Identifying Individual Variation in the Discrete Calls of the Killer Whale, *Orcinus orca*

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October 27, 2007
Beam Reach Marine Science and Sustainability School
http://beamreach.org/071

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Abstract

The southern resident killer whales have a complex social system revolving around maintaining group cohesion within matrilines and their larger pods. In such a system, there may be a need to identify individuals based on audible differences between their vocalizations. Since each whale's sound-producing structures will vary in size and shape from those of others, it is possible that the fundamental frequency and resulting resonating bands of harmonics (formants) will differ between individuals. In this study, I measured the differences in the formants of four discrete calls of two whales to determine whether such variation exists. I did not find significant differences between the calls of these two individuals; this lack of difference may be a result of vocal learning and mimicry, the relatedness of the two whales, or the process of filtering sounds within the nasal passages of killer whales.

Introduction

The population of killer whales (*Orcinus orca*) that inhabits the Salish Sea in northwestern Washington and southwestern British Columbia is composed of three pods that make up the southern resident killer whale (SRKW) population (Ford 1987). These three pods are known as J, K, and L pods. The members of each these pods spend at least 50% of their time together and are composed of one to nine matrilineal groups; these matrilineal groups consist of a female, her male offspring, and her young female offspring (Bigg et al. 1990). The fish-eating SRKW population is isolated from the fish-eating northern resident killer whale (NRKW) population by their different distributions and from the transient mammal-eating population of killer whales by their behavioral and dietary patterns. The SRKW population does not share any of the same vocalizations as the NRKW or transient populations, so they are isolated acoustically from these two groups as well as behaviorally and socially (Bigg et al. 1987).

Orcas produce two major sound types – whistles and pulsed sounds (Ford 1987). Whistles have a continuous waveform of variable structure with little to no harmonics. Pulsed sounds are composed of series of short bursts of sound (Ford 1989). Echolocation clicks, variable calls, and discrete calls are all pulsed sounds (Ford 1987). Echolocation clicks are primarily used in navigation and in prey location (Au et al. 2004); they are composed of short sound pulses that are generally broadband with repetition rates up to 300 pulses per second (Ford 1989). Variable calls and discrete calls are also pulsed sounds, but their repetition rates extend to more than 4,000 pulses per second; this high repetition rate leads to a smooth waveform appearance in spectrograms without sufficient resolution to identify each individual pulse (Ford 1989). Discrete calls are repeated and have distinct tonal qualities that vary between calls and that may vary between matrilineal groups or pods. Variable calls are not repeated between individuals (Ford 1987).

Ford (1987) compiled a catalog of vocalizations made by individuals in the SRKW and NRKW populations and noted that most of the vocalizations produced by these animals were discrete calls. Previous work has determined that there are distinct differences between SRKW pods not only in call repertoire, but also in the characteristics of certain calls (Ford 1987, Reisch et al. 2006, Thomson et al. 2001). Pod-specific variations in the structure of calls may be indicators of social affiliations of the whales, who may use their perceived variations to maintain group cohesion (Thomson et al. 2001). Attempts to detect intra-pod variability in the characteristics of discrete calls of A-pod in the northern resident community has indicated that there is a difference between matrilineal units in the durations of certain syllables, a smaller acoustic unit of a call, of at least six calls (Miller and Bain 2000). Just as the pod-specific calls may be used for social distinction, these matrilineal group-specific variations could possibly help individuals from different matrilineal lines locate one another and maintain group cohesion.

Individual variation in vocalizations allows recognition of specific animals (Vannoni and McElligott 2007). Such recognition is based on the variation in the size and shape of the sound producing apparatus (phonic lips in killer whales) and sound filtering structures (nasal passages and melon) (Amundin and Andersen 1983, Reby et al. 2006, Vannoni and McElligott 2007). The ability to recognize individuals would be advantageous in a population with a complicated social system such as that of the southern residents and would facilitate the movement and organization of groups.

The source-filter theory of animal sound production, first proposed by Fant (1960), suggests that sounds made by an animal are affected by both the sound producing apparatus (the source) and the subsequent path the sound takes through the animal's vocal or nasal tract (the filter). The fundamental frequency of a sound in killer whales is produced by the vibration of the phonic lips, and the resulting sound is modified and "focused" in the nasal passages and melon. Harmonics, whose frequencies are positive integer multiples of the fundamental frequency, are generated in the process. During the focusing and filtering in the nasal passages and melon, certain bands of one or more harmonics are amplified above the other harmonics. These bands of amplified harmonics are called formants. These formants are dependent on the variations in the phonic lips and sound filtering apparatus of each whale and hence may provide information about the identity of the individual vocalizing (Vannoni and McElligott 2007).

Vanonni and McElligott (2007) and Reby et al. (2006) analyzed formants in the calls of fallow deer (*Dama dama*) and red deer (*Cervus elaphus*), respectively. These investigators discovered that such analysis can allow identification of individuals based on calls. If there are, in fact, such indicators in the parameters of the vocalizations of other animals, it is reasonable to expect that there may be such variations in the calls of orcas.

In this study, I focused on using source-filter theory to examine the calls of killer whales in J-clan. Since there are differences in size and shape between individuals, and as a result, their sound-producing structures; it is likely that the formant characteristics of each whale's calls are slightly different (Reby et al. 2006). I examined four different discrete calls of two members of J-pod to determine whether or not there are differences between the calls of these individuals.

Methods

Study Animals and Recording Equipment

On September 1, 2007, we encountered a group of three whales off of False Bay at San Juan Island in the San Juan Archipelago in Washington State. We made recordings from the *Gato Verde*, a 42-ft hybrid-biodiesel catamaran. During our recording session, which lasted from 16:42:40 until18:04:18, the *Gato Verde* ran on battery power so that the noise from the propellers was minimal and practically inaudible in our recordings. We followed the Be Whale Wise Guidelines (http://www.nwr.noaa.gov/Marine-Mammals/upload/BeWhaleWise.pdf) during our encounters with the whales so as to disturb their behavior as little as possible while we collected data.

