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PULSED AND NOISY CALLS OF BELUGA WHALES (*DELPHINAPTERUS LEUCAS*) IN A SUMMER ASSEMBLAGE OFF SOLOVETSKY ISLAND IN THE WHITE SEA

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The results of perceptive and acoustic analysis of pulsed and noisy signals are demonstrated, and also the data of the signals of mechanical and unknown origin, recorded in the reproductive gathering of beluga whales off Solovetsky Island in the White Sea. A high similarity of the signals of the given categories with those in belugas from other populations has been revealed. A temporal pattern of the series of echolocation impulses of wild belugas has been analysed. The echolocation series are characterised by a high regularity of click repetition rate and a short duration. No echolocation series consisting of click packets were found.

Introduction. Beluga whale (*Delphinapterus leucas*) is a widespread species of toothed cetacean in Arctic. A characteristic feature of the vocal repertory of beluga is abundance and a variety of pulsed and noisy calls, using for communication. At the same time, it has been proved experimentally that belugas possess a highly adaptive and sophisticated echolocation system, superior to that of bottlenosed dolphins (*Tursiops truncatus*) in many respects [6]. It is shown that trained beluga can use a strategy of emission of echolocation clicks, at which the clicks within the series are grouped in packets [6]. To date, the works on description of the wild beluga signals are done in the Canadian High Arctic [5], in the St Lawrence River Estuary [3], in Bristol Bay in Alaska [1] and in Svalbard [4]. Extensive material has been accumulated during long-term surveys of the vocal behaviour of the White Sea and Amur River Estuary belugas [2]. Under their conducting the first evidences of possible geographic variability of beluga acoustic behaviour were obtained [2]. Nevertheless, a detailed description of the beluga vocal repertory for these two points of geographic range performed in objective manner is still absent. The data about fine temporal pattern of echolocation series of wild belugas are also scarce. Thereupon, acoustic analysis and quantitative description of communicative pulsed and noisy signals of the White Sea beluga whales, and also an analysis of their echolocation series have become the aim of this work.

Materials and methods. Materials were taken in June-August 1997, 1999 – 2004 in the reproductive gathering of beluga whales off Cape Beluzhy (65°43'N; 35°31'E) of Solovetsky Island in the White Sea. We recorded beluga signals, using a system of stationary hydrophone, amplifier and MD Sony MZ-35 (or tape recorder "Vesna 320" / "Ritm 415"), having a relatively flat frequency response (±3 -4.5 dB) approximately to 16-20 kHz (depending on recorder type). More than 230 hours of records were made in total. Their primary processing was performed with the software Cool Edit Pro 1.2 (spectrogram parameters: FFT = 256, Hamming windowing function). In total, for acoustic analysis 709 signals of high quality were chosen. Acoustic measurements were performed with the help of movable cursors of the software Syrinx 2.1 (developed by John Burt, Cornell University, USA). Spectrograms had transform size of FFT equal to 256 and Hamming windowing function. Besides, for the determining of the rate and the portion of each type of signals, 152 two-minute fragments were randomly sampled from the initial record body. In each fragment, using running spectrograms (5-s window), all signals were counted with Cool Edit Pro 1.2. A total of 13653 signals were counted. Echolocation series (n = 1025) were selected with the help of Cool Edit Pro 1.2 from the 10 h high quality records of 2002. Analysis of echolocation trains was performed automatically using the algorithm for the MatLab 6.0.

Results and discussion. Pulsed signals of beluga whales were divided into two basic categories: communicative impulse signals and echolocation clicks.

Table. Characteristics of the types of communicative impulse signals of belugas (m ± SD).

