3 dB) deployed from the side of the *RV Hero*, a National Science Foundation wooden sailing research ship. The sonobuoy filled with saltwater to activate the battery, ejected an antennae on the top of the buoy, dropped a hydrophone to a 30-m depth, and operated until the battery ran out. Sounds were retrieved from an onboard radio-frequency sonobuoy receiver and recorded onto a Nagra III reel-to-reel recorder at 7.5 cm/s (frequency response linear from 20 Hz to 20 kHz ± 2 dB). The best recordings were made when the ship moved away from the sonobuoy to reduce self-noise from the ship. All analog recordings were digitized by the Bioacoustics Research Program at the Cornell Laboratory of Ornithology.

The February 2007 recordings were made using a handheld Sony TRV-900 digital video camcorder in a waterproof Light and Motion Bluefin housing and recorded onto Sony DVM60ME tapes (linear frequency response up to 48 kHz). Sounds were recorded on the mono microphone input of the video camcorder inside the waterproof housing, which was not ideal because the waterproof housing masked sound reception, but the crabeater seal was at close range, about 40 m away, and sounds were clearly audible on the DVD and visible on spectrograms. The DVD was viewed using Apple *QuickTime*, and the audio track was converted to .wav sound format.

Acoustic Analyses

For both sets of recordings, simultaneous sonograms and oscillograms were generated using *Spectrogram*, Version 20.0, software (Richard Horne, Visualization Software LLC) and displayed on an hp model s3220n computer. Several time and frequency variables were measured using the cursor (see examples of variables in Figure 2). The maximum and minimum frequencies of the dominant part of the sound (band with the highest amplitude) were measured. The bandwidth was the total frequency range over the call (maximum frequency minus minimum frequency). The total duration was the time from the beginning to the end of the sound. Often, a crabeater seal could be heard calling near the hydrophone, and attenuated calls from one or more distant crabeater seals were heard afterwards. If multiple animals were calling, the time between any crabeater seal vocalizations was scored as the inter-call interval.

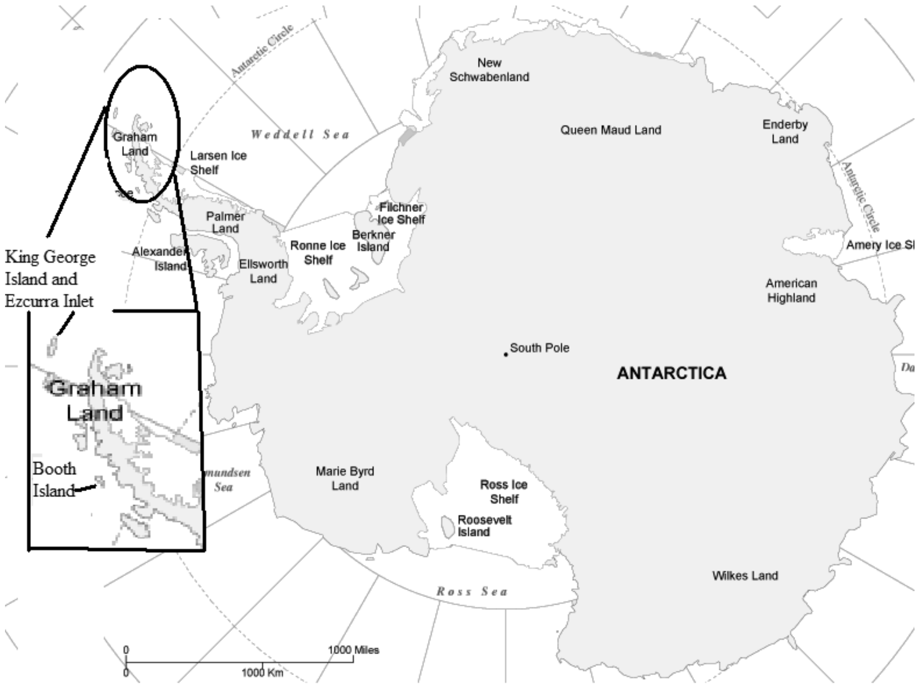

Figure 1. Map of the Western Peninsula of Antarctica; Ezcurra Inlet was the site of the November 1978 recordings, and Booth Island was the site of the 2007 recordings. Map is courtesy of istockphoto.com.

