AIRBORNE AND UNDERWATER VOCALIZATIONS OF THE ANTARCTIC ROSS SEAL *(OMMATOPHOCA ROSSII)*

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ABSTRACT

The Antarctic Ross seal *(Ommatophoca rossii)* is the least known of all the pinnipeds primarily due to the harsh environment they inhabit. On only three occasions have researchers been able to make recordings of sounds from this species. Audiocassette tapes were analyzed from three different collectors spanning 34 years: 1) in 1999/2000 Ian Stirling recorded aerial and underwater vocalizations in the Ross Sea, 2) in 1997 Tracy Rogers recorded underwater vocalizations off the back of a ship near Davis Station in the Davis Sea, and 3) in 1966 Carleton Ray recorded in both mediums in Robertson Bay near Cape Adare and South Coulman Island in the Ross Sea. The objectives of this study on the recordings of Ross seal sounds were to: 1) classify airborne and underwater vocalizations, 2) identify frequency and time characteristics for each vocalization, 3) examine differences in vocalization characteristics by month/year, 4) examine differences in vocalization characteristics by location, and 5) examine differences in vocalization characteristics by sex of the seal.

The Ross seals' vocal repertoire consists of 12 calls (6 aerial and 6 underwater). Three of the six underwater calls showed geographic variation, one underwater call showed differences over thirty years, and one aerial call varied by gender of the seal. The number of vocalizations in Antarctic seals varies with the mating system. The Ross seal has an intermediate number of sounds compared to other Antarctic species. More investigations are needed to understand the acoustic behavior and lifestyle of the elusive Ross seal.

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INTRODUCTION

The Ross seal *(Omatophoca rossii)* is the least known of the Antarctic seals and of all pinnipeds primarily due to their dense pack ice habitat (Thomas 2002). They have a circumpolar distribution with local areas of abundance and are virtually unknown outside of the Antarctic (King 1983). Of the seals that inhabit pack or floating ice, Ross seals prefer denser mid pack ice; whereas, crabeater (*Lobodon carcinophagus*) and leopard (*Hydrurga leptonyx)* seals prefer the outer loose pack ice (Laws 1993). They may be found some distance from the coastline. They are mainly solitary, but have been observed in groups of up to five animals. Because these seals have not been encountered often, there are few behavioral observations and analyses of vocalizations (Watkins and Ray 1985).

Ross seals are true seals, belonging to the family Phocidae and the subfamily Monachinae (southern phocids). The four species of Antarctic seals: Ross, leopard, crabeater, and Weddell *(Leptonychotes weddellii)*, belong to the tribe Lobodontini. The Ross seal is named after the British explorer, Sir James Clark Ross, who led an expedition to the Antarctic in 1839 and described the species from two skeletons collected in the Ross Sea. These seals have been referred to as the "big-eyed" or "singing" seals because they assume the head-up, mouth open posture when approached, looking as if they were projecting their sounds. However, the open mouth display of the teeth and thrusting out of the striped chest also could serve as an aggressive posture (Thomas 2002).

Ross seals have very large eyes, 60 mm in diameter compared to most seals at approximately 40 mm; therefore, allowing better light gathering capabilities in low level lighted environments (Bonner 1990). The animal's head is short and wide with a small mouth. Thomas (2002) reported that there is no distinct difference in body size to indicate sexual dimorphism, except that females tend to be slightly larger. Adult males are 1.68-2.08 meters in length and weigh 129 to 216 kilograms and females are 1.96-2.5 meters in length and weigh 159 to 201 kilograms. Their bodies are dark silver gray dorsally and silver white ventrally. They have parallel streaks of silver on the throat between the face and fore-flipper extending down the chest and have gray and white spots at the line of demarcation.

Like the leopard seal, Ross seals have reduced nails on their flippers while the other southern phocids have well developed nails (Bonner 1990). The Weddell and Ross seals have similar dentition, unlike the leopard and crabeater seals that have specialized tricodont cheek teeth with accessory cusps for straining their euphasid prey. Ross seals have recurved canines and well-developed throat muscles, which seem to be for catching and holding their slippery prey, the squid (Riedman 1990).

Cephalopods make up the majority of the Ross seal's diet, while fish, krill, and other invertebrates constituting a smaller portion of their diet. Even though the Ross seal shares its habitat with the crabeater seal, they exploit different food items, with crabeaters feeding mainly on krill (Riedman 1990). Squid feeders are

adapted to hunting quick-moving prey in a deep dark environment, as indicated by the Ross seal's dentition, muscular neck, and large eyes.

There is limited information available about the Ross seal's breeding behavior. Males and females reach sexual maturity between 2 to 7 years and 3 to 5 years, respectively. It remains unknown whether the seal copulates on ice or in the water, although it is thought to occur in the water similar to the other Antarctic phocids (Thomas 2002). Mating occurs in December with an estimated 11-month gestation period. Thomas et al. (1980) reported peak pupping season from 3 to 18 November. They also described the pup's lanugo pelage, having a yellowish belly and the striping pattern similar to the adults and noted the pup exhibited the classic head-up "singing" posture characteristic of the adults.

The Ross seal is thought to be the least abundant, at only 1-2%, of all pinnipeds in the Antarctic with a population estimated as high as 220,000 individuals, but as low as 20,000 (Thomas 2002). Leopard seals and killer whales *(Orcinus orca)* are the top mammalian predators in the Antarctic ecosystem and feed opportunistically on seasonally available species (Thomas et al. 1987). The Convention for the Conservation of Antarctic Seals in 1972 protected the Ross seal from being killed and prohibited its use for commercial purposes.

Some descriptions of their vocal behavior have been documented. Airborne vocalizations produced by the Ross seal were described as chugs and trills by Ray (1981). They also produce underwater vocalizations, such as pulses and buzz sounds of varying frequencies. Most true seals, such as harbor seals

(Phoca vitulina), ringed seals *(Phoca hispida)*, and harp seals *(Phoca groenlandica),* can hear frequencies as low as 0.5 kHz and as high as 48 kHz (Thomas 1991), so this is the expected frequency range in which Ross seals would call. There still remains the need to classify and describe the entire repertoire and to measure acoustic characteristics of their vocalizations.

The objectives of this study on the recordings of Ross seal sounds were to: 1) classify all airborne and underwater vocalizations, 2) identify frequency and time characteristics for each vocalization, 3) examine differences in vocalization characteristics by month/year, 4) examine differences in vocalization characteristics by location, and 5) examine differences in vocalization characteristics by sex of the seal. This study attempts to quantify and categorize the whole vocal repertoire of the Ross seal and can then serve as a basis for further examination of the species by allowing for the acoustical identification of the animal and for comparisons to other repertoires. Identification of the sound types at geographically different locations can help determine if there are geographically different breeding populations of the species around the Antarctic Continent.

MATERIALS AND METHODS

Field Collection

Audiocassette tapes were analyzed from three different collectors spanning 34 years: 1) in 1999/2000 Ian Stirling recorded aerial and underwater vocalizations near McMurdo Station in the Ross Sea, 2) in 1997 Tracy Rogers recorded underwater vocalizations off the back of a ship near Davis Station in the Davis Sea, and 3) in 1966 Carleton Ray recorded in both mediums in Robertson Bay near Cape Adare and near South Coulman Island in the Ross Sea (Figure 1). All recordings were limited in frequency response by the recording device to the human audible range or about 0.1 to 12.0 kHz.

Recordings were made in both air and water by Ray on 1, 2, 10, and 12 January in 1966. Varying locations were used (Table 1). Equipment included an RG Nagra III tape recorder, Atlantic Research LC-50 hydrophone, and WHOI-Watkins amplifier. The response of the system was approximately 50 Hz to 20 kHz $\pm$ 2 dB.

Rogers' underwater recordings were made using a Sony Digital Audio Tape-Corder TCD-D8 and sonobouys (Sparton Electronics AN/SSQ-57A) off the back of the RV *Aurora Australis*. Sonobuoys were tossed overboard and drifted away from the ship. The hydrophone in the sonobuoy automatically lowered to a depth of 18 m, and an antenna atop the sonobuoy transmitted signals back to two 9-element Yaggi antennas (YH09, RF Industries Pty Ltd) and a receiver located on the ship. The system frequency response was determined by the sonobouys, which was 10 to 20,000 Hz $\pm$ 3 dB. Sonobuoys also receive noise

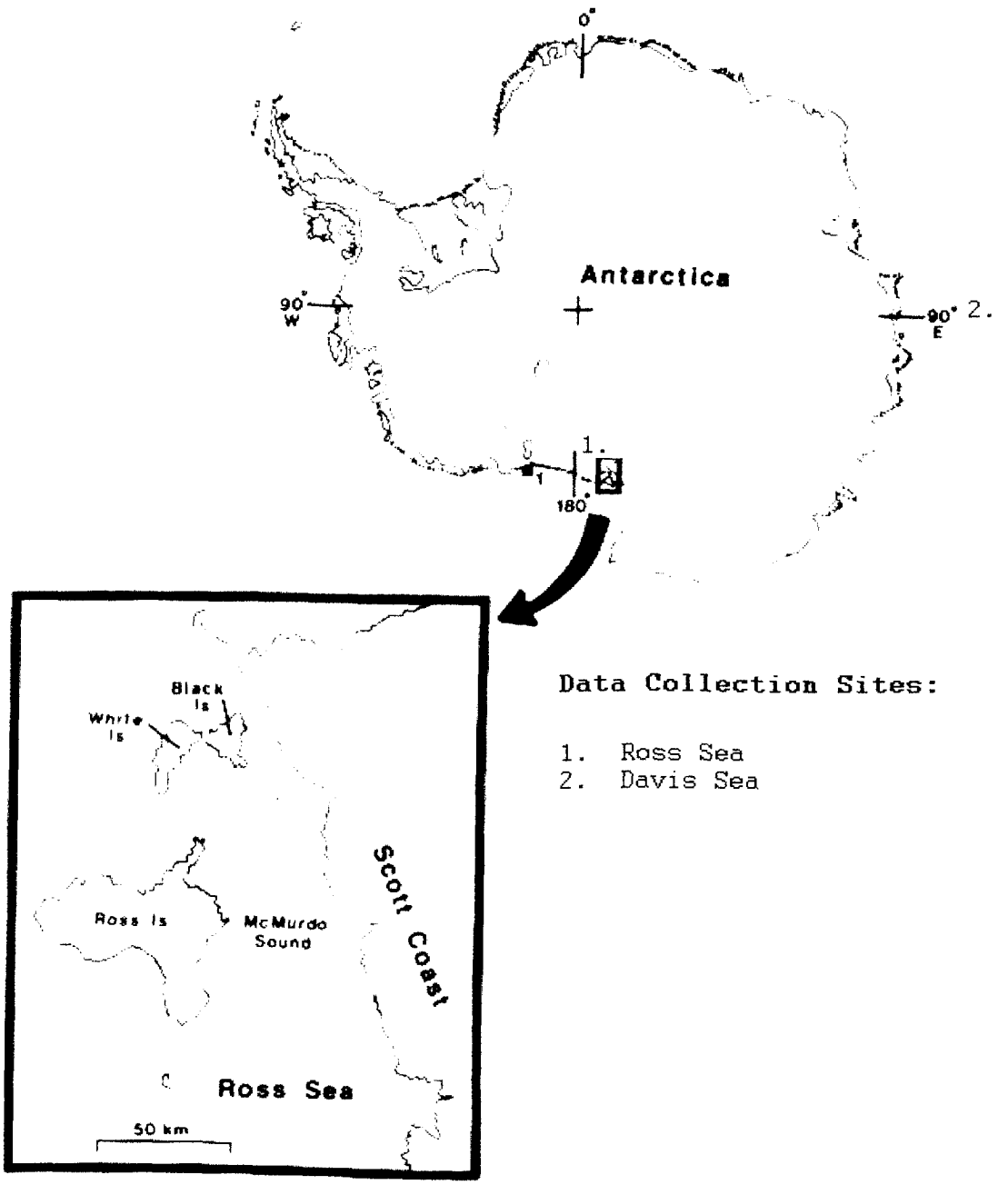


Figure 1. Map of Antarctica showing the two collection sites.

Table 1. Specific locations of Ross seal vocalizations recorded by three collectors.