I used an array composed of four LAB-core hydrophones towed off the port stern of the *Gato Verde* to record vocalizations from the whales. The peak sensitivity of the hydrophones was approximately 5,000Hz, which dropped by 30dB at about 200Hz and at about 10,500Hz. The hydrophones were spaced approximately 10m apart and were weighted down to be towed about 3.5 m underneath the surface of the water. The array was towed behind the *Gato Verde* so that the first hydrophone was about 10.73m from the stern of the boat. I recorded the calls with custom-built four-channel instrumentation and an amplifier with a National Instruments 16-bit analog-to-digital converter at a sampling rate of 50,000 samples per second. I saved the recordings as four-channel files using the Beam Reach Sound Analyzer program, which continuously saved the sounds in one-minute-long files.

During this encounter with the three whales, one of the whales (a calf) approached our boat so that it was within 100m of the array. The two other whales remained further away from the boat. After passing close to our boat, the calf joined the two adults ahead of the boat. Other observers took photos of the dorsal fins and saddle patches of the three whales. Later, with Balcomb et al.'s (2006) *Offical Orca Survey* photos, I employed Bigg et al.'s (1987) technique of examining the differences in saddle patch and dorsal fin characteristics to identify these whales. I identified the two that remained further away from the boat as J-22 and her son J-34. The whale that approached the boat was much smaller than the other two and had a much darker saddle patch, so I was unable to use its saddle patch characters to identify it; however, since J-22 and her son were present, it is possible that it was J22's youngest calf, J-38. This younger whale will hereafter be referred to as the "calf".

Sound Localization

During the time when the calf approached and passed the boat, it repeated many discrete calls that we were able to record clearly with our array. One or both of the other whales also vocalized during this recording session. Five of our minute-long recordings contained discrete calls of the same call type from both one of the adults and the calf. I chose to examine these calls of the same call type so I could compare them between the calf and the vocalizing adult.

I used the localization software Ishmael 1.0 (Mellinger 2001) to determine the source of each call I examined. I used the Hyperbolic Localization function in Ishmael, which returned a coordinate in the x-y plane that it had calculated as the source of the sound in relation to the origin of the hydrophone array (the point of attachment of the array to the boat). Using the x and y values of this coordinate, I used the Pythagorean Theorem to calculate the distance from the boat to the source of the call.

During the minutes that the calf passed close to the boat, I was able to use the differences in distances obtained in Ishmael to determine which calls came from the calf and which ones came from one of the adults. Because J-22 and J-34 remained relatively close together, I could not distinguish between the calls of each of them and hence refer to any calls made by either of them as made by an “adult”.

After the calf had passed the boat, it joined the two adults. Its calls came from approximately the same location as those of the adults after it had joined them, so I was unable I to use the source of the call’s distance from the array to determine which whale had produced it. I compared both the sound quality and the spectrograms of the calls in question to calls which I had already localized to either the calf or the adult. There was an audible difference between the calls of the adult and those of the calf and a visual difference in the spectrogram in which harmonics were amplified (Figures 1-7). I used these characteristics to assign these later calls to a source whale.

Formant Analysis

I analyzed four call types using Praat 4.6.31 (Institute of Phonetic Sciences) (Figure 8). The hydrophone array recorded sounds in four channels, and Praat can only use one-channel sound files. I used the Beam Reach Sound Analyzer to split each four-channel file into four one-channel files. Since there were four possible channels to analyze, I chose to examine the channel with the highest visible signal-to-noise ratio, which I selected in Ishmael from the four channels displayed.

I examined the syllables of each call separately and used Ford’s (1987) call catalog to determine where in a call each syllable began and ended. I used Praat to examine eight characteristics of the first two formants (four each for F1 and F2) of each syllable: start and end frequency, maximum frequency, and the Maximum Frequency Location, measured as the time from the start of the syllable to when the maximum frequency occurred divided by the duration of the syllable (L_{max}, similar to McCowan and Hooper's (2002) Peak Frequency Location). I also measured the duration of each syllable. Each call had a total of three syllables so that I analyzed a total of 27 variables per call. During each minute of recording, the calf made between four and 10 repeated calls, and the adult made between one and four repeats of the same call type as the calf.

Statistical Analysis

I used the StatCat program in Excel (Moriarty 2007) to analyze the differences between the vocalizing adult and the calf for each variable. Since during one recording, the adult only performed the same call type (S3) as the calf one time, I needed to assume equal variance and so performed a t-test of equal variances.

Results

I analyzed four recordings from this encounter which had at least one vocalization of the same discrete call type from both the adult and the calf. Each recording contained a different call type repeated by both the adult and the calf (S3, S7, S12, and S19; Figures 1-7). Of the 108 comparisons with the test of equal variance, 11 variables were found to differ significantly between the vocalizing adult and the calf (Table 1).

I recorded 14 S7 calls between 17:51:22 and 17:52:22; 10 from the calf and four from the adult. Seven variables differed significantly between the S7 calls of these two whales: the duration of the first syllable ($p= 0.01425$), the start frequency of the F1 of the first syllable ($p=0.01498$), the start frequency of F2 of the first syllable ($p=0.00921$), the maximum frequency of F1 in the first syllable ($p=0.009$), the maximum frequency of F2 in the first syllable (p=0.01189), the L_{max} of the F2 of the second syllable (p=0.009), and the maximum syllable of F2 of the third syllable (p=0.00751).