Although sounds were examined up to 20 kHz, all sound content was below 6 kHz, so this was the upper-frequency scale used for all sound types. On numerous November 1978 recordings, leopard seals vocalized between the crabeater vocal exchanges. Leopard seals are actively breeding and acoustically active during this time. Leopard seal sounds were recognized according to descriptions in Golladay & Thomas (1995) and were not analyzed herein.

From the video footage, the presence or absence of bubble-blowing by the crabeater seal, scars, and whether the seal was facing the camera or investigating the ocean floor were noted for each vocalization. No other marine mammal sounds were heard during the February 2007 recording.

Statistical Analyses

All statistical analyses were conducted using *MYSTAT*, Version 12.0 (Systat Software Inc, San Jose, CA). Statistical tests were conducted at the $\alpha = 0.05$ level of significance. Descriptive statistics (mean, sample size, minimum, maximum, and SD) were calculated for each variable by each vocalization type.

To determine which acoustic parameters were important in describing the variability in the 1978 and 2007 data sets, principle component analysis (PCA) was conducted. Initial analysis showed that dominant maximum frequency and dominant minimum frequency were highly correlated, so another PCA analysis was conducted omitting dominant minimum frequency and using only dominant maximum frequency, inter-call interval, duration, and bandwidth as variables.

Hierarchal cluster analysis with single-linkage of correlation coefficients among sound types was employed to produce a classification dendrogram (see Figure 6). Distance between clusters measured the similarities among the acoustic variables by sound types. In the single-linkage model, short distances between clusters represent similar vocalizations and long distances represent less similar sound types.

Results

Underwater recordings of crabeater seal vocalizations from four dates in November 1978 were analyzed spectrographically. A total of 908 s of recordings had 315 vocalizations; all were the same type, a long groan. The February 2007 video recording was only 20 s in duration but had 18 vocalizations. The average call duration, inter-call interval, minimum and maximum frequencies, and bandwidth for vocalization recordings during 1978 and 2007 are shown in Table 1.