Collector	Date	Location	Coordinates
Carleton Ray	1&2 January 1966	Burton Islands, Cape Jones	73° 14'S 169° 14'E
	1 January 1966	between Cape Jones and Coulman Islands	73° 14'S 169° 14'E
	10 January 1966	Cape Adare, Robertson Bay	71° 4'S 170° 4'E
			71° 5'S 170° 5'E
			71° 14'S 170° 14'E
	12 January 1966	South Coulman Islands	73° 14'S 169° 14'E
Tracy Rogers	16 December 1997	near Davis Station	64° 16' S 86° 28' E
	18 December 1997	near Davis Station	64° 31' S 81° 51' E
	26 December 1997	near Davis Station	68° 58' S 63° 12' E
Ian Stirling	30 December 1999	Ross Sea	72° 45' S 165° 30' W
	19 January 2000	Ross Sea	69° 44.6'S 135° 34.8'E
	21 January 2000	Ross Sea	67° 28.7'S 139° 09.6'E
	23 January 2000	Ross Sea	69° 23.8'S 144° 27.8'E
	24 January 2000	Ross Sea	71° 11.1'S 41° 37.7'E
	24 January 2000	Ross Sea	71° 17.4'S 41° 37.7'E
	25 January 2000	Ross Sea	71° 31.1'S 141° 50.1'E

from the ship, so there is an ideal distance (1-2 km) between them when ship noise is minimal and seal sounds were strong. Recordings were taken near the Australian Davis Station (see Table 1) on 16, 18, and 26 December 1997.

Stirling recorded off ice flows, and a zodiac in the Ross Sea near the U.S. Navy Station in McMurdo Sound between 30 December 1999 and 4 February 2000. Exact locations are listed in Table 1. Recordings were made on a Marantz PDM430 cassette recorder using a hand-held Sennheiser K3N/ME88 directional microphone, with a system frequency response of 10 to 20,000 Hz $\pm$ 3 dB.

Laboratory Analysis

Spectral analysis of sounds was conducted at the same frequency scale so that any differences in frequency or time measurements would be due to the recordings, not the analysis bandwidth associated with different frequency scales or software programs. Two different types of real-time sonogram analysis programs were used. *Audioscope* software of Physics Academic Software (by Gregory Marlow 1999) was used from a Toshiba Notebook laptop computer, but had no ability to filter out noise. *Real Time Software* (RTS) program of Signal Software (by Kim Beeman 2000) was used on noisy recordings so that a low-pass and high-pass filter could be used in analysis. Frequency ranges used were either 0 to 5000 kHz or 500 to 5000 kHz, depending on the sound type. For some noisy recordings, sounds below 500 Hz were filtered out.

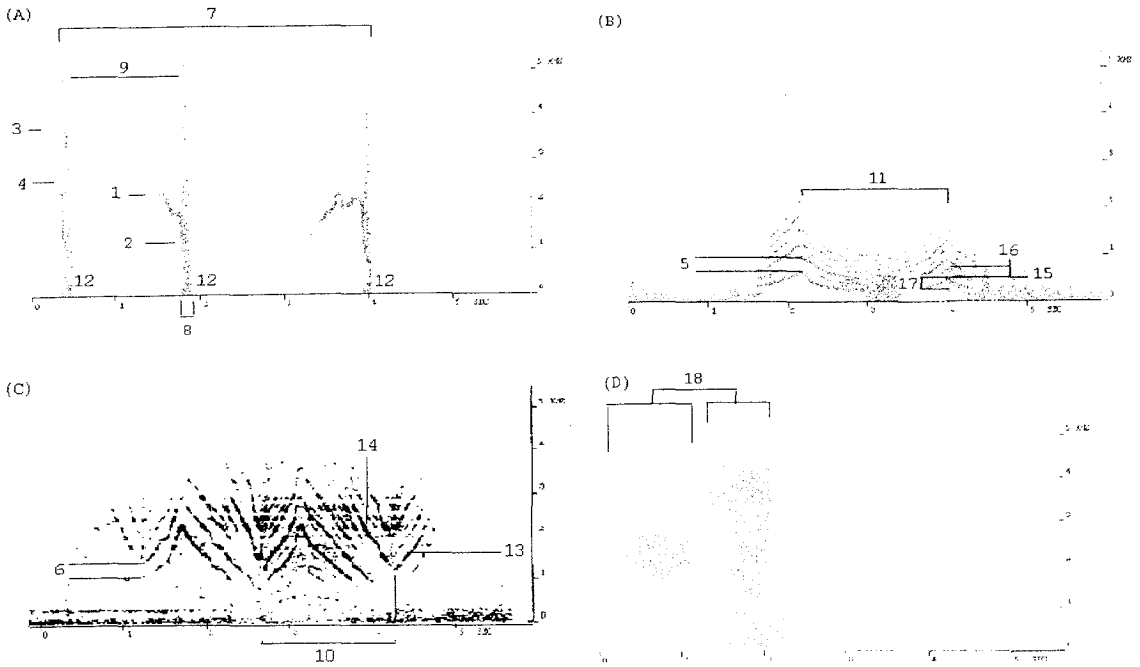
Ray's audio-cassette tapes were transferred to .WAV files on a CD-ROM, which were played on a Toshiba Notebook computer using RealPlayer. The *Audioscope* real-time sonogram program was used for analysis.

Rogers' recordings were made on digital audiocassette tapes (DAT) that were transferred to audiocassette tapes using a Sony Digital Recorder and a Marantz cassette player. Tapes were then analyzed on the Gateway 486 with the *RTS* program.

Stirling's audiocassette tapes were played on a Marantz cassette player connected to a Compac Presario computer and displayed as real time spectrograms, using both *Audioscope* and *Signal* programs. Underwater recordings were analyzed using a Gateway 486 computer and *Signal* software with the real-time spectrogram program, *RTS*.

Audioscope spectrograms were transferred to the *Microsoft Paint* software program for printing. A call was determined by visually using the sonograms and audibly listening for the silence between the calls. Measurements were taken for each vocalization using a cursor while paused as a spectrogram (frequency in kHz on the Y-axis and time in secs on the X-axis). Some sounds were made up of parts separated by time. Each part was called a component (Figure 2).

The dominant or darkest part of the sound, indicating the highest amplitude portion of the call, was used to measure frequency variables (beginning frequency, ending frequency, maximum frequency, minimum frequency, first harmonic interval, and first sub-harmonic interval). Time variables were measured in seconds, which included total sound duration,



Measurements:
1 – beginning frequency
2 – ending frequency
3 – maximum frequency
4 – minimum frequency
5 – first harmonic interval
6 – first subharmonic interval
7 – total duration
8 – component duration
9 – interval to the next component
10 – ITI (inter-trough interval)
11 – IPI (inter-peak interval)
12 – number of components
13 – number of upsweeps
14 – number of downsweeps
15 – second peak maximum
16 – second peak harmonic interval
17 – second peak subharmonic interval
18 – call pair

Figure 2. Measurements taken on all Ross seal calls. Sonograms of (A) call C with associated attachments, (B) call S, (C) underwater call A3, and (D) call pair of call B and call N.

component duration, interval to the next component, ITI (inter-trough interval), and IPI (inter-peak interval). Calls were described further by the number of components, number of up-sweeps, and the number of down-sweeps.

Frequency measurements were measured in Hertz (Hz) at the dominant (darkest) part of each call. Beginning and ending frequency was taken at the start and end of the dark part and the maximum and minimum frequency was taken at the highest and lowest portion of the dark part. Harmonic and sub-harmonic intervals were measured by the number of Hz between the dominant portion and the first harmonic or between the dominant portion and the first sub-harmonic structure (Figure 2).

Time measurements were measured in seconds at the beginning and end of the dominant part of a component or the entire sound (if composed of more than one component). Total duration was taken by using the difference in the beginning and end time. The number of components in a call was counted and for each component the time from start to end was measured as component duration. The time interval between the end of one component and the start of the next component was documented as the component interval.

Other variables were added: inter-trough interval (ITI) was measured as the time interval between the two lowest frequency points in a component, inter-peak interval (IPI) was the time between the two highest frequency points in a component (Figure 2), second peak maximum frequency, second peak harmonic interval, second peak sub-harmonic interval, call pairs, and frequency and time measurements for associated attachments. The term "associated attachment"

will refer to calls that were attached to one another, but also could be heard alone as independent calls. Second peak measurements were taken on the second peak in the call Ss (Figure 2). Call pairs were vocalizations that commonly were associated and occurred together in the same computer screen (5-sec time frame), but separated by a time interval.

Statistical Analysis

All measurements taken on each spectrogram were stored as a database file in Microsoft *Excel*, with each record being a component of a sound. The complete *Excel* database file was imported into the statistical analysis program, *SYSTAT* Version 10.1. Statistical analyses performed were one-way analysis of variance (ANOVA) with Bonferroni adjustments, and Pearson's correlation analysis. Acoustic variables were tested for differences based on the seals' geography and gender, the year the recording was collected, and the collector's methods of recording. All statistical tests were performed at the alpha equals 0.05 level of significance.

RESULTS

Six different aerial vocalizations (Figures 3-8) were detected from Ross seals by Stirling and Ray, four of which were recorded by both collectors. Rogers did not record aerial sounds. Calls were arbitrarily given letter names (H, N, C, S, Q, and B). Table 2 shows the mean number of components and total duration for these aerial vocalizations. Mean total duration for all the aerial calls were between 0.2 and 2.4 secs. The call H, call N, and call C were documented by both Ray and Stirling and heard from both sexes of seals; the call S was heard from males by Stirling and from females by Ray.

Underwater calls (Figures 9–14) were documented by all three collectors. Table 3 shows the mean number of components and total duration for these six different underwater calls. They were arbitrarily given letter names (S, C, A1, A2, A3, and B). Only Rogers documented the call C; three calls were heard from all collectors: the call S, call A with 2 components, and the call B. Underwater calls had mean total durations between 0.3 and 3.6 sec and mean number of components between 1.0 and 3.3.

Mean total duration of the call H sound (Figure 3) was < 1 sec and usually consisted of one component. This sound was similar to an exhalation. The call N (Figure 4), another exhalation sounding call, had a mean total duration of < 1.5 sec and consisted mostly of one component. The call N was described by Ray during his recordings as being made "as he exhales the animal's tracheal area under the throat vibrates. I think he exhales through the mouth and inhales through the nostrils."

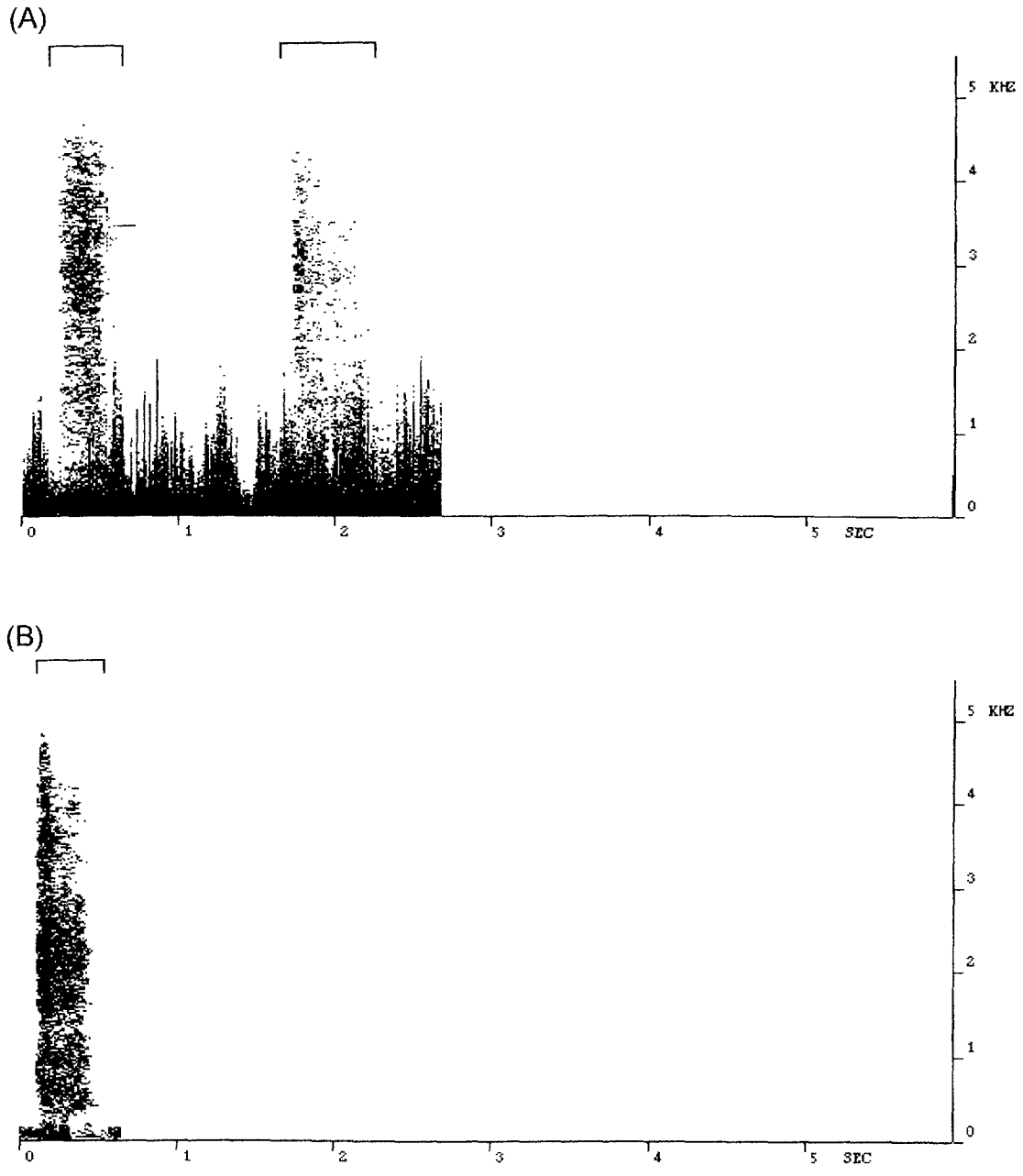


Figure 3. Sonogram of the Ross seal in-air call H as documented by (A) Stirling in 1999 and (B) Ray in 1966 from the Ross Sea.