Between17:27:55 and 17:28:55, I recorded a total of seven S12 calls. The calf made five of these, and one of the adults made two calls. In these S12 calls, three variables differed significantly between the adult and the calf: the duration of the first syllable (p=0.00776), the L_{max} of F1 in the first syllable ($p=2.3*10^{-6}$), and the end frequency of F1 in the third syllable (p=0.01258).

The calf made five S19 calls between 17:53:22 and 17:54:22, and the adult made three. For this call type, the maximum frequency of F1in the first syllable was significantly different between the two whales (p=0.04192).

For the other 97 tests of equal variances, the variables examined were not significantly different between the two whales (p>0.05).

Discussion

Of the four call types examined (S3, S7, S12, and S19), three of them (S7, S12, and S19) elucidated at least one parameter of the 27 measured that differed significantly between the vocalizing adult and the calf. In total, there were 11 comparisons that differed between the two whales. Two of these parameters were significant in two call types: the duration of the first syllable (S7 and S12) and the maximum frequency of F1 in the first syllable (S7 and S19).

In these three call types, there were only three significant differences between parameters of the second and third syllables (in call types S7 and S12). The other eight significant differences all occurred within the first syllable of all three call types in which I found such significance. None of the parameters in the first syllable were different between the two whales for all four of the call types examined. Even so, since eight significant differences were found in the first syllable of three of the four call types I recorded from the adult and the calf, it may be that this first syllable may be more diagnostic of individuality in vocalization than the other two syllables.

Since only 11 of 108 comparisons returned significant differences between the two whales, with no strong pattern evident as to the specific formant or parameter (start, end, or maximum frequency; duration; or L_{max}) that is different between calls across call types, I cannot reject my null hypothesis that there are not individual variations in each discrete call type. This lack of variation may be explained not only by the small sample size (between only five and 14 calls per call type made by two whales) and relatedness of the two whales (the adult is likely either mother or sibling to the calf), but also by possible functional differences between call types and even the possible functions of the calls themselves.

To date, researchers have been unable to report a link between behaviors and call types produced by killer whales (Morton at al. 1986, Weiß et al. 2006), so the functions of specific calls and even discrete calls as a category of vocalizations are unknown. It is possible that differences in function for each call type would require or select for different levels of individual distinctiveness, depending on whether or not the receiver of the caller's signal needed to know the signaler's identity to respond appropriately (Vannoni and McElligott 2007). Many more parameters in the S7 calls (seven parameters) were significantly different between the two whales, so it may be that this particular call may be used in a context in which individual distinctiveness is useful.

Several researchers (Miller and Bain 2000, Nousek et al. 2006, Thomson et al. 2001) have postulated that discrete calls may be used in killer whales for group cohesion and that their findings that the parameters of discrete calls only differ between matrilines support the hypothesis that these calls are used to maintain these matrilineal units. If so, the lack of distinctiveness between the vocalizations of the adult and calf in this study may come from requirement that the discrete calls of a matriline are similar to allow group recognition and cohesion. Using similar-sounding, familiar discrete calls would be helpful in identifying kin in a population with such strong familial bonds and such a complex social system (Bradbury and Vehrencamp 1998). Individual distinctiveness would have no function if these calls are used to keep specific related groups (and not collections of individuals) together.

It is also possible that vocal learning has played a role in making the vocalizations of the adult and the calf so similar. Assuming that killer whale calves must learn each of the discrete calls, a calf would be most likely to learn from its mother and siblings, with whom it spends most of its time (Bigg et al. 1990). If the calf observed in this study was actually J-22's calf, it would have learned many of its vocalizations from its mother and J-34, its brother. The similarity in their calls may come from the calf's learning to mimic the calls of its mother and brother.

It is likely that being able to recognize different whales in relation to their matrilines is important to the social functions of the SRKW population, so it may also be that individual distinctiveness may play a role in such group organization. Larger samples of calls from more call types, as well as calls from more individuals of both the same and different matrilines would help elucidate if such variation exists or plays a major role in the function of killer whale calls.

Since killer whale sound production (and that of all other odontocetes) takes place not at the larynx, but at the phonic lips in the nasal passages, it is possible that their sound filtering processes differ from those of terrestrial vertebrates as well. The filtering process in terrestrial mammals takes place while the sound travels through the extensive air passages of the throat, mouth, and nasal passages. Odontocetes recycle the air that they use to make sound by passing it back through the tubular sacs involved in producing sound (Amundin and Andersen 1983). This process may drastically alter the filtering process of sound and may change what distinctive characteristics can be used to identify the vocalizing individuals. If that is the case, it may be that formant analysis is not the most appropriate technique for analysis of individual variation in killer whale vocalizations. Further research on the sound filtering processes in odontocetes is necessary to determine the best technique for such analysis.