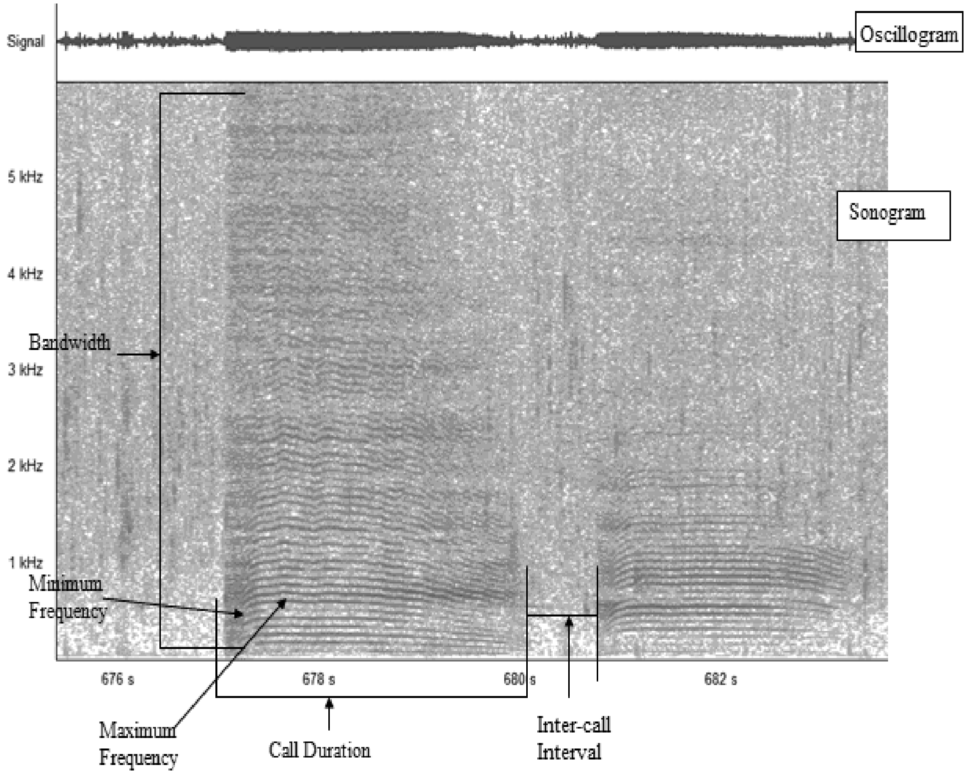

Figure 2. Oscillogram (upper display) and sonogram (lower display) showing acoustic characteristics measured for sounds produced by a crabeater seal at Ezcurra Inlet, Antarctica, on 18 November 1978

Table 1. Description of crabeater seal underwater recordings by collection location and date in the Palmer Peninsula area of Antarctica, along with the number of underwater vocalizations and averages (± SD) for call duration, inter-call interval, minimum and maximum frequencies, and bandwidth for each recording location

Location and year	Total number of vocalizations	Call duration (s)	Inter-call interval (s)	Maximum frequency (Hz)	Minimum frequency (Hz)	Bandwidth (Hz)
Ezcurra Inlet, 1978	315	2.887 ± 3.208	20.031 ± 19.017	985.7 ± 637.7	649.2 ± 351.1	2,570.9 ± 1,563.0
Booth Island, 2007	18	1.516 ± 2.425	6.738 ± 5.210	1,230.3 ± 528.5	501.4 ± 556.6	1,771.3 ± 1,476.5

Only one vocalization, a long groan, was present in the November 1978 recordings. Four previously unreported vocalizations were identified in the February 2007 recordings (Table 2). The long groan was a low-frequency vocalization, rich in harmonics, had little frequency modulation, and occurred multiple times in every recording from 1978 (Figure 3). The average bandwidth for the long groan was 2,570.9 Hz, and the average duration was 2.9 s. Distant crabeater seals seemed to respond to long groans with their own long groan calls after a short, average 20.0-s interval.

The four new vocalizations included whistle, grunt, short groan, and screech; all were shorter in duration, had few harmonics, and were slightly higher in frequency than the long groan (Figure 4). The video recording focused on a single seal that produced several sounds close in time (average of 6.7 s apart), which were likely part of a single sequence. Neither other crabeater seals nor other marine mammal sounds were heard during the videotape.

The most common of new vocalizations was the short groan, which occurred in 2.4% of all the vocalizations, with an average bandwidth of 1,022.3 Hz and an average duration of 1.0 s. The grunt and the screech were the next most common—1.5% and 1.2%, respectively. Both were short vocalizations—0.02 and 0.59 s in duration, respectfully. The whistle vocalization only occurred once in the recordings. In one instance, several new vocalizations were used in a series

Table 2. Underwater sound repertoire of crabeater seals on the western Palmer Peninsula of Antarctica summarized by vocalization type, total number of vocalizations recorded, percent of repertoire, and average (± SD) frequency and time variables

Vocalization name	Total number sounds recorded	Percent of repertoire	Maximum frequency (Hz)	Minimum frequency (Hz)	Duration (s)	Bandwidth (Hz)
Long groan	315	94.6	1,298.5 ± 634.1	962.2 ± 349.6	2.887 ± 3.148	2,570.9 ± 1,571.5
Short groan	8	2.4	1,151.9 ± 495.9	315.3 ± 308.9	1.034 ± 0.6	1,022.3 ± 437.0
Grunt	5	1.5	1,387.7 ± 1161.4	1,110.0 ± 43.9	0.161 ± 0.035	1,962.7 ± 966.7
Whistle	1	0.3	1,200.0	878.0	1.14	332.0
Screech	4	1.2	1,145.7 ± 463.6	513.8 ± 589.8	0.582 ± 0.04	2,436.0 ± 959.7
Total	333					