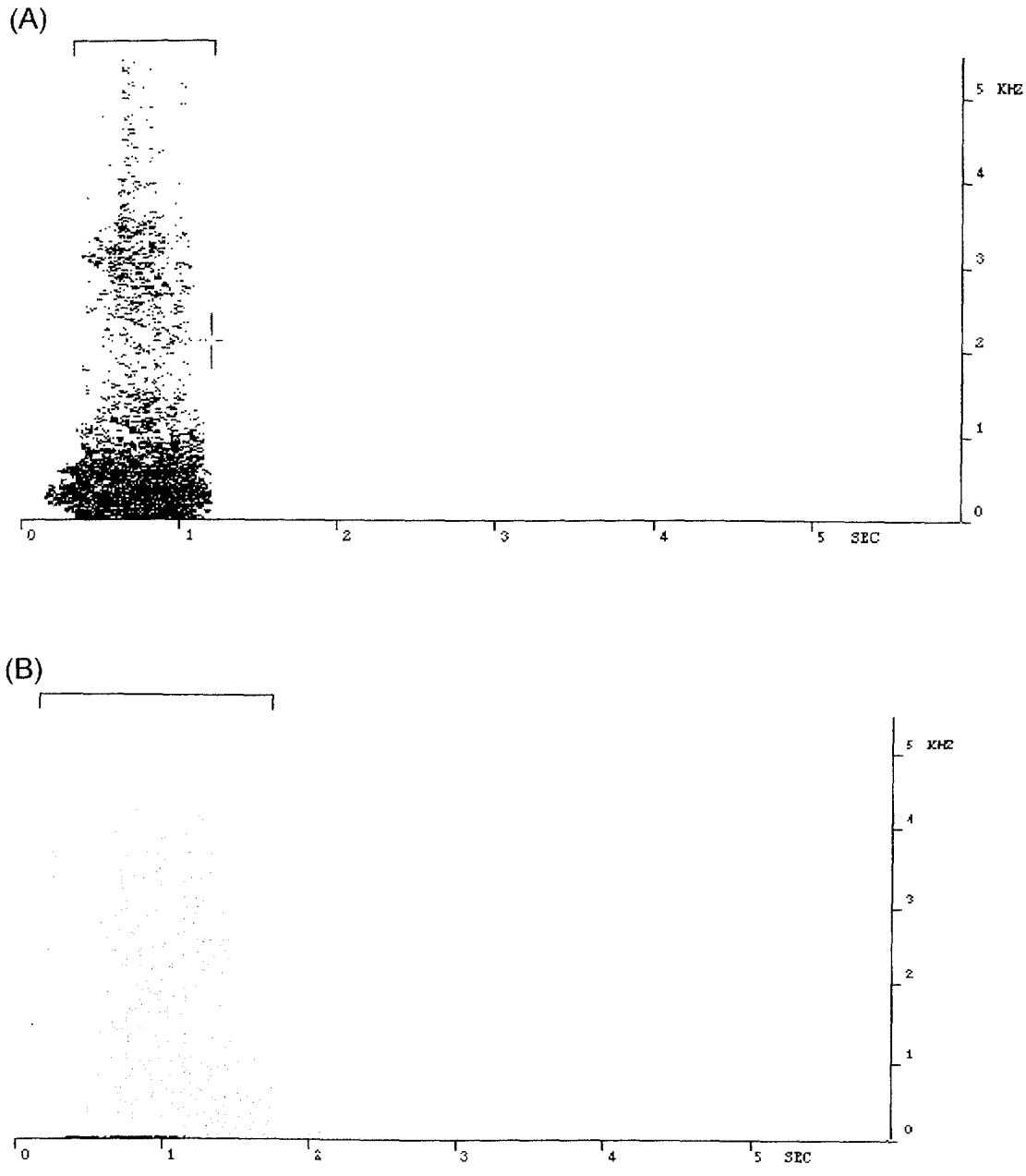


Figure 4. Sonogram of the Ross seal in-air call N as documented by (A) Stirling in 1999 and (B) Ray in 1966 from the Ross Sea.

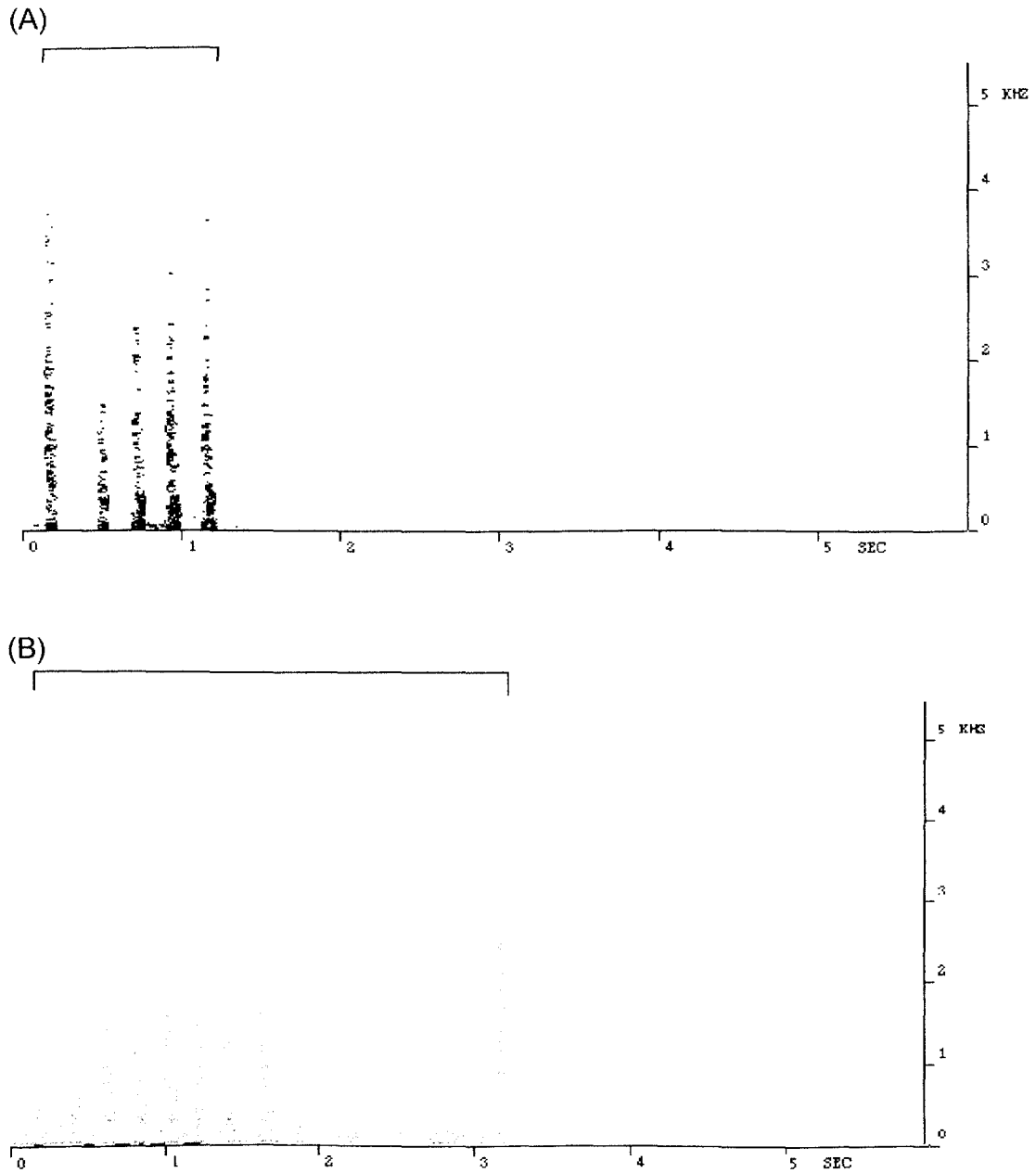


Figure 5. Sonogram of the Ross seal in-air call C as documented by (A) Stirling in 1999 and (B) Ray in 1966 from the Ross Sea.

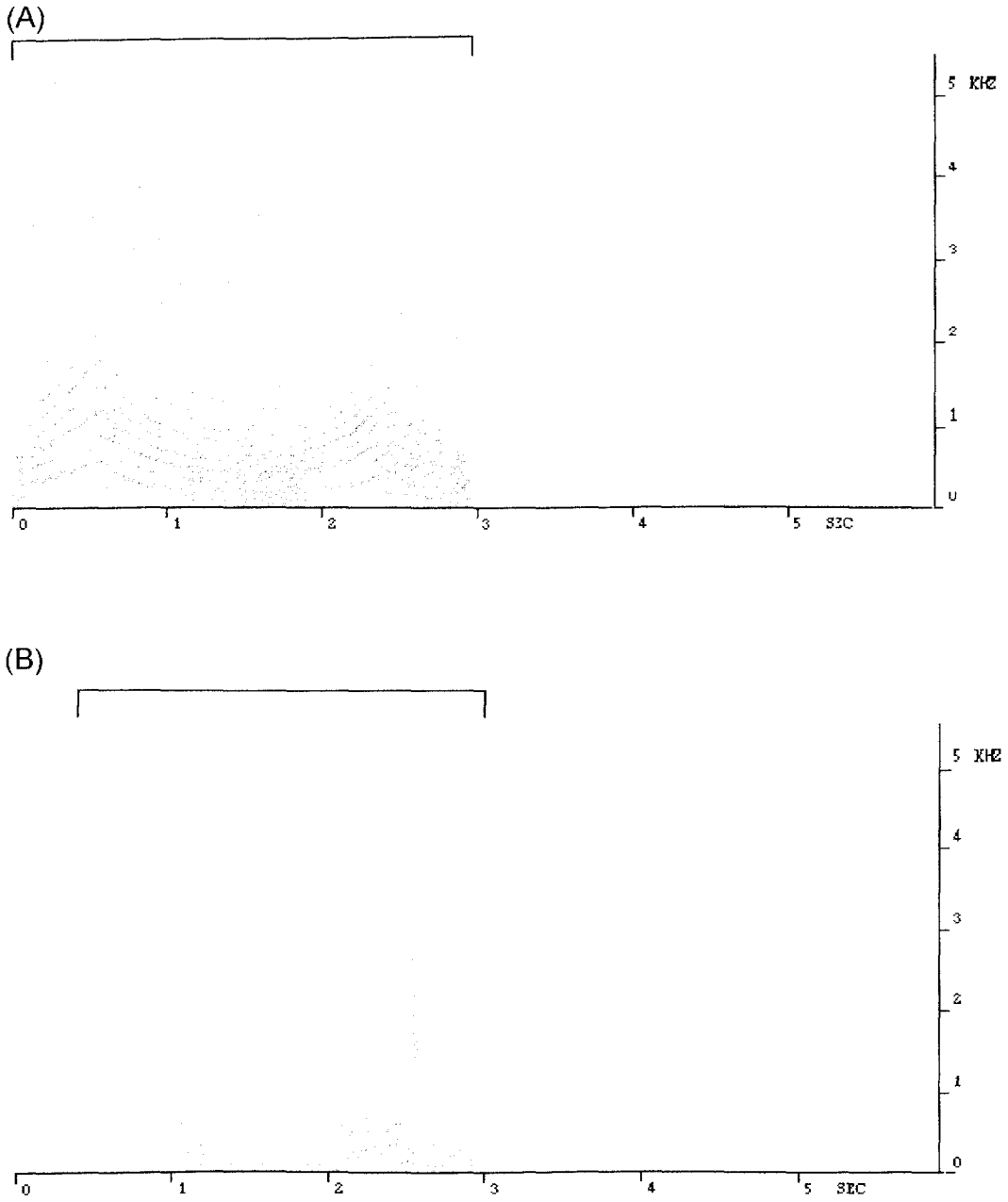


Figure 6. Sonogram of the Ross seal in-air call S as documented by (A) Stirling in 2000 and (B) Ray in 1966 from the Ross Sea. Stirling documented this call in males and Ray documented it in females.