Type of signals, n	Share (**%**)	Duration, **s**	Pulse repetition rate, **pulses/s**		Dominant frequency, **kHz**	Limits of frequency band, **kHz**	
			Minimum	Maximum		Lower	Upper
hPT1, 50	1.3	0.78 ± 0.45	1050 ± 194	1298 ± 185	5.2 ± 3.0	1.1 ± 0.2	> 20
hPT2, 34	0.2	0.73 ± 0.11	628 ± 44	1110 ± 50	2.4 ± 1.5	0.6 ± 0.1	> 20
hPT3, 16	0.2	0.71 ± 0.66	685 ± 75	863 ± 123	11.3 ± 2.1	8.8 ± 1.4	14.3 ± 0.8
hPT4, 37	0.4	0.78 ± 0.22	217 ± 285	761 ± 427	2.4 ± 2.3	0	18.4 ± 1.4
hPT5, 11	0.13	0.11 ± 0.06	1300 ± 700	2700 ± 1000	4.4 ± 2.1	1.3 ± 0.7	> 20
lPT1, 50	12.7	0.15 ± 0.04	208 ± 106	365 ± 83	2.5 ± 1.4	0.3 ± 0.1	2.3 ± 0.6
lPT2, 50	11.0	0.62 ± 0.25	125 ± 84	330 ± 64	0.7 ± 0.1	0.1 ± 0.1	2.3 ± 0.5
lPT3, 68	3.77	0.87 ± 0.43	136 ± 92	420 ± 62	6.1 ± 1.0	4.0 ± 1.3	8.9 ± 2.0
lPT4, 7	0.01	1.52 ± 0.36	467 ± 45	467 ± 45	2.3 ± 1.6	0.5 ± 0.1	20.0 ± 0
lPT5, 57	0.84	1.15 ± 0.58	303 ± 72	407 ± 105	1.2 ± 1.4	0.3 ± 0.1	11.1 ± 6.4
lPT6, 9	0.15	0.76 ± 0.47	167 ± 104	593 ± 140	2.0 ± 1.5	0.2 ± 0.1	18.8 ± 0.7
lPT7, 37	1.5	1.36 ± 0.43	34 ± 35	376 ± 132	5.7 ± 4.8	0	15.9 ± 0.8
Type of signals, n	Share (**%**)	Duration, **ms**	Interclick interval, **ms**		Dominant frequency, **kHz**	Limits of frequency band, **kHz**	
			Minimum	Maximum		Lower	Upper
bIS1, 74	5.4	1480 ± 660	6 ± 2	25 ± 19	6.0 ± 3.1	0.1 ± 0.5	15.9 ± 0.5
nIS1, 57	1.62	1460 ± 890	13 ± 8	45 ± 27	1.1 ± 0.4	0.1 ± 0.2	2.4 ± 0.7
nIS2, 12	0.35	841 ± 456	18 ± 8	58 ± 28	4.4 ± 2.8	3.9 ± 2.3	6.0 ± 3.2
nIS3 13	0.01	471 ± 166	14 ± 6	31 ± 12	4.3 ± 0.5	2.0 ± 0.5	5.8 ± 1.2
nIS4, 7	0.07	539 ± 41	11 ± 2	22 ± 5	8.5 ± 0.3	7.6 ± 0.2	9.2 ± 0.2
N1, 27	0.31	560 ± 140	-	8 ± 2	1.8 ± 0.6	0.3 ± 0.4	11.4 ± 1.4
N2, 35	1.7	742 ± 278	-	24 ± 9	7.8 ± 0.3	6.2 ± 0.5	10.6 ± 0.5
N3, 48	0.9	490 ± 140	-	13 ± 5	1.1 ± 0.3	0.4 ± 0.1	4.7 ± 2.1
N4, 10	0.3	920 ± 330	-	-	5.9 ± 2.2	0	> 20

Parameters of the types of communicative impulse signals are given in the table, and spectrograms of the representative signals are shown at the Fig. 1-2.