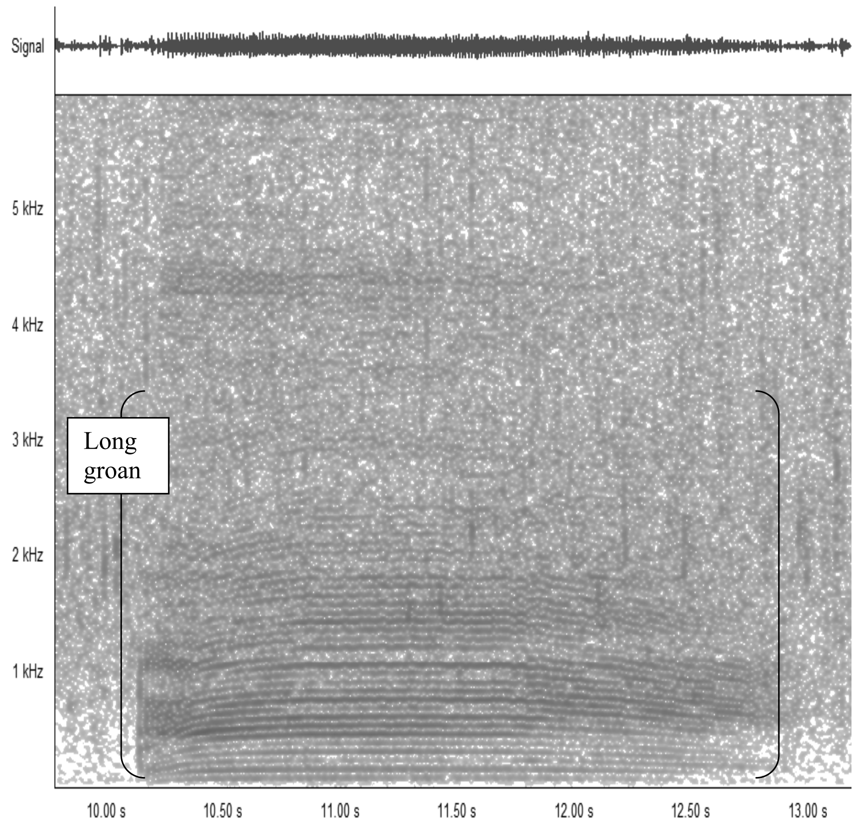

Figure 3. Oscillogram (upper display) and sonogram (lower display) of the most common underwater vocalization of the crabeater seal, the long groan, recorded on 21 November 1978 at Ezcurra Inlet, Antarctica

consisting of several short groans, a whistle, and screeches (Figure 5).

A PCA of all acoustic variables for November 1978 and February 2007 data sets combined resulted in only two significant factors. Significant parameters in Factor 1 (meaning they were the most important in explaining the variance in the data set) were maximum frequency, bandwidth, and inter-call interval. Factor 2 was represented by duration of the sounds (Table 3).

Using all recordings, hierarchical cluster analysis using single-linkage contained the number of clusters and the distance between clusters and showed the relationships among the crabeater seals' underwater vocalizations (Figure 6). The long groan was clearly different acoustically from the four previously undescribed sound types.