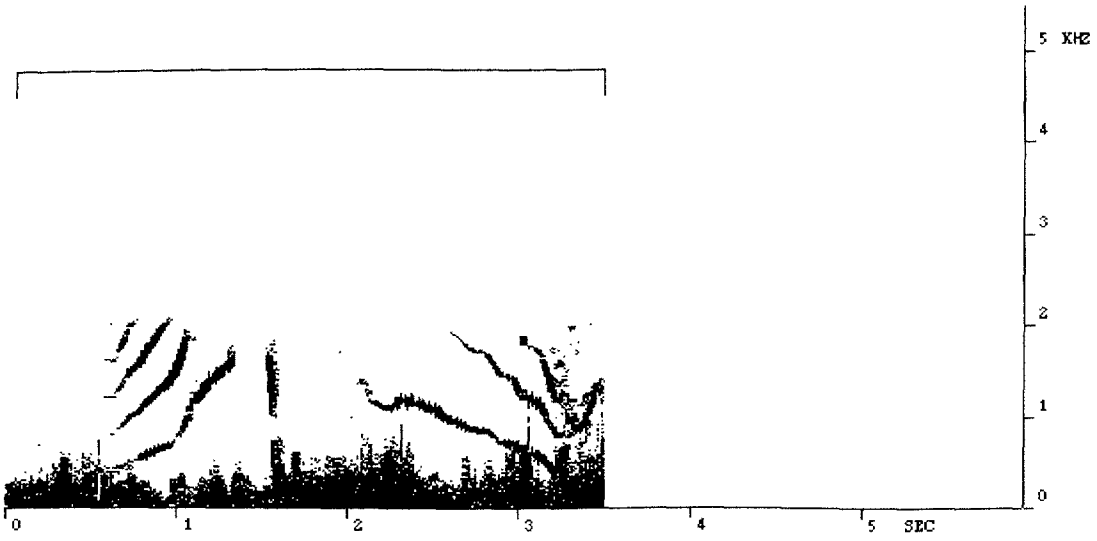


Figure 7. Sonogram of the in-air call Q as documented by Stirling in 1999 from the Ross Sea by a female Ross seal.

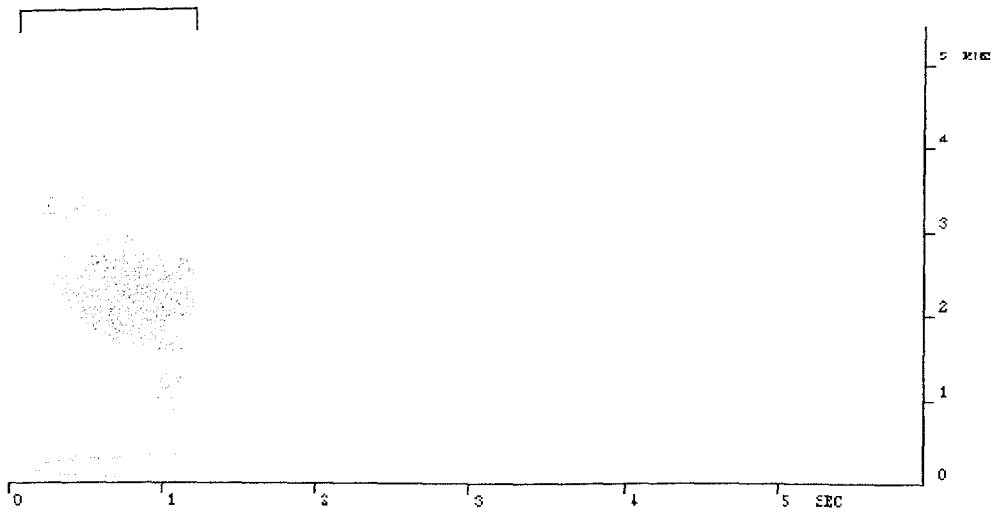


Figure 8. Sonogram of the Ross seal in-air call B as documented only by Ray in 1966 from the Ross Sea by a female Ross seal.

Table 2. Acoustic characteristics (mean, standard deviation, and sample size) of in-air vocalizations of Ross seals by collector in the Ross Sea.

Ross seal		Ray's Data 1966						Stirling's Data 1999-2000					
Sex	Call Type	Total Duration (sec)			Number of Components			Total Duration (sec)			Number of Components		
		mean	SD	n	mean	SD	n	mean	SD	n	mean	SD	n
Male													
	H	0.4	0.02	8	1.0	0	8	0.2	0	1	1.0	0	1
	N	1.3	0.02	5	1.0	0	5	0.8	0.17	31	1.0	0	31
	C	1.9	0.62	4	9.8	2.6	4	1.7	1.6	33	7.3	2	33
	S			none				2.4	0.91	12	1.0	0	12
Female													
	H	0.5	0.19	10	1.1	0.3	10	0.8	0.91	4	1.2	0.5	4
	N	0.5	0.17	21	1.0	0	21	1.1	0.15	13	1.1	0.3	13
	C	1.7	1.98	23	6.8	2.7	23	0.8	0.71	16	4.7	3.4	16
	S	2.2	0.35	15	1.1	0.3	15			none			
	B	1.0	0.04	2	1.0	0	2			none			
	Q			none				1.6	1.61	2	1.5	0.7	2

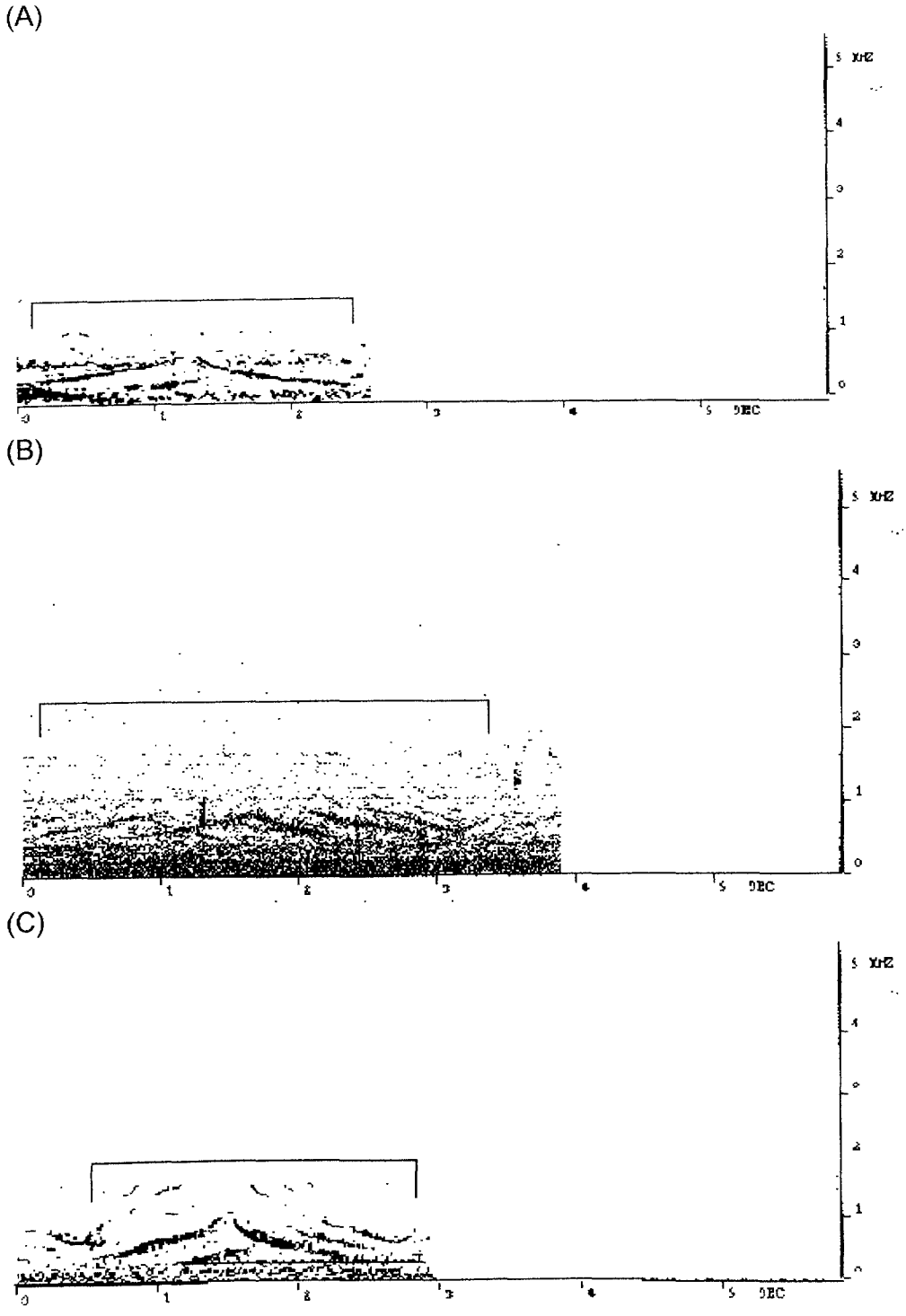


Figure 9. Sonograms of the Ross seal underwater call S as documented by (A) Stirling in 2000 and (B) Ray in 1966 from the Ross Sea and from (C) Rogers in 1997 in the Davis Sea.

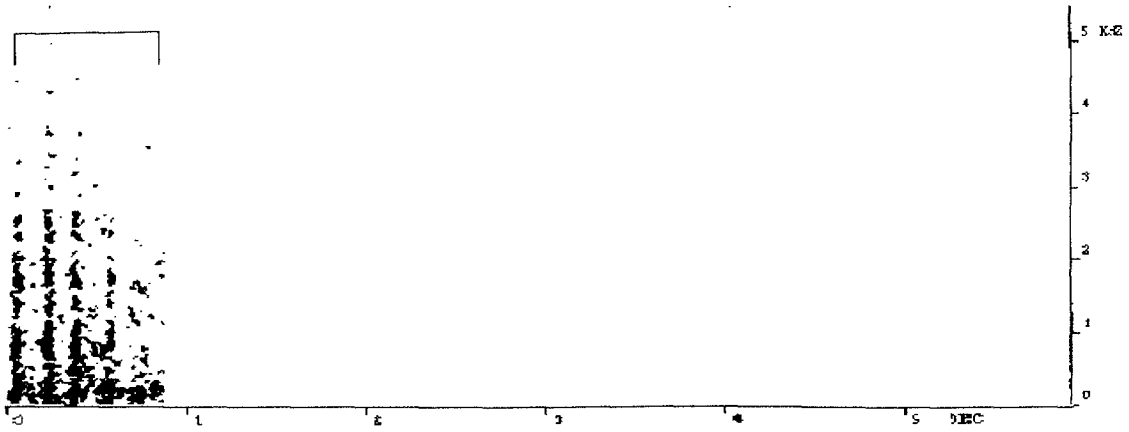
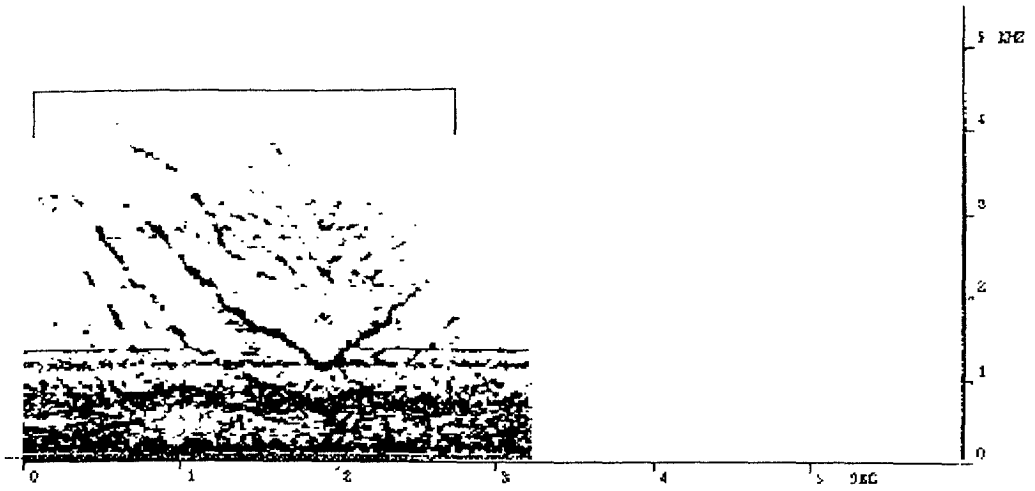


Figure 10. Sonogram of the Ross seal underwater call C documented only by Rogers in 1997 from the Davis Sea.