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Tables and Figures

	S3		S7		S12		S19	
Parameter Measured	Calf	Adult	Calf	Adult	Calf	Adult	Calf	Adult
Syllable 1 Duration	0.19 (±0.01)	0.19 (±0.01)	**0.53** **(±0.05)**	**0.10**	**0.66** **(±0.03)**	**0.54** **(±0.05)**	0.71 (±0.11)	0.92 (±0.13)
Syllable 1 Start F, F1	3949.46 (±181.37)	3535.55 (± 1072.71)	**4058.01** **(±108.28)**	**3047.97**	3778.80 (±206.31)	3762.27 (±199.06)	4001.23 (±88.06)	3841.08 (±115.92)
Syllable 1 Start F, F2	5379.62 (±161.53)	5102.89 (±825.30)	**5613.66** **(±85.45)**	**4592.51**	5688.74 (±266.30)	5387.24 (±19.81)	5547.81 (±146.04)	5624.02 (±171.23)
Syllable 1 End F, F1	3014.78 (±716.54)	3165.05 (±300.58)	3193.65 (±1103.86)	2707.52	4154.64 (±394.47)	4157.45 (±160.94)	3818.57 (±490.58)	4095.53 (±136.51)
Syllable 1 End F, F2	5017.37 (±385.17)	4774.28 (±283.01)	4961.52 (±759.05)	4616.93	5270.90 (±195.72)	5539.14 (±601.58)	5447.79 (±580.34)	5666.93 (±41.27)
Syllable 1 Max F, F1	4202.13 (±350.35)	4174.27 (±223.42)	**4244.62** **(±67.75)**	**3425.51**	4755.57 (±64.39)	4636.95 (±77.96)	**4353.14** **(±170.11)**	**4732.77** **(±37.85)**
Syllable 1 Max F, F2	5549.70 (±252.20)	5565.96 (±130.62)	**5917.72** **(±79.44)**	**5083.86**	6258.84 (±178.77)	6428.61 (±83.98)	5851.11 (±180.66)	6091.51 (±67.27)
Syllable 1 Lmax, F1	0.28 (±0.36)	0.07 (±0.09)	0.61 (±0.13)	0.81	**0.96** **(±0.02)**	**0.10** **(±0.08)**	0.52 (±0.24)	0.90 (±0.09)
Syllable 1 Lmax, F2	0.36 (±0.44)	0.03 (±0.05)	0.41 (±0.13)	0.75	0.28 (±0.39)	0.56 (±0.56)	0.66 (±0.38)	0.41 (±0.12)
Syllable 2 Duration	3.74 (±11.76)	0.01 (±0.01)	0.04 (±0.03)	0.16	0.04 (±0.02)	0.06 (±.02)	0.15 (±0.05)	0.17 (±0.08)
Syllable 2 Start F, F1	3084.04 (±696.83)	3171.09 (±307.95)	3369.75 (±687.23)	2794.18	4027.18 (±427.47)	4204.42 (±94.52)	3862.24 (±499.38)	4104.55 (±234.26)
Syllable 2 Start F, F2	5017.80 (±385.66)	4813.88 (±314.72)	4991.06 (±810.96)	4877.26	5271.01 (±190.97)	5776.76 (±937.63)	5447.57 (±581.89)	5668.07 (±66.94)
Syllable 2 End F, F1	2814.58 (±879.39)	3041.17 (±280.05)	3826.05 (±266.72)	3093.54	3691.53 (±129.28)	3823.32 (±138.76)	3858.74 (±247.05)	4087.43 (±91.86)
Syllable 2	4629.00	4654.26	4865.52	4371.71	5437.78	5379.96	5325.30	5670.82

End F, F2	(±566.50)	(±364.97)	(±802.47)		(±116.41)	(±191.81)	(±263.88)	(±5.23)
Syllable 2 Max F, F1	3216.79 (±724.45)	3190.57 (±299.37)	3974.97 (±205.49)	3950.25	4179.47 (±472.24)	4252.16 (±27.01)	4309.40 (±115.18)	4388.48 (±207.99)
Syllable 2 Max F, F2	5074.36 (±335.66)	4829.55 (±324.62)	4997.47 (±818.95)	5077.12	5522.36 (±191.94)	5906.00 (±754.86)	5781.69 (±314.10)	6078.09 (±59.35)
Syllable 2 Lmax, F1	0.34 (0.42)	0.25 (±0.50)	0.75 (±0.43)	0.68	0.32 (±0.44)	0.05 (±0.06)	0.42 (±0.41)	0.39 (±0.20)
Syllable 2 Lmax, F2	0.25 (±0.36)	0.08 (±0.17)	**0.01 (±0.03)**	**0.32**	0.76 (±0.38)	0.29 (±0.40)	0.59 (±0.20)	0.32 (±0.14)

Table 1: Average values and standard deviations for each measured parameter for calls from the adult and calf, per call type: duration of each syllable (s); start, end, and maximum frequencies (Hz) for each of two formants, F1 and F2; and L_{max} for each of two formants (expressed as a percent of the total call length). Significant comparisons are in bold.

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	S3		S7		S12		S19	
Parameter measured	Calf	Adult	Calf	Adult	Calf	Adult	Calf	Adult
Syllable 3 Duration	0.21 (±0.05)	0.22 (±0.09)	0.21 (±0.02)	0.16	0.26 (±0.03)	0.22 (±0.07)	0.12 (±0.07)	0.08 (±0.01)
Syllable 3 Start F, F1	2756.33 (±904.93)	3085.08 (±284.99)	3819.18 (±313.61)	2988.53	3732.28 (±122.10)	3794.90 (±98.57)	3748.77 (±411.02)	4101.80 (±103.50)
Syllable 3 Start F, F2	4640.34 (±546.21)	4638.89 (±353.75)	5072.99 (±470.57)	4293.64	5483.63 (±153.95)	5491.37 (±349.36)	5303.43 (±302.99)	5032.31 (±1210.58)
Syllable 3 End F, F1	3889.21 (±816.48)	3585.09 (±706.81)	3620.47 (±1069.28)	3400.50	**3995.26 (±132.91)**	**3608.18 (±57.58)**	3693.68 (±505.03)	4949.75 (±1030.12)
Syllable 3 End F, F2	5363.67 (±447.41)	4892.62 (±655.79)	5226.85 (±749.70)	4695.92	5151.96 (±207.00)	5541.07 (±152.13)	4973.94 (±1183.47)	5725.18 (±21.18)
Syllable 3 Max F, F1	4232.35 (±695.49)	4171.46 (±138.57)	4375.76 (±311.55)	3836.70	4372.01 (±129.07)	4347.59 (±32.81)	4199.96 (±32.54)	4241.64 (±15.60)
Syllable 3 Max F, F2	5647.04 (±447.24)	5291.78 (±239.93)	**5673.40 (±67.38)**	**4780.41**	5566.67 (± 72.54)	5733.12 (±159.31)	5658.37 (±206.32)	6007.70 (±0.42)
Syllable 3 Lmax, F1	0.40 (±0.28)	0.79 (±0.20)	0.72 (±0.13)	0.62	0.79 (±0.14)	0.56 (±0.42)	0.43 (±0.38)	0.48 (±0.43)
Syllable 3 Lmax, F2	0.65 (±0.14)	0.78 (±0.22)	0.62 (±0.34)	0.77	0.38 (±0.42)	0.41 (±0.37)	0.56 (±0.38)	0.21 (±0.09)