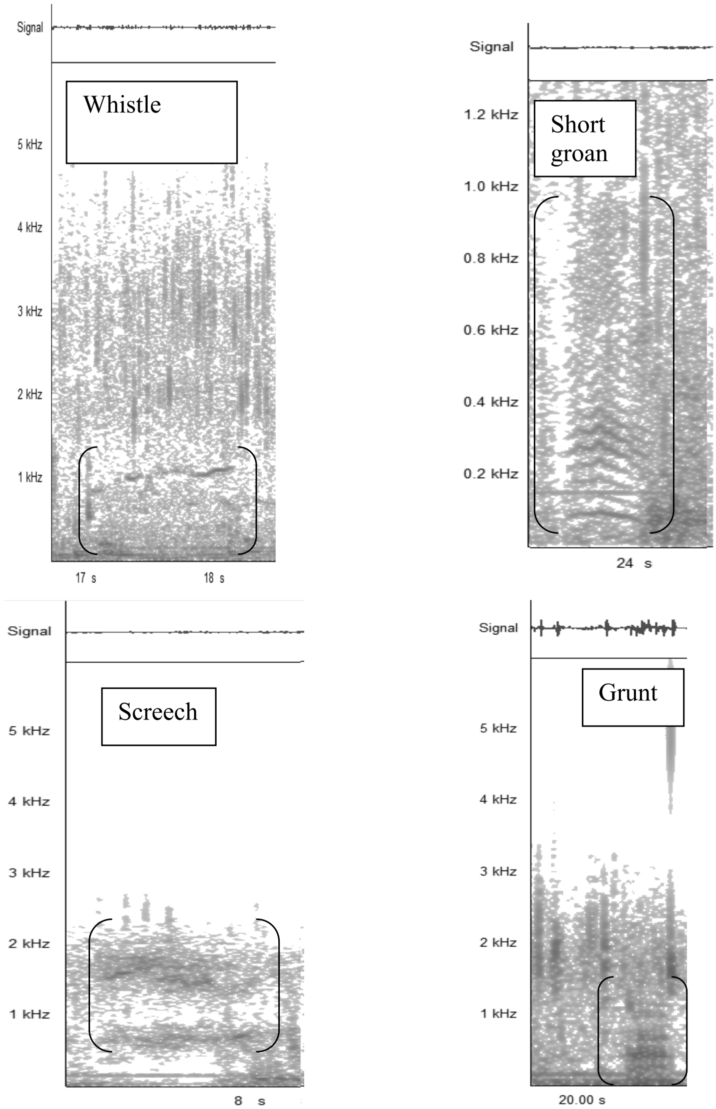

Figure 4. Oscillograms (upper display) and sonograms (lower display) of the four new underwater vocalizations—whistle, short groan, screech, and grunt—by crabeater seals at Booth Island, Antarctica, all recorded on 14 February 2007

Discussion

The underwater acoustic repertoire of the Antarctic Weddell seal (Thomas & Kuechle, 1982) and leopard seals (Golladay & Thomas, 1995) are fairly well-documented during the breeding season. Recently, underwater vocalizations of Ross seals during the austral spring were documented by Stacey (2006). Unfortunately, the underwater acoustic behavior of the crabeater seal remains sketchy. In this study, the acoustic properties of the common long-groan call and four previously undescribed underwater sounds by the crabeater seal were documented.

The long groan by the crabeater seal has been reported or heard by several investigators during the October/November breeding season (near McMurdo Sound by J. A. Thomas in 1976 and 1977; near Palmer Peninsula by Stirling & Siniff, 1978; and near Palmer Peninsula by Thomas & DeMaster, 1982). All investigators heard only one underwater sound type but noted that crabeater seal sounds did not overlap; rather, near and far seals seem to call and respond with the same long groan.