(A)



(B)

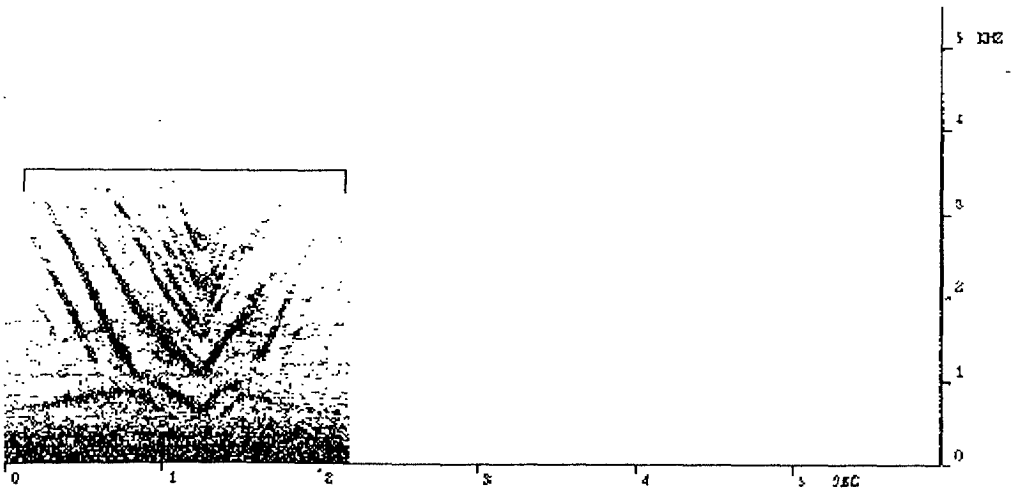


Figure 11. Sonogram of the Ross seal underwater call A1 documented by (A) Stirling in 2000 and (B) Ray in 1966 from the Ross Sea.

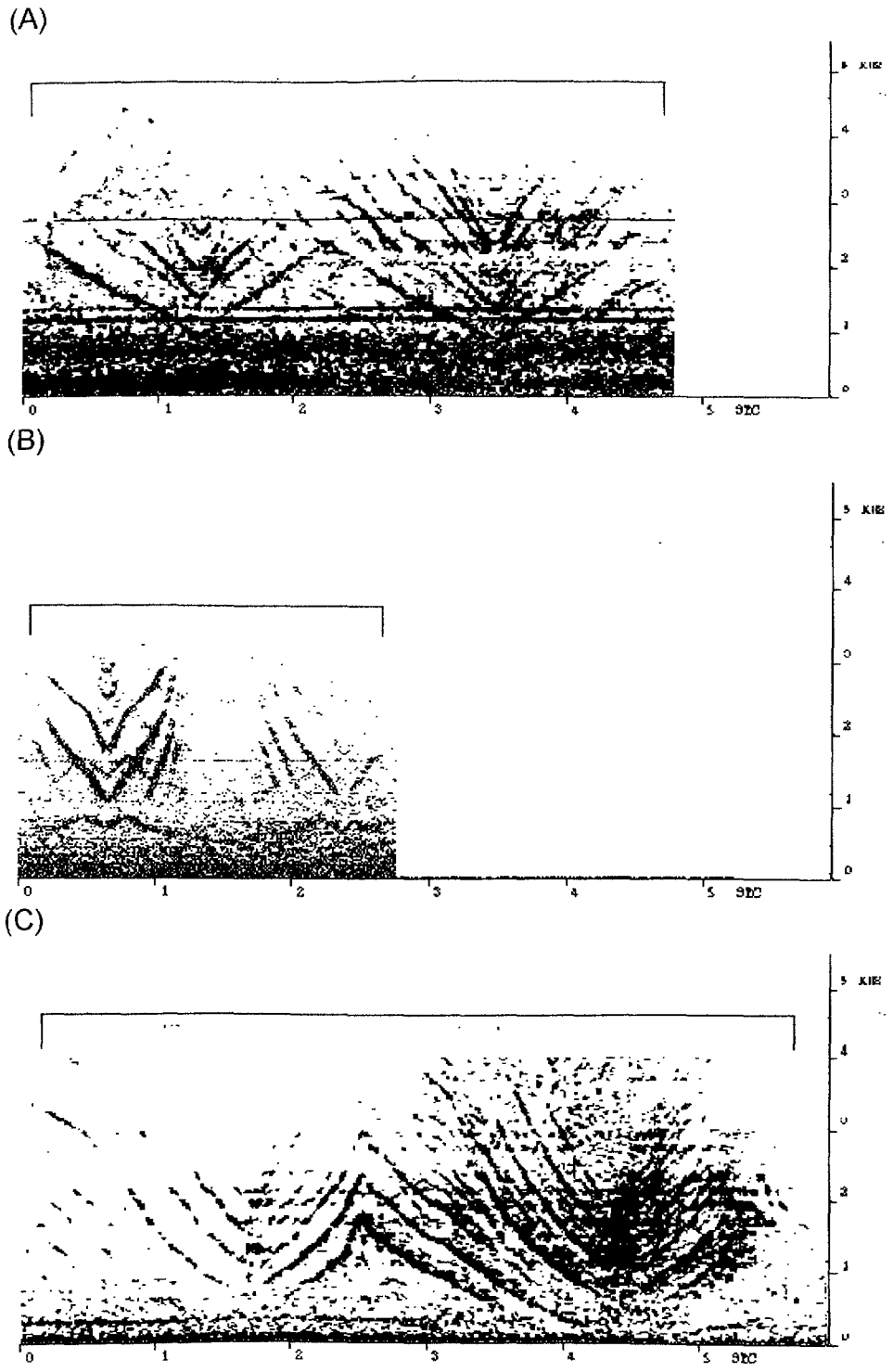
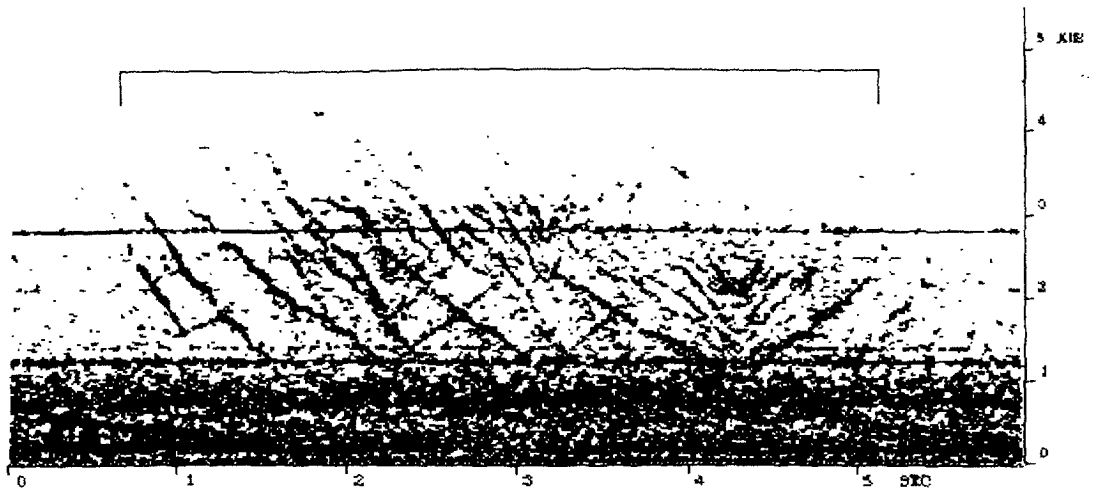


Figure 12. Sonogram of the Ross seal underwater call A2 documented by (A) Stirling in 2000, (B) Ray in 1966 from the Ross Sea, and (C) Rogers in 1997 from the Davis Sea.

(A)



(B)

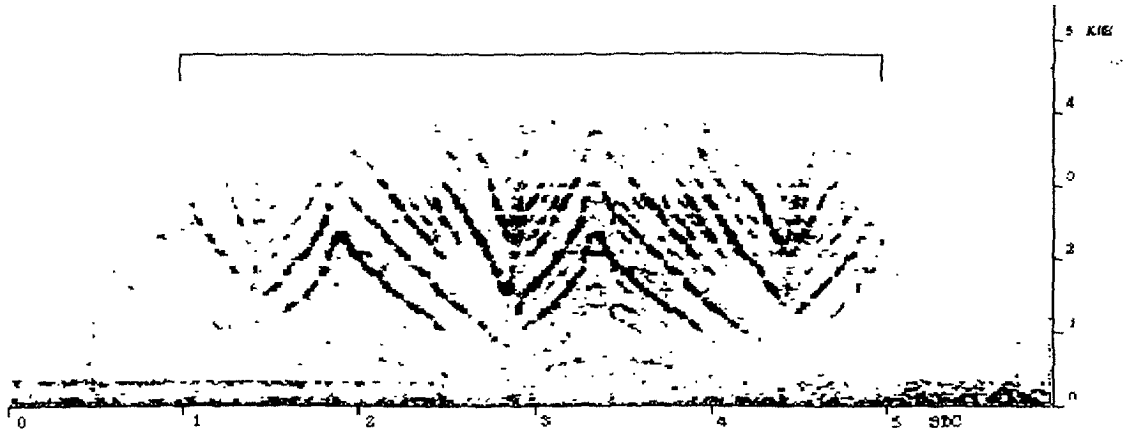


Figure 13. Sonogram of the Ross seal underwater call A3 documented by (A) Stirling in 2000 from the Ross Sea and (B) Rogers in 1997 from the Davis Sea.