Table 1, cont: Average values and standard deviations for each measured parameter for calls from the adult and calf, per call type: duration of each syllable (s); start, end, and maximum frequencies (Hz) for each of two formants, F1 and F2; and L_{max} for each of two formants (expressed as a percent of the total call length). Significant comparisons are in bold.

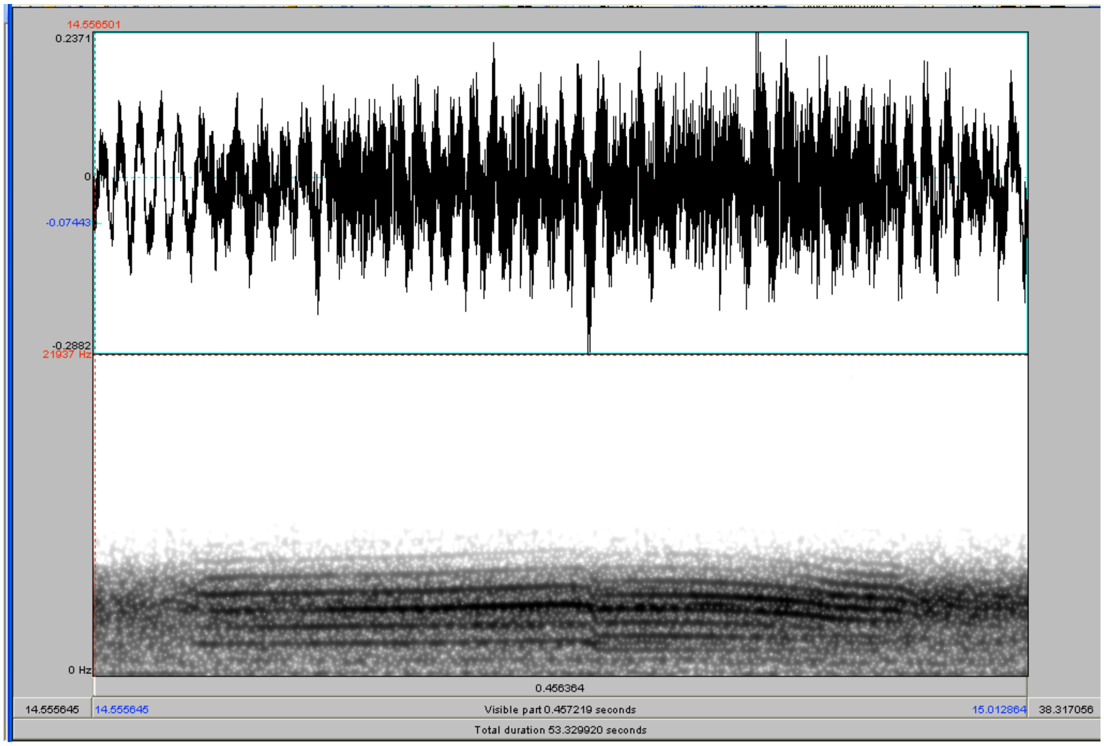

Figure 1: Amplitude time series and spectrogram of an S3 call made by the adult. (Praat 4.6.31, window length: 0.005s, sampling rate: 50,000 samples per second)

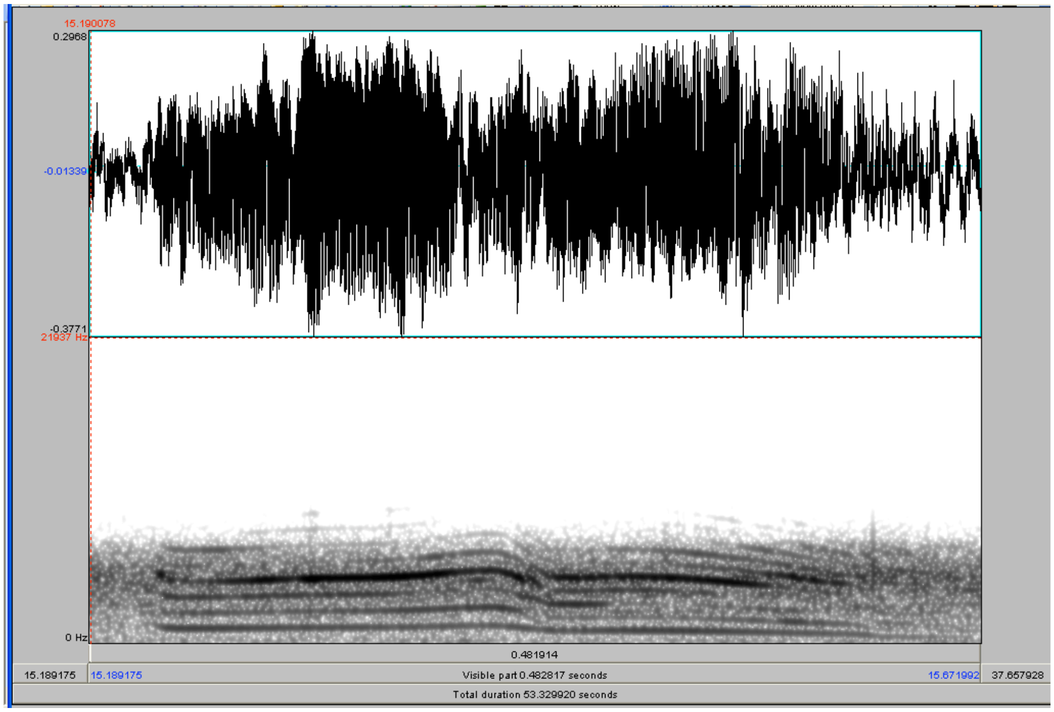

Figure 2: Amplitude time series and spectrogram of an S3 call made by the calf.