This is the first report of detailed spectrographic analysis of this long-groan sound type; examination of the prevalence of the call during

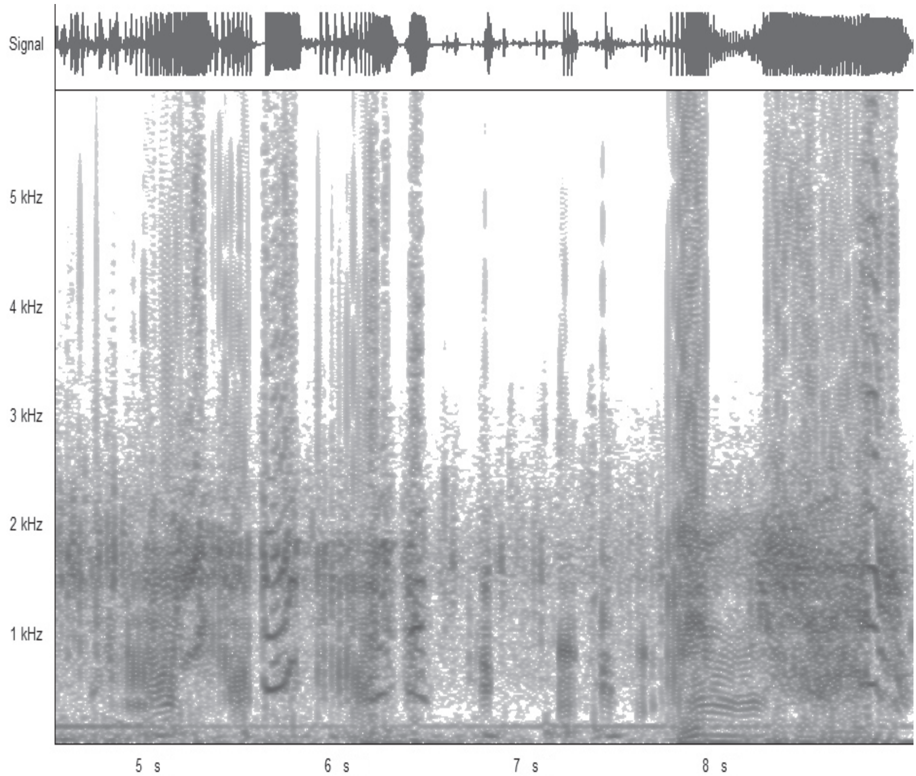

Figure 5. Oscillogram (upper display) and sonogram (lower display) of underwater vocalization series by a crabeater seal at Booth Island, Antarctica, recorded on 14 February 2007

Table 3. Component loadings by factor from a PCA of the acoustic variables for November 1978 and February 2007 recordings combined; minimum frequency was omitted from analysis. Significant component loadings are in bold.

Variables	Factor 1	Factor 2
Duration	0.381	**0.771**
Inter-call interval	**0.720**	0.064
Maximum dominant frequency	**-0.514**	0.085
Bandwidth	**0.461**	**-0.646**

the breeding season; and documentation of call intervals, which could be antiphonal acoustic behavior by this species. The long groan is a low-frequency, broadband, short duration, underwater sound with rich harmonic structure and little frequency modulation, which is repeated during the breeding season by crabeater seals and was the only crabeater seal sound recorded during the breeding season in November 1978 at Ezcurra Inlet, near Palmer Peninsula.

Although the February 20007 video recording of a single crabeater seal was short, it provided the first documentation that this species uses other vocalizations outside the breeding season—at least four previously unreported sound types. These sounds were from a single crabeater seal of unknown age or sex exploring the rocky ocean bottom. Perhaps it was foraging, but no fish or

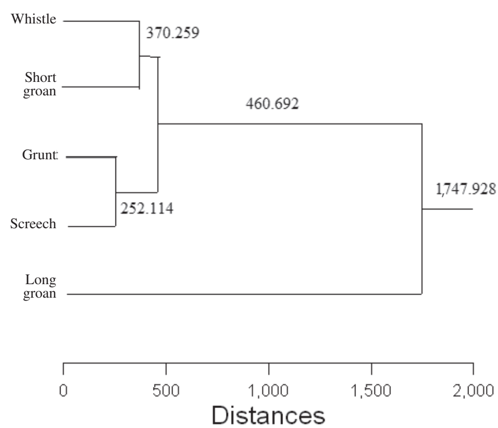

Figure 6. A dendrogram of all underwater vocalization types of crabeater seals based on hierarchical cluster analysis; the distance is Euclidian, and single-linkage was the model.

krill were videotaped. The previously unreported sounds were shorter, had a narrower bandwidth, had fewer harmonics, and were lower in frequency than the long groan. Although it cannot be confirmed, the animal appeared to be a juvenile. These results imply separate underwater acoustic repertoires during breeding and feeding periods or, alternatively, a sex- or age-related difference in the acoustic repertoire.