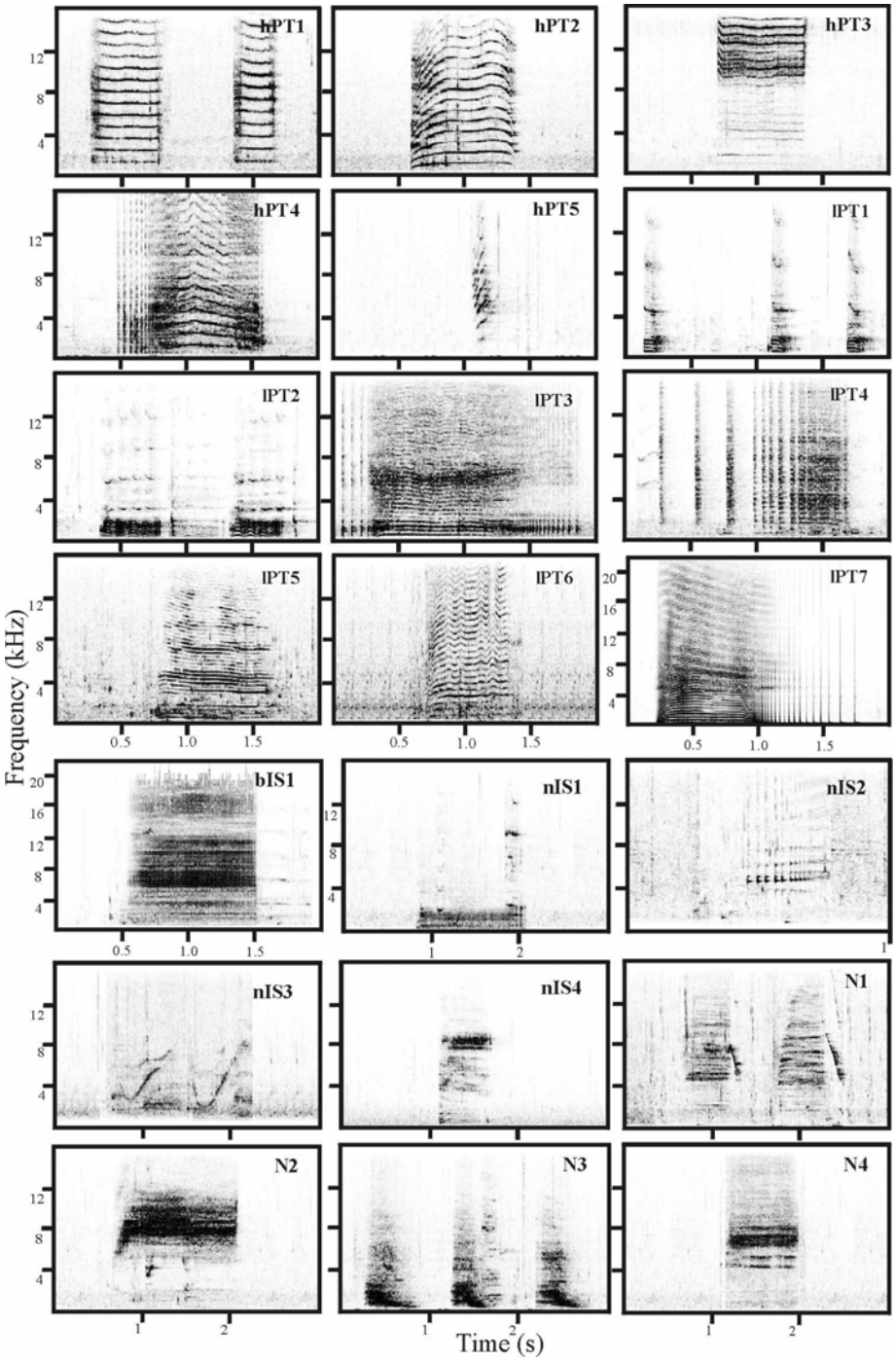

Fig. 1. Sonograms of representative signals of beluga whales.

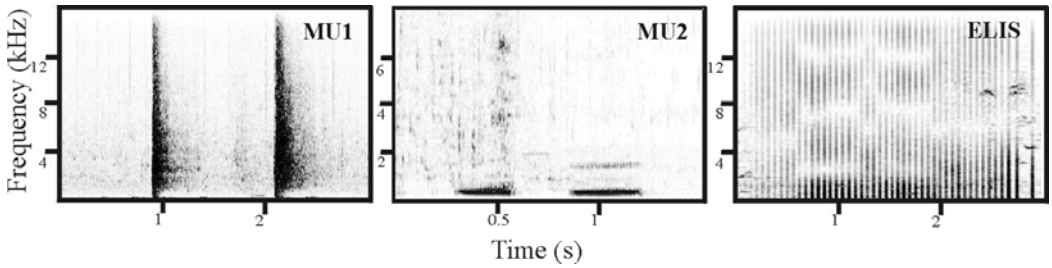

Fig. 2. Sonograms of the representative signals of beluga whales. For decoding of the abbreviations refer to the text. Sonogram parameters for all the figures are: transform size of FFT = 256, Hamming windowing function. Note that sonograms have different time and frequency scale.

Communicative impulse signals were divided into four main categories on the basis of, first of all, pulse repetition rate (PRR), frequency and temporal characteristics of the indidual impulses, and, at a lesser extent, on the basis of auditory images of the signals. Pulsed tones were included into the first category. They were perceived as continuous ones, but in real they were consisted of impulses, going one after another with a rather high rate. Pulsed tones were divided into the signals with high PRR (**hPT**), such as "cries" and "screams", and the signals with a low PRR (**lPT**), such as "vowels", "bleats" and "moan". Series of discrete communicative impulses were included into the second category. On the basis of the width of frequency band of a separate impulse they were divided into the series of broadband impulses (**bIS**) and series of narrow-band impulses (**nIS**). The third category combined different noisy calls (**N**). The fourth category concluded the signals of mechanic and unknown origin (**MU**), such as jaw claps (MU1) and extremely low-frequency sounds "ooh-ooh" (MU2).

Echolocation impulse series (**ELIS**) duration varied from 34 to 18013 ms with a median of 614 ms. The number of clicks in train ranged from 3 to 447 ones, with a median 14. Beluga echolocation series were notable for high regularity, i.e. click repetition rate within the train usually changed gradually, or remained relatively constant. Duration of adjacent inter-click intervals (ICI) differed on average by 12 ± 12%. The average ICI within train varied from 5 to 249 ms with a mean of 56 ± 33 ms. In contrast to experimental conditions [6], echolocation trains consisting of click packets were not found in wild.

Communicative impulse sounds of the White Sea beluga whales are very similar to those of belugas from other populations [1-5]. This is probably stipulated by the fact that most of these signals have a high emotional nature, and, as it is known, emotional signals are usually shared, i.e. identical in all individuals of a species.

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