(Praat 4.6.31, window length: 0.005s, sampling rate: 50,000 samples per second)

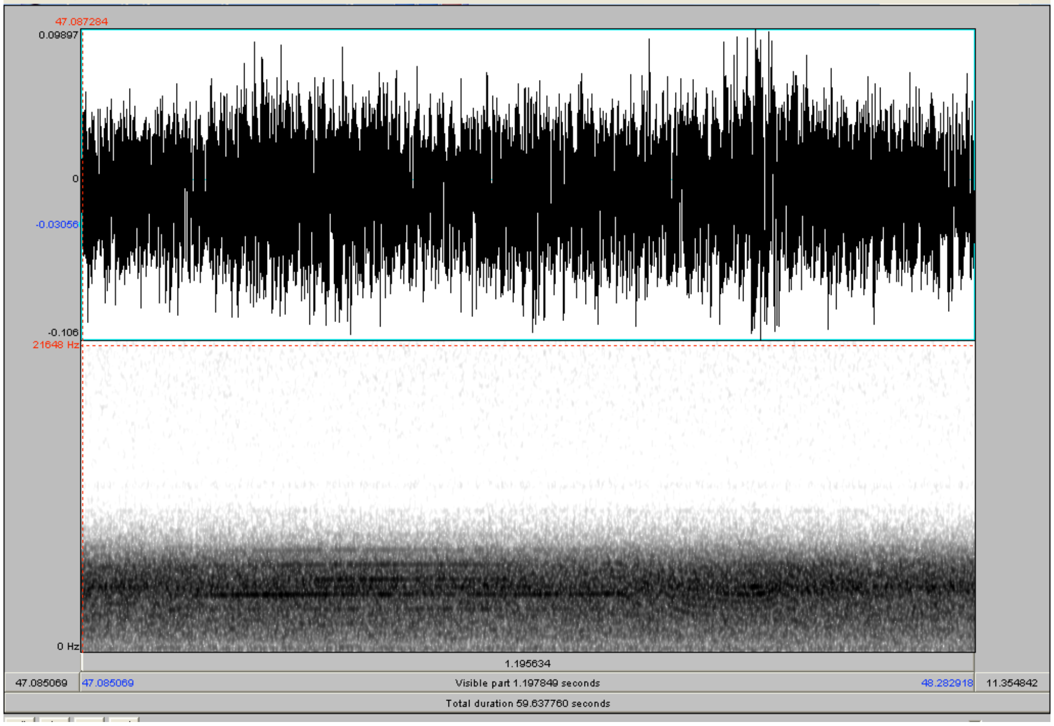

Figure 3: Amplitude time series and spectrogram of an S7 call made by the adult. (Praat 4.6.31, window length: 0.005s, sampling rate: 50,000 samples per second)

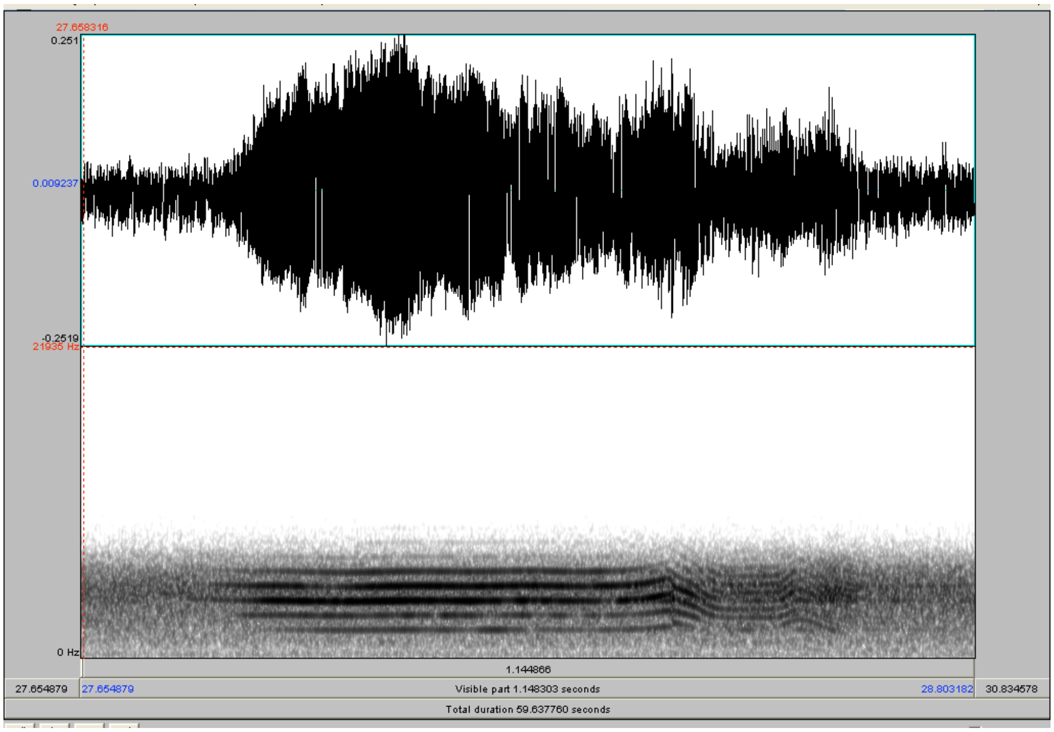

Figure 4: Amplitude time series and spectrogram of an S7 call made by the calf. (Praat 4.6.31, window length: 0.005s, sampling rate: 50,000 samples per second)