Acoustic Properties of Vocalizations

The PCA for all acoustic variables of crabeater seal sounds produced during all recordings indicated frequency variables (dominant maximum and bandwidth), along with inter-call interval, were of primary importance in describing the variability in call types. The time variable, duration, seemed to be of secondary importance in the classification of sound types. Other studies using PCA on sounds by marine mammals found similar results. For example, vocalizations of the northern elephant seal (*Mirounga angustirostris*) and the northern fur seal (*Callorhinus ursinus*) showed considerable differences in frequency over any other factor (Insley, 1992). Frequency often distinguishes the different types of sounds from bottlenose dolphins (*Tursiops truncatus*) (Boisseau, 2005) and from migrating humpback whales (Dunlop & Noad, 2007). In a study of leopard seals, PCA showed that frequency was of primary importance in vocalization identification (Golladay & Thomas, 1995). Overall, these studies indicated that frequency is the key factor in describing variation in marine mammal sound types. Therefore, when examining acoustic data, frequency should be used as the primary discriminating factor for sound types.

Hierarchical cluster analysis showed that the acoustic properties of nonbreeding season (February 2007) and breeding season (November 1978) vocalizations by crabeater seals were not closely related. The long groan was distinctly separate from the four other sound types, and the Euclidean distance was large between the long groan and the four other sounds. This analysis supports that the sound type assignment used herein was reliable.

Vocalizations During the Breeding Season

Many marine mammals have distinct vocalizations used exclusively during the mating season. For example, Weddell seals have an elaborate repertoire of 34 underwater sounds used only during the breeding season, a different repertoire of airborne sounds used by mothers and pups while they are hauled-out on the ice, and few sounds are produced outside the breeding season (Thomas & Kuechle, 1982). The humpback whale has a series of clicks followed by a buzz when foraging, but a more connected "song" during mating and raising calves (Stimpert et al., 2007). It seems unlikely that crabeater seals would be an exception to the trend of having different vocalizations used during and between breeding and nonbreeding seasons.

The mating season for crabeater seals ranges from early October to mid-November (Wall et al., 2007), and the long groan was produced exclusively during this breeding season. Rogers (2003) suggested that the long groan is an aggressive call between competing males. In the November 1978 recordings, a crabeater seal produced a long groan, and then a more distant seal often seemed to reply with a long groan. Whether both males and females produce this sound type is unknown, but it is assumed that the female is predominantly on the ice tending her pup, and therefore, the underwater calls by crabeater seals would be from males.

Vocalizations During the Nonbreeding Season

Most crabeater seals spend their post-breeding times away in open water, diving to greater than 100 m to feed (Wall et al., 2007). The recordings collected during February 2007 were that of a single young adult crabeater seal of unknown sex diving in shallow water, foraging near the rocky bottom, only a short distance from the ice. This individual produced a variety of vocalizations but no long groans. The most common sound was the short groan, which on two occasions was accompanied by the seal blowing bubbles into the water. Foraging Weddell seals blow bubbles at the underside of ice so fish will dart out and be captured (Stone, 1998). Perhaps bubble-blowing by this single crabeater seal into the rocks in a shallow water area indicates that small fish are part of its diet.

The purpose of the four new vocalizations is unclear. On one occasion, the seal directed its vocalizations toward the rocky substrate, which could imply foraging. However, at other times, the vocalizations were directed at the video camera, which could indicate curiosity.