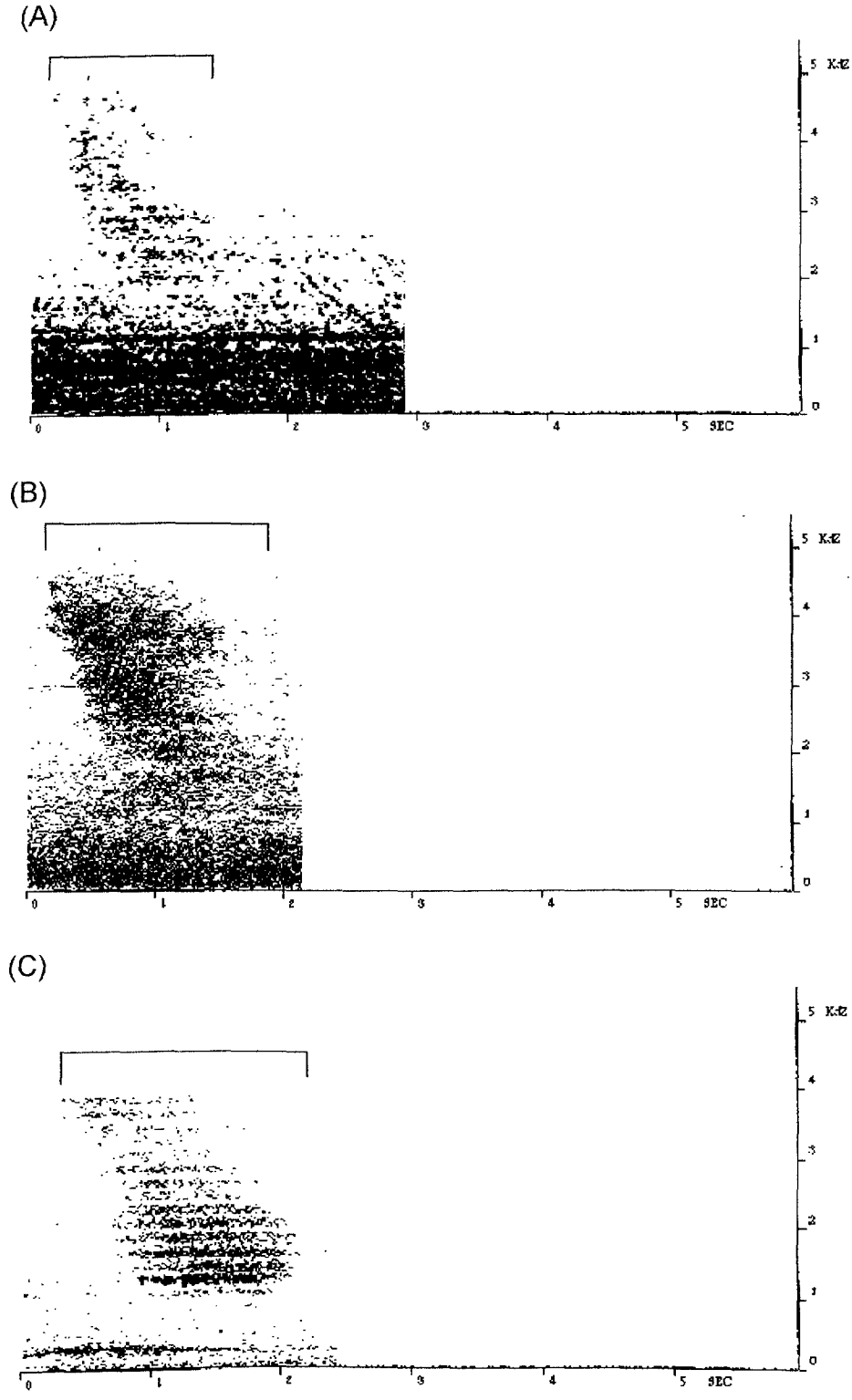


Figure 14. Sonogram of the Ross seal underwater call B documented by (A) Stirling in 2000, (B) Ray in 1966 from the Ross Sea, and (C) Rogers in 1997 from the Davis Sea.

Table 3. Acoustic characteristics (mean, standard deviation, and sample size) of underwater calls from Ross seals by three collectors; data on gender of seal not available.

Call	Ray's Data 1966 Ross Sea						Stirling's Data 1999-2000 Ross Sea						Roger's Data 1997 Davis Station					
Type	Total Duration (sec)			Number of Components			Total Duration (sec)			Number of Components			Total Duration (sec)			Number of Components		
	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD	n	mean	SD	n
S	2.1	0.73	20	1.2	0.41	20	2.3	0.62	21	1.1	0.3	21	1.8	0.4	10	1.0	0	10
C			none						none				0.3	0.15	3	3.3	1.15	3
A1	1.5	0.4	23	1.0	0	23	1.5	0.25	20	1.0	0	20			none			
A2	3.5	0.75	20	2.0	0	20	3.2	0.74	21	2.0	0	21	3.2	0.33	9	2.0	0	9
A3			none				3.6	0.65	19	3.0	0	19	3.0	0.13	20	3.0	0	20
B	1.3	0.3	9	1.0	0	9	1.2	0.46	12	1.1	0.3	12	1.1	0.2	4	1.0	0	4

The call C vocalization (Figure 5) had a mean total duration between 0.8 to 1.9 sec. This call had the largest number of components in the Ross seal repertoire, averaging between 4.7 and 9.8 components. Table 4 shows the component duration, interval to the next component, and number of components. Call C was documented by all three collectors: Ray and Stirling in air and only by Rogers under water. This was the most common of all the in-air calls. Mean component duration of all aerial call C for males and females from both Ray and Stirling data was 0.1 sec. The aerial call C had a mean interval to the next component between 0.1 and 0.2 sec. There were only five incidences of underwater call C (Figure 10) documented by Rogers. The underwater call C had a mean component duration of 0.4 sec and had a mean interval to the next component of 0.1 sec. Stirling documented two different call C vocalizations from a male seal that had associated prefix attachments (Figure 15). In this case, the call Q was the prefix to the call C. Table 5 lists the mean frequency, mean duration, and mean number of sweeps for the associated prefix attachments. The first call C had a series of four components with the last two having associated prefix attachments. Frequencies for these two prefixes ranged between 3144 and 4888 Hz and had total durations of 0.2 and 0.3 sec. Both were characterized by one down-sweep.

The second call C documented had a series of seven components with only the first component not having a prefix. The first six prefixes ranged from 1443 to 4737 Hz, with total durations of 0.2 or 0.3 sec. All were characterized by one down-sweep, except for the fifth component, which had one down-sweep

Table 4. Acoustic characteristics (mean, standard deviation, and sample size) for number of components, component duration, and interval to next component of the Ross seal call C by collector.

Collector/Date/Location	Medium	Seal Sex	Component Duration (sec)			Interval to Next Component (sec)			Number of Components		
			mean	SD	n	mean	SD	n	mean	SD	n
Ray											
January 1966	air	male	0.1	0.01	39	0.1	0.01	35	9.7	2.6	4
Ross Sea	air	female	0.1	0.01	153	0.2	0.26	133	6.8	2.7	23
	air	both	0.1	0.01	192	0.2	0.23	168	7.2	1.8	27
Stirling											
December 1999/January 2000	air	male	0.1	0.01	240	0.2	0.29	207	7.3	2.0	33
Ross Sea	air	female	0.1	0.01	64	0.1	0.03	55	4.7	3.4	16
	air	both	0.1	0.26	304	0.2	0.26	262	6.4	2.8	49
Rogers											
December 1997 Davis Station	water	unknown	0.04	0.00	5	0.1	0.02	3	3.3	1.2	3

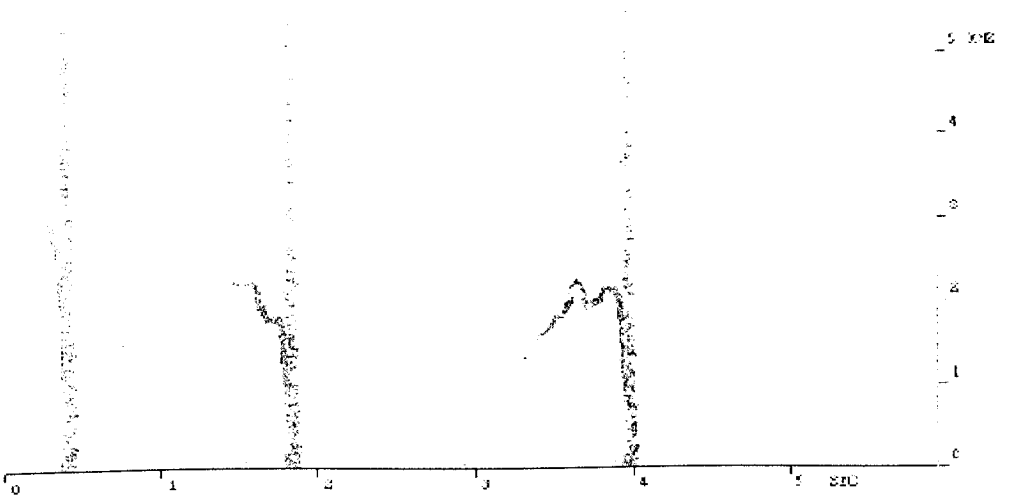


Figure 15. Sonogram of the associated attachment on the in-air call C as documented by Stirling in 2000 in the Ross Sea by a male Ross seal.

Table 5. Acoustic characteristics (mean frequency, mean duration, mean number of sweeps, and mean interval to the first harmonic) of prefix attachments on two call C vocalizations from a male Ross seal as documented by Stirling in 2000 in the Ross Sea.

Component No.	Prefix	Mean Frequencies (Hz)				Mean Duration (sec)	Mean No.of Sweeps		Mean Interval to First Harmonics (Hz)
		Beginning	Ending	Maximum	Minimum		Up	Down	
1	no	-	-	-	-	-	-	-	-
2	no	-	-	-	-	-	-	-	-
3	yes	4888	4221	4888	4221	0.2	0.0	1.0	none
4	yes	4027	3144	4027	3144	0.3	0.0	1.0	none
1	no	-	-	-	-	-	-	-	-
2	yes	3273	2347	3273	2347	0.2	0.0	1.0	none
3	yes	2584	1443	2584	1443	0.2	0.0	1.0	none
4	yes	4737	3273	4737	3273	0.3	0.0	1.0	none
5	yes	3833	2885	3833	2885	0.2	1.0	1.0	none
6	yes	2261	1830	2261	1830	0.3	0.0	1.0	2661
7	yes	689	2024	2239	689	0.8	2.0	2.0	1034

and one up-sweep. The last prefix had a much lower frequency range of 689 to 2239 Hz, with a longer total duration of 0.8 sec. This prefix was characterized by having two down-sweeps and two up-sweeps. The last two prefixes in this series had sub-harmonics with an interval to the first sub-harmonic being 2661 and 1034 Hz. This was the only call that was documented in the Ross seal repertoire having associated attachments.

The aerial call S (Figure 6) was documented by Stirling as only given by males and in Ray's recordings was only given by females. Mean total duration for females was 2.2 sec and for males 2.4 sec (Table 2). This vocalization mainly had only one component. Ray (1981) described this siren call and pulses as being "heard emanating from the throat and pharynx, accompanied by considerable enlargement and pulsations of the airways, but apparently without escaping air." All collectors documented this call under water (Figure 9). Referring back to Table 3, mean total duration for the underwater call S ranged between 1.8 and 2.3 sec, with a mean number of components between 1.0 and 1.2. Table 6 lists the mean frequency and time characteristics of the call S, both in air and under water by collector. Mean frequencies for the first component ranged between 131 to 798 Hz and 108 to 898 Hz for the second component. Some call S vocalizations had a second peak and were only seen in the first component. Mean maximum sec peak frequencies ranged between 361 and 693 Hz. Harmonic and sub-harmonic structures were seen in both the air and underwater call S. Mean harmonic intervals were between 301 and 825 Hz, with mean sub-harmonic interval between 244 and 522 Hz. Sub-harmonic structures

Table 6. Acoustic characteristics (mean, standard deviation, sample size) of the in-air and underwater call S from Ross seals by collector.

Collector, Year, & Location	Sex	Medium	Component Number		Beginning Frequency (Hz)	Ending Frequency (Hz)	Maximum Frequency (Hz)	Minimum Frequency (Hz)	Second Peak Maximum (Hz)	Interval to First Harmonic (Hz)	Interval to First Subharmonic (Hz)	Second Peak Interval to First Harmonic (Hz)	Second Peak Interval to First Subharmonic (Hz)	Inter-peak Interval (sec)
Stirling	male	air	1	mean	260	206	440	190	378	307	244	218	242	-
1999-2000				SD	126.7	75.4	148.2	68.6	124.3	66.2	98.9	19.9	20.5	-
Ross Sea				n	12	12	12	12	9	11	6	9	4	0
Ray	female	air	1	mean	189	195	429	131	449	301	258	308	388	1.4
1966				SD	56.1	121.8	98.4	36.7	131.6	91.5	91.2	135.6	-	0.22
Ross Sea				n	15	15	15	15	12	7	10	2	1	14
			2	mean	108	172	431	108	-	366	-	-	-	-
				SD	-	-	-	-	-	-	-	-	-	-
				n	1	1	1	1	0	1	0	0	0	0
Stirling	unknown	water	1	mean	394	400	798	332	578	615	449	620	-	1.4
1999-2000				SD	139.4	132.1	179.9	103.9	296.3	280		257.5	-	0.48
Ross Sea				n	21	21	21	21	5	4	1	4	0	7
			2	mean	605	547	898	547	-	-	-	-	-	-
				SD	0	55.2	55.9	55.2	-	-	-	-	-	-
				n	2	2	2	2	0	0	0	0	0	0

Table 6. Continued

Ray unknown	water	1	mean	461	352	713	350	361	825	-	-	-	1.4
1966			SD	184.7	127.4	211.4	130.4	10.5	32.6	-	-	-	0.76
Ross Sea			n	20	20	20	20	4	3	0	0	0	8
		2	mean	554	495	834	495	0	388	-	-	-	-
			SD	26.9	39.3	11	39.3	-	-	-	-	-	-
			n	4	4	4	4	-	1	0	0	0	0
Rogers unknown	water	1	mean	203	295	773	195	693	325	522	-	-	1.3
1997			SD	48.6	110	189.4	43.7	137.8	164	7.1	-	-	0.14
Davis			n	10	10	10	10	4	4	2	0	0	4
Station													

were not seen on the second component. Harmonic and sub-harmonic structures also were seen on the first component's second peak. Stirling and Ray both documented this in air and only Stirling documented harmonics under water. Mean second peak harmonic intervals were between 218 and 620 Hz and mean sub-harmonic intervals ranged between 242 and 388 Hz. Time characteristics were described by the inter-peak interval (IPI), and were measured in seconds between the first and second peaks; mean IPI was 1.4 sec.