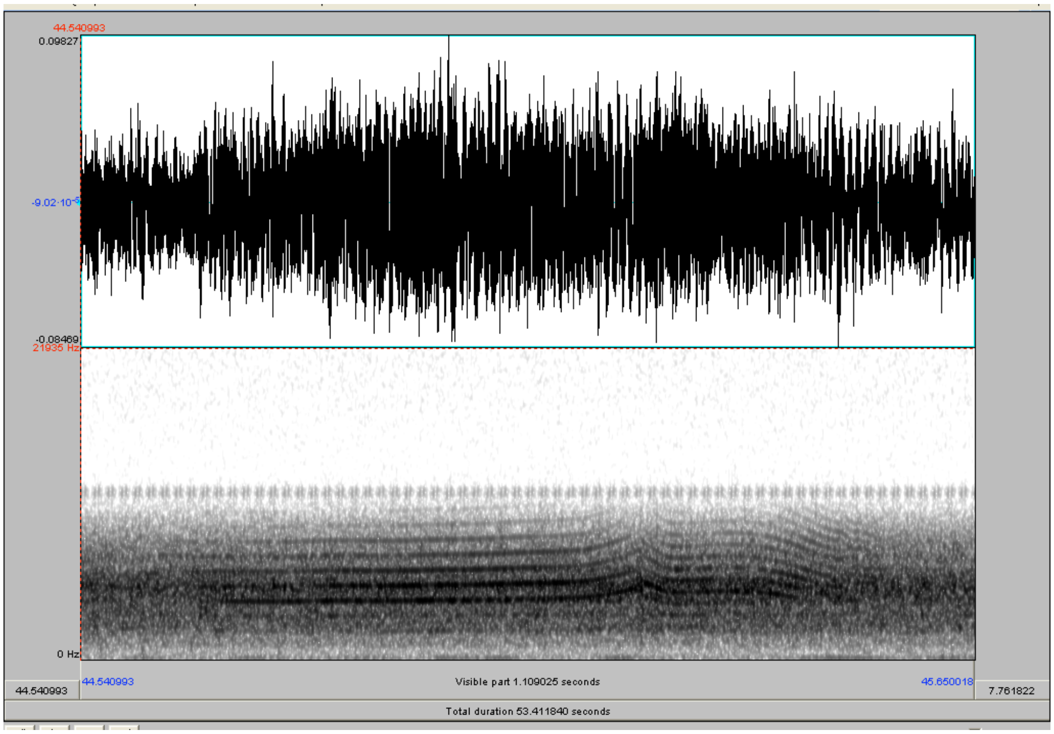

Figure 5: Amplitude time series and spectrogram of an S12 call made by the adult. (Praat 4.6.31, window length: 0.005s, sampling rate: 50,000 samples per second)

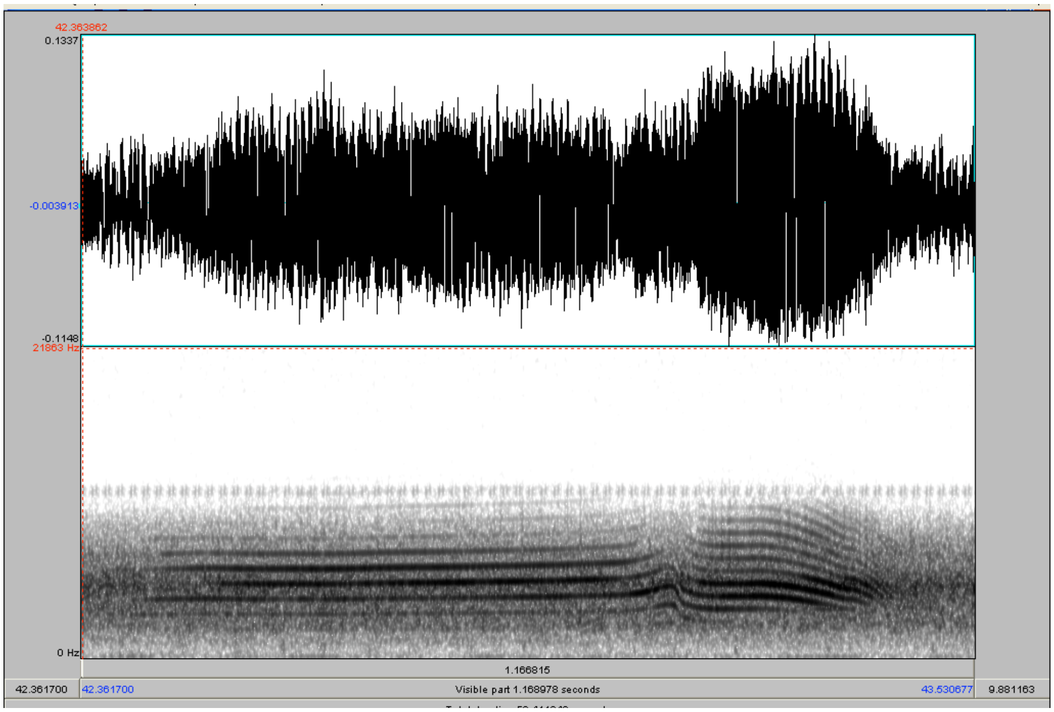

Figure 6: Amplitude time series and spectrogram of an S12 call made by the calf. (Praat 4.6.31, window length: 0.005s, sampling rate: 50,000 samples per second)