Implications of the Mating System on the Number of Vocalization Types

According to Stirling & Siniff (1978), the only crabeater seal underwater vocalization is a groan (equivalent to the long groan in this study). The long groan comprised over 90% of the recordings analyzed herein. Because of the seasonally monogamous mating system of this species, it is not surprising that there is only one vocalization used during the breeding season; there would be no need for an elaborate underwater vocal repertoire to attract a mate nor for territorial defense. Rogers (2003) reported that phocid species that tend to be polygynous have more vocalization types. Stirling & Thomas (2003) reported that female availability (or the number of days a female can be accessed by a male for mating) might shape the number of vocalizations in the repertoire of phocids. Rogers (2003) suggested that phocids, like the crabeater seal, in which males have greater access to females, tend to have small vocal repertoires composed of short duration, broadband sounds, typically used for aggressive displays between males. The crabeater seal's long groan fits this description.

Stirling & Thomas (2003) reported that polygynous phocid species with a long lactation period need long-term communication and, therefore, have a large number of underwater sounds. Crabeater seals do not have a particularly long lactation period compared to other phocids (Bengtson, 2009) and, hence, would not need a large number of sound types. Stirling & Thomas (2003) also suggested that when predation is high, there should be a low number of vocalizations in the acoustic repertoire. The single, monotonous underwater vocalization by monogamous crabeater seals could reflect their need to prevent detection by predators.

Implications of Distribution and Number of Vocalization Types

The variability in the number of vocalization types among Antarctic pinniped species might reflect the population's genetic variability. Lehman et al. (2004) examined a region of the major histocompatibility complex gene in Antarctic Weddell, crabeater, Ross, and leopard seals from the Ross Sea for patterns of genetic variability. They found substantial differences in patterns of population genetic diversity among these seals, with the crabeater seals being the most diverse (over 30 crabeater seals were examined, and 93% of loci were heterozygous). Crabeater seals have a population range evenly distributed around the continent, so their vocalizations would be contiguous rather than different by location. In contrast, studies by Golladay & Thomas (1995) reported significant geographic variation in leopard seal underwater vocalizations, and Thomas et al. (1984) found distinct geographic variation in Weddell seal vocalizations around the continent. Perhaps crabeater seals do not have a more elaborate repertoire because their distribution is contiguous; they do not need to distinguish different geographic populations of conspecifics.

Future Research

Even though the crabeater seal is the most abundant phocid in the world, there is minimal information on this species because of limited access to their habitat during a short daylight austral spring and difficulties with their capture and study on small icebergs. The initiative of D. Cothran to videotape the crabeater seal provided valuable data on acoustic behavior of this seal during the nonbreeding season. Currently, there are three types of U.S. vessels that venture to the Antarctic: (1) NSF research vessels, (2) Coast Guard icebreakers, and (3) tourist ships. Research effort needs to concentrate on documenting the underwater vocalizations of crabeater seals and other Antarctic marine mammals during January and February. Sonobuoys could be launched from these vessels.

Another means of collecting acoustic data during the austral winter would be the application of a satellite tag with an acoustic sensor. Satellite tags have been deployed on crabeater seals, but none have had an acoustic sensor (Bengtson & Stewart, 1992, 1997; Nordøy et al., 1995; Southwell, 2004).

Understanding the basic vocal repertoire of marine mammals is important for examining potential impacts from anthropogenic noise. Antarctica is becoming an increasingly popular tourist destination. Over the past decade, boat traffic has increased because of commercial whaling in the Antarctic neutral zone, and tourist cruises and excess noise generated by these boats has increased as well (Harris, 1991). Therefore, it is important to understand the natural acoustic repertoire of the Antarctic marine mammals to observe any changes caused by anthropogenic noise. Even with the addition of recordings from 2007, crabeater seals seem to have one of the smallest vocal repertoires of any phocid. Thus, more research is needed to obtain a complete baseline on the crabeater seals' acoustic repertoire.

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