The call Q (Figure 7) was documented only in females and only by Stirling. The sample size for the call Q was small, with only two documented calls. The first call had two components and the second call had one component. The mean total duration for the call Q was 1.6 sec, with the mean number of components being 1.5 components (Table 2). Frequency characteristics are listed in Table 7, with mean frequencies ranging between 409 and 1809 Hz. Harmonic structures were seen in both components and were 366 and 517 Hz.

The aerial call B (Figure 8) had a mean total duration of 1.0 sec, with the mean number of components being 1.0 (Table 2). The sample size was small; only two cases were heard and both were documented by Ray. All three collectors documented the call B under water (Figure 14). Mean total duration (Table 3) was between 1.1 and 1.3 sec and had a mean number of components of 1.0 in both Rays and Rogers' data. Stirling's call B had a mean number of components of 1.1. Table 8 shows mean maximum frequency for the in-air and underwater call B and showed the frequency range of 2148 and 2796 Hz.

Table 7. Frequency characteristics of the in-air call Q exhibited by a female Ross seal as documented by Stirling in 1999 in the Ross Sea.

Call	Component No.	Mean Frequency (Hz) Beginning	Ending	Maximum	Minimum	Mean Inverval to First Harmonic (Hz)
Q1	1	409	1809	1809	409	none
	2	1400	668	1400	388	366
Q2	1	732	689	732	538	517

Table 8. Maximum frequency (mean, standard deviation, and sample size) of the in-air and underwater call B of Ross seals by collector.

Collector	Year	Location	Medium	Component No.	Maximum Frequency (Hz)		
					Mean	n	SD
Rogers	1997	Davis Station	water	1	2296	4	279.8
Ray	1966	Ross Sea	water	1	2515	9	492.5
Stirling	1999-2000	Ross Sea	water	1	2796	12	375
				2	2148	1	-
Ray	1966	Ross Sea	air	1	2239	2	487.2

Call A (Figures 11 – 13) had between 1 and 3 components. All collectors recorded call A with two components (A2), with two collectors recorded call A with one component (A1) and call A with three components (A3). This call was unique from the other Ross seal vocalizations in that its components overlapped. Table 9 shows the mean frequency variables (beginning, ending, maximum, minimum, and interval to the first harmonics), time (duration and ITI) variables, and the number of sweeps in each component for each call.

Call A with one component (Figure 11) was documented by both Ray and Stirling. Its mean total duration (Table 3) was 1.5 sec for both collectors; frequency (Table 9) ranged from 977 to 3291 Hz. Mean characteristic number of sweeps for Ray's data were 1.2 up-sweeps and 1.1 down-sweeps and for Stirling's data were 1.0 in both cases. Mean interval to the first harmonics ranged between 500 and 620 Hz; mean interval sub-harmonic was between 443 and 615 Hz.

Call A with two components (Figure 12) was documented by all collectors. Mean total duration (Table 3) was 3.2 sec for both Stirling and Rogers' data and 3.5 sec for Ray's data. The mean frequencies (Table 9) for call A with 2 components ranged between 613 and 3015 Hz for the first component and 903 and 3181 Hz for the second component. Mean component duration for both components for both Ray and Stirling was 1.4 or 1.5 sec; Rogers' mean component duration for the first component was 2.4 sec and for the second was 1.38 sec. Mean characteristics for sweeps were between 1.0 and 1.2 for up-sweeps and 1 and 1.9 for down-sweeps. Harmonics and sub-harmonics were

Table 9. Acoustic characteristics (mean, standard deviation, and sample size) of Ross seals underwater Call A with one, two, and three components by collector.

Collector & Year	Call Type	Component Number	Frequency (Hz)				Mean Duration (sec)	Mean Number of Sweeps		Mean Interval to First (Hz)		Mean ITI (sec)
			Beginning	Ending	Maximum	Minimum		Up	Down	Harmonics	Subharmonics	
Ray	A1	1 mean	3112	2924	3291	1364	1.5	1.2	1.1	620	615	-
1966		SD	812.2	488.6	494.0	432.1	0.4	0.4	0.3	178.3	154.5	-
		n	23	23	23	23	23	23	23	23	18	0
Stirling	A1	1 mean	2601	2153	2739	977	1.5	1	1	500	443	-
1999-00		SD	622.3	459.0	480.7	140.8	0.3	0.2	0.0	108.2	73.7	-
		n	20	20	20	20	20	20	20	20	13	0
Ray	A2	1 mean	2521	2682	2895	1081	1.5	1.2	1.1	617	587	2.1
1966		SD	702.7	644.8	521.3	402.0	0.4	0.4	0.3	74.0	150.5	0.67
		n	20	20	20	20	20	20	20	20	4	20
		2 mean	2974	2644	3037	1023	1.4	1.1	1.1	615	426	-
		SD	339.4	580.1	336.1	175.1	0.4	0.3	0.3	106.7	216.0	-
		n	20	20	20	20	20	20	20	20	5	0
Stirling	A2	1 mean	2396	2133	2641	983	1.4	1	1.1	605	426	1.8
1999-00		SD	429.6	639.5	461.9	159.7	0.4	0.2	0.3	149.5	80.0	0.68
		n	21	21	21	21	21	21	21	19	10	21
		2 mean	2196	2054	2407	903	1.4	1	1	617	443	-
		SD	579.1	443.1	539.8	218.7	0.3	0.2	0.0	206.1	31.8	-
		n	21	21	21	21	21	21	21	21	6	0
Rogers	A2	1 mean	2408	613	3015	613	2.4	1	1.9	562	596	2.1
1997		SD	422.9	123.0	103.3	123.0	0.3	0.0	0.3	160.4	94.1	0.06
		n	9	9	9	9	9	9	9	9	9	9
		2 mean	3181	2483	3181	1102	1.38	1	1	452	269	-
		SD	326.8	335.9	326.8	129.7	0.1	0.0	0.0	71.6	148.1	-
		n	9	9	9	9	9	9	9	9	8	0

Table 9. Continued

Stirling	A3	1 mean	2356	2254	2509	1062	1.3	1	1	608	433	1.1
1999-00		SD	455.7	408.7	391.9	239.2	0.2	0.2	0.0	195.0	100.8	0.5
		n	19	19	19	19	19	19	19	17	11	19
		2 mean	2212	2001	2343	987	1.2	1	1	614	393	1.1
		SD	374.0	390.6	361.8	118.9	0.3	0.0	0.0	289.6	92.6	0.58
		n	19	19	19	19	19	19	19	15	8	19
		3 mean	2317	2081	2443	959	1.4	1	1	612	449	-
		SD	473.7	367.7	431.0	156.8	0.2	0.2	0.0	128.3	191.6	-
		n	19	19	19	19	19	19	19	18	12	0
Rogers	A3	1 mean	2765	952	3152	952	1.3	1	1.9	563	617	1.1
1997		SD	306.4	137.8	58.0	137.8	0.1	0.0	0.2	187.4	147.2	0.03
		n	20	20	20	20	20	20	20	20	20	20
		2 mean	3192	960	3225	960	1.4	1	2	694	580	1.2
		SD	156.6	86.0	138.2	85.1	0.1	0.0	0.0	166.4	184.9	0.03
		n	20	20	20	20	20	20	20	20	20	20
		3 mean	3251	2599	3258	1271	0.8	1	1	819	234	-
		SD	396.4	320.0	388.3	30.7	0.1	0.0	0.2	95.2	170.6	-
		n	20	20	20	20	20	20	20	20	15	0

observed for both components by all collectors. Mean intervals for the first harmonic ranged from 452 to 617 Hz and for the first sub-harmonic from 269 to 596 Hz. Mean inter-trough interval (ITI) mean was the same for Ray and Rogers' data at 2.1 sec and 1.8 sec for Stirling's data.

Call A with three components (Figure 13) was documented by Stirling and Rogers and had mean total durations (Table 3) of 3.6 and 3.0 sec, respectively. Mean frequencies (Table 9) ranged from 952 to 3258 Hz. Mean component durations were 1.3 sec for the first component from both collectors, 1.2 and 1.4 sec for the second component and 1.4 and 0.8 for the third component for Stirling and Rogers, respectively. Mean number of up-sweeps for both collectors for all three components was 1.0. All three components from Stirling's data had a mean of 1.0 down-sweeps. Mean number of down-sweeps for Roger's data was 1.9 for the first, 2.0 for the second, and 1.0 for the third component. Mean interval to the first harmonics from both collectors ranged from 563 and 819 Hz and to the first sub-harmonic ranged from 234 to 617 Hz. Inter-trough interval means were 1.1 sec for the first component for both collectors, 1.1 sec for the second component from Stirling, and 1.2 sec for Rogers' data.

Some calls often were heard in the company of another. These call pairs (Table 10) were most common in the aerial vocalizations and occurred within 2 sec of each other. Most prevalent (n=51) was the call pair of call C and call N. Call N also was paired with call B and with call S. Call C was paired with the call H, call B, and with a call S and call N. This last combination (call C, call S, call N) was heard only once.

Table 10. Total number of calls heard within 2 seconds of each other as collected by Ray in 1966 (Ross Sea), Rogers in 1997 (near Davis Station), and Stirling in 1999 and 2000 (Ross Sea), Antarctica.

	C	B	S
N	51	1	4
H	1	-	-
S&N	1	-	-
B	1	-	-

The underwater call S had a significant difference (Table 11) in minimum frequency ($F_{2,183} = 7.278$, $p = 0.001$). Rogers' data (or the Davis Station underwater call S) was significantly lower in frequency than data from the other two collectors in the Ross Sea.

The call A with two components had many characteristics with significant geographic differences. The Davis Station call had significant differences in component 1 minimum frequency ($F_{2,47} = 8.801$, with Bonferroni adjusted p-values between Rogers and Stirling of $p = 0.006$ and between Rogers and Ray of $p = 0.000$), and in the number of down-sweeps (analysis of variance $F_{2,47} = 24.143$ and Bonferroni adjusted $p = 0.000$). The minimum frequency was lower in the Davis Station location; this was due to the additional down-sweep causing the lower minimum frequency.

Call A with two components also had a significant difference ($F_{2,47} = 4.198$ with Bonferroni adjusted p-values between Rogers and Stirling of $p = 0.029$ andcomparing Rogers and Ray data of $p = 0.034$) in the second component. The Davis Station call had a lower harmonic interval than both data from the Ross Sea location.

The call A with three components had many significant differences in all of its components and in its total duration. Component 1 had significant differences in beginning frequency $F_{1,37} = 10.917$, $p = 0.002$; ending frequency $F_{1,37} = 181.480$, $p = 0.000$; maximum frequency $F_{1,37} = 52.611$, $p = .000$); number of down-sweeps ($F_{1,29} = 195.516$, $p = 0.000$); sub-harmonic interval ($F_{1,29} = 13.606$, $p = 0.001$); and inter-trough interval ($F_{1,29} = 6.172$, $p = 0.019$). The Davis Station

Table 11. Significant differences in acoustic characteristics of the Ross seal vocal repertoire by collector.