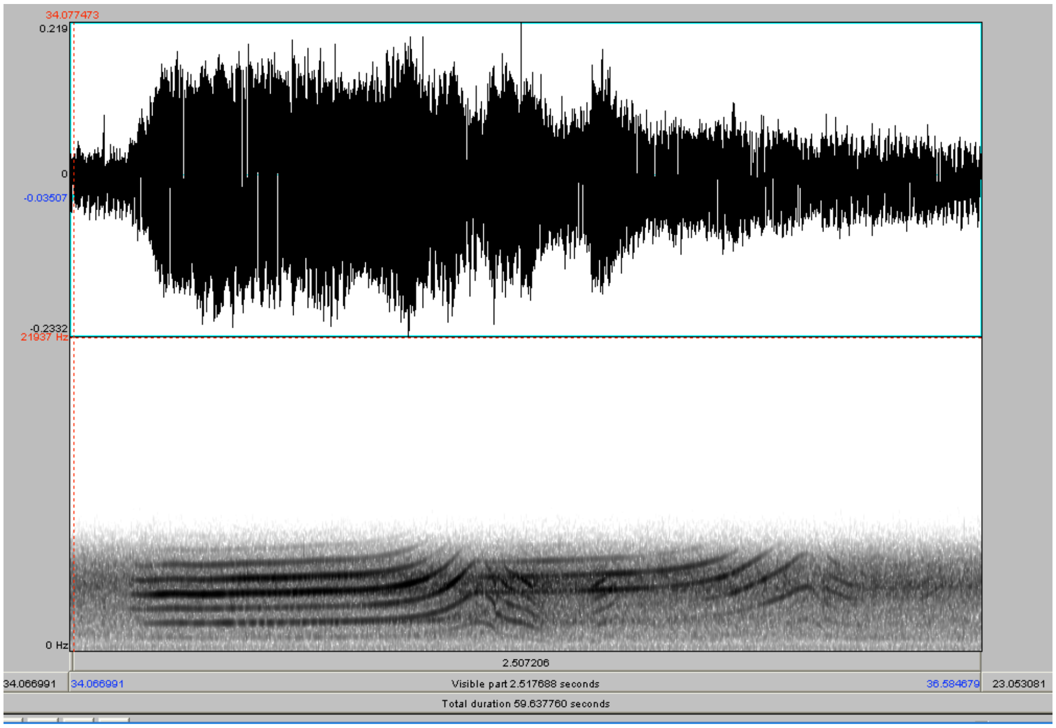

Figure 7: Amplitude time series and spectrogram of S19 calls made by the calf (first call) and the adult (second call). (Praat 4.6.31, window length: 0.005s, sampling rate: 50,000 samples per second)

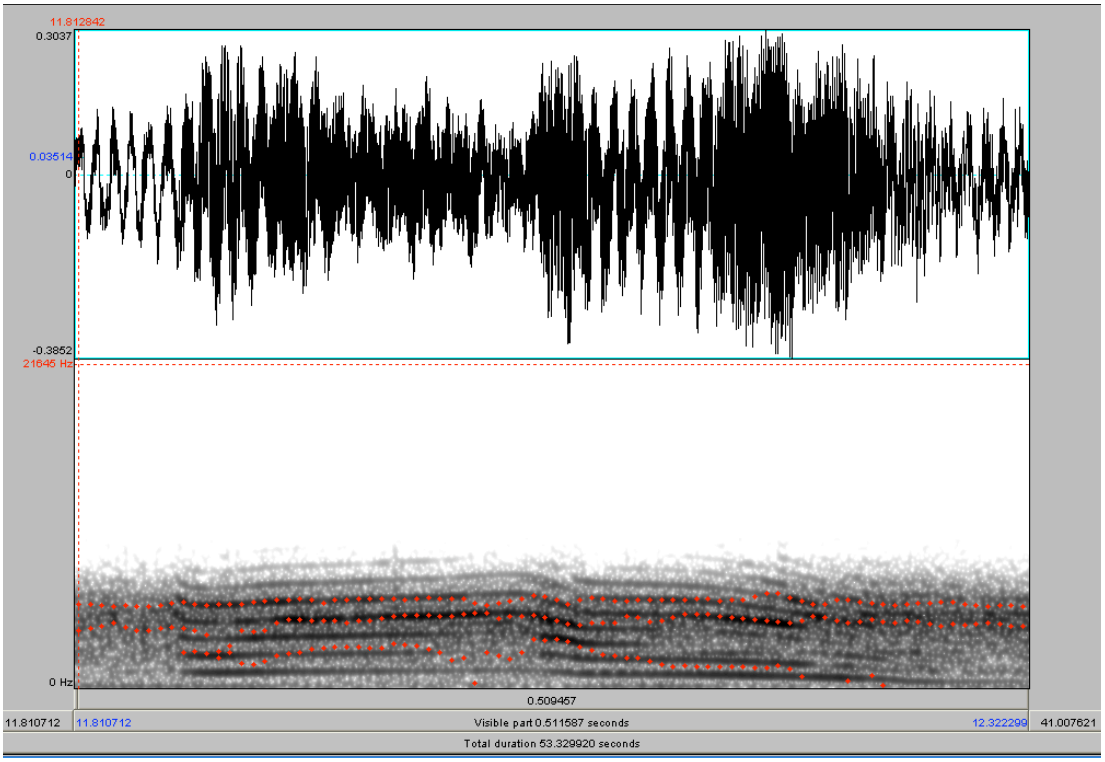

Figure 8: Formants (displayed along red dots) and amplitude time series of an S3 call. (Praat 4.6.31, window length: 0.005s, sampling rate: 50,000 samples per second)