Medium	Call Type	Variable	Significant Difference by Collector		
			Ray Ross Sea (1966)	Stirling Ross Sea (1999-2000)	Rogers Davis Station (1997)
air	N	total duration	males are longer than Stirling	females are longer than Ray	no air data
	C	total duration	both sexes are longer than Stirling		no air data
		number of components	males have larger number than females	males have larger number than females	no air data
			both males and females have larger number than Stirling		no air data
		component duration	longer than Stirling		no air data
			males are longer than females	males are longer than females	no air data
	S	total duration		longer than Ray	no air data
		beginning frequency		higher than Ray	no air data
		minimum frequency		higher than Ray	no air data
		second peak harmonic interval		larger than Ray	no air data
underwater	S	minimum frequency			lower than both
		ending frequency	lower than Stirling but higher than Rogers	highest	lowest
	A1	beginning, ending, maximum, minimum frequencies	higher than Stirling		no A1 data
		harmonic interval	larger than Stirling		no A1 data
		subharmonic interval	larger than Stirling		no A1 data
	A2 component 1	downsweeps			larger number than both
		subharmonic interval		smaller than both	
		minimum frequency		lower than Ray	lower than Stirling
		ending frequency	higher than Stirling	higher than Rogers	
	A2 component 2	beginning frequency		Stirling was lower than both	

Table 11. Continued

	ending frequency	higher than Stirling		
	maximum frequency		lower than both	
	minimum frequency			higher than Stirling
	harmonic interval			smaller than both
A3 component 1	beginning frequency	no A3 data		higher than Stirling
	ending frequency	no A3 data	higher than Rogers	
	maximum frequency	no A3 data		higher than Stirling
	downsweeps	no A3 data		larger number than Stirling
	subharmonic interval	no A3 data		larger than Stirling
	inter-trough interval	no A3 data	smaller than Rogers	
	total duration	no A3 data	longer than Rogers	
A3 component 2	beginning frequency	no A3 data		higher than Stirling
	ending frequency	no A3 data	higher than Rogers	
	maximum frequency	no A3 data		higher than Stirling
	subharmonic interval	no A3 data		larger than Stirling
A3 component 3	beginning, ending, maximum, minimum frequencies	no A3 data		higher than Stirling
	harmonic interval	no A3 data		larger than Stirling
	subharmonic interval	no A3 data	larger than Rogers	

location had calls with significantly longer total duration and higher beginning and maximum frequency, sub-harmonic interval, number of down-sweeps, and ITI than Stirling's data from the Ross Sea. Opposite of this pattern was the characteristic of ending frequency in which the Ross Sea location was significantly higher than the Davis Station location.

Component 2 of call A with three components had significant differences in beginning frequency $F_{1,37} = 116.022$, $p = 0.000$; ending frequency $F_{1,37} = 135.616$, $p = 0.000$; maximum frequency $F_{1,37} = 103.305$, $p = 0.000$; and in sub-harmonic interval $F_{1,26} = 7.290$, $p = 0.012$. The Davis Station location had calls with significantly higher beginning frequency, maximum frequency, and sub-harmonic interval. The Ross Sea location call A had a significantly higher ending frequency similar to the first component.

The third component of call A with three components had significant differences in all frequency characteristics (beginning frequency $F_{1,37} = 44.743$, $p = 0.000$; ending frequency $F_{1,37} = 22.035$, $p = 0.000$; maximum frequency $F_{1,37} = 38.566$, $p = 0.000$; and minimum frequency $F_{1,37} = 76.386$, $p = 0.000$). There were also significant differences in both harmonic interval ($F_{1,36} = 32.455$, $p = 0.000$) and sub-harmonic interval ($F_{1,25} = 9.522$, $p = 0.005$). The Davis Station calls had significantly higher frequencies (beginning, ending, maximum, and minimum) and a larger harmonic interval, whereas the Ross Sea calls had a significantly larger sub-harmonic interval.

DISCUSSION

Significant variation in call characteristics could indicate differences in the recording techniques, change of calls over time, gender differences, and/or geographic variation.

Differences by Location

Stirling and Rays' data were collected in the Ross Sea near McMurdo Sound area, but Rogers recorded from the opposite side of Antarctica, near the Australian Davis Station. Some calls or call characteristics had significant differences that seem to indicate a variation by location.

Three of the Ross seal underwater calls showed this geographic variation: underwater call S, call A with two components, and call A with three components. Watkins and Ray (1985) documented underwater sounds of Ross seals that were similar to their aerial sounds, except that underwater sounds had: (1) a greater range of frequencies, (2) were longer, and (3) usually had three to five strong harmonics. The geographic variation is probably a good indication of distinct breeding areas of Ross seals near the Davis Station area compared to seals on the opposite side of Antarctica in the Ross Sea region. Because some of the underwater calls were similar at the two opposite locations, calls may gradually vary around the continent, resulting in geographic variation when sampled over the greatest distance. Geographic variation also has been documented in other Antarctic seals. Thomas and Golladay (1995) showed geographic variations were evident in leopard seal *(Hydrurga leptonyx)* underwater vocalizations sampled between two distant sites (about 1/3 of the continental perimeter away),

Palmer Peninsula and McMurdo Sound. They found some similar sounds, but each site had unique sounds not found at the other location. Leopard seals are solitary, but have a contiguous distribution around the Antarctic continent. So, likely the geographic variations reflect a gradual change in the underwater repertoire around the continent that is highlighted when sampled at the two distant sites.

Thomas et al. (1988) examined Weddell seal underwater sounds at three locations around Antarctica that approximately divided the continental perimeter into thirds: Davis Station, McMurdo Sound, and Palmer Peninsula. Vocalizations at Davis Station were similar, but not identical to Weddell sounds at either Palmer Peninsula or McMurdo Sound and some vocalizations were totally unique to Davis Station. The degree of difference indicated another geographic variant in their repertoire, which probably reflects the existence of distinct breeding populations. The magnitude of the geographic variations in the Weddell seal sounds likely results from them being colonial species, from males vocally maintaining underwater territories for nearly two months, and the fact they have great site fidelity for their breeding colonies.

Ross seals are not colonial like Weddell seals, nor solitary like leopard seals, their mating system is not really well documented. Sometimes they are found alone, other times in small groups. Ross seals also have a contiguous distribution around the continent, so sampling at these extreme locations would maximize the likelihood of detecting any geographic variation in their sounds.

Sound Differences by Date

There was a 30-year span among data collection by Ray in 1966, Rogers in 1997, and Stirling from 1999 to 2000. This difference in time span could be enough for a call to change over time at the same location. Significant differences in frequency characteristics (beginning, ending, maximum, and minimum frequency; harmonic interval; and sub-harmonic interval) were found in the call A with one component. Ray's 1966 data showed that this call was higher in all frequency variables and in both harmonic and sub-harmonic intervals compared to Stirling's 1999-2000 data at approximately the same location. Therefore, over the thirty years span, the frequency range of the call became lower.

It is not known whether Ross seals inhabit the same areas year after year. There is some evidence that some marine mammals can change their sounds over a short period of time. The humpback whale (*Megaptera novaeangliae*) songs become increasingly different over time and after 3 or 4 years nearly all the elements have been modified (Payne and Payne 1985). It seems that animals that congregate at the same location year after year maintain group cohesion by changing their repertoire.

Some marine mammals can also change their calls based on environmental noise on a short term basis. Au et al. (1985) showed evidence of adaptive capability of a beluga whale's (*Delphinapterus leucas*) biosonar system when it shifted frequency and intensity based on the ambient noise in the environment. False killer whales (*Pseudorca crassidens*) have been able to

increase the frequency of sounds, make them longer in duration, and repeat them more often in areas of high ambient noise (Nester 1999).

Differences by Gender

There was only one aerial call that showed any significant difference by sex of the seal. Watkins and Ray (1985) observed sounds from the Ross seals in air and described them as "characteristic explosive unvoiced exhalation sounds with the mouth slightly open. Voiced sequences also were produced with the mouth and nostrils usually closed, including pulses or call chugging sounds and longer tonal siren calls with lowering and then rising frequency." The aerial call C had significant differences in the number of components and in component duration. Ray and Stirlings' data both reported males with a higher number of components and with a longer component duration. Thomas and Kuechle (1982) reported that the colonial breeding Weddell seal had ten distinct sex-related differences in vocalization usage, with trills (T-calls) being produced exclusively by males and in general females were less vocal. This extreme difference between the sexes in their vociferous nature was not seen in this study of Ross seals, probably because males do not defend underwater territories as in the Weddell seal.

Differences by Collector

There were a few calls that indicated significant difference by collector. This could be an indication of possible differences in the researchers' data collection methods, equipment, or battery charge status. The aerial call N had significant difference in total duration and the aerial call C in total duration,

number of components, and component duration. Ray's data indicated that the male call N was longer in duration than in Stirling's data collected at nearly the same location. For call C, Ray's data also followed this trend in that the total duration and component duration was longer, as well as had a higher number of components, than Stirling's data. This difference could be due to the difference in each researcher's methods of data collection in the field. Each collector narrated and described how they approached the seal and collected the vocalizations. Ray who collected data thirty years earlier experimented more with encouraging the animal to vocalize by standing close and tested how aggressive it would become. This style seemed to change over the years as demonstrated by Stirling's approach. He would ease up next to an animal and place a microphone near and back away to record. This technique allowed the animal to vocalize as it would naturally. This difference in technique could be the reason for the significant differences in collector.

Vocal Repertoire Among Antarctic Seals

When comparing the Ross seal's repertoire to the other species of Antarctic seal, the Ross seal falls between the extremes. The number of vocalizations appears to be linked to the seal's system of breeding. Thomas et al. (1987) and Stirling and Thomas (2003) reported the crabeater seal *(Lobodon carcinophagus)* with one underwater vocalization is related to its seasonal monogamy, the leopard seal with a vocal repertoire between five to nine underwater calls correlated to its promiscuity behavior, and the extensive repertoire of the Weddell seal with 34 or more underwater calls is due to its

polygyny mating system (Stirling and Thomas 2003). The Ross seal with its 12 calls and promiscuity in breeding is similar to the leopard seal. A large vocal repertoire is used for mate attraction and territorial defense. For the Ross and leopard seal, it seems that their limited number of calls is used for mate attraction during their short breeding period.

Within the Ross seal's vocalization repertoire, there were some calls that were heard often in the company of another. This was especially true for the in-air call C and call N vocalizations, although both also could be heard independently from one another. Terhune et al. (1994) documented that Weddell seals also have a tendency to group calls together.

Thomas et al. (1982) and Awbrey et al. (2003) reported a captive leopard seal capable of producing ultrasonic vocalizations. These vocalizations had a frequency of up to 164 kHz. Ultrasonic sampling has not been used often when studying pinnipeds, therefore none have been reported in wild. This study also did not look for ultrasonic vocalizations because of equipment limitations. Recordings above 20 kHz should be made on Ross seals, and all Antarctic seals in the wild.

Uses For a Species Identified Vocal Repertoire

There are other uses for knowing the vocal repertoire of a species besides adding to the species scientific base of knowledge. Thomas and Demaster (1982) reported that sampling of vocal behavior of pinnipeds may be used to determine their diel haulout patterns. Their study was to determine if the daily pattern of underwater vocalizations of the leopard seal and crabeater seal was

negatively correlated with their haulout pattern. For both species, the maximum haulout period corresponded with minimum time of underwater vocalizations, indicating that quantifying vocalizations by hour of the day could be used to adjust census counts of seals hauled out on the ice. Diel sampling of Ross seal sounds should be conducted.

Geographic variations among calls are probably a good indication of different colonies of seals and therefore, specific breeding populations. Investigations into other Antarctic seal repertoires have suggested at least two different breeding populations of leopard seals (Thomas and Golladay 1995) and Weddell seals (Thomas and Stirling 1983) between Palmer Peninsula and McMurdo Sound. Further investigation will be needed to determine whether Ross seals have an additional breeding population in the Palmer Peninsula area since data were not collected from that area.

Knowing the vocal repertoire of a species can lead investigators to find the function or motivation for making a call. Thomas et al. (1983) used underwater playback of vocalizations to determine function of a particular Weddell seal vocalizations. They were able to assign the function of eight calls as serving a purpose in breeding whether it be territorial defense, aggression, or submission. Playbacks of conspecific sounds to Ross seals would provide clues to function; however, playbacks probably not practical for this species due to their relative low numbers, remoteness, and difficult habitat. Ross seals are found by opportunistic encounters in pack ice areas that are not suitable for a long-term study.

Watkins and Ray (1985) suggested that the underwater (siren) call or the underwater call A from the Ross seal stands out particularly well from the other Antarctic springtime underwater noises of other marine mammals; therefore, the call could probably be useful by other Ross seals, as well as people for locating these elusive seals.

These descriptions and characteristics of the calls of the Ross seal's vocal repertoire in this study will serve as a foundation on which future investigations into the life of the Ross seal, the least well known of all the pinnipeds, will be conducted.

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