

Siberian crane duet as an individual signature of a pair: comparison of visual and statistical classification techniques

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Received: 25 October 2009 / Revised: 28 February 2010 / Accepted: 12 April 2010 / Published online: 5 May 2010
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Abstract Vocal individuality varies between species and/or ontogenesis stages depending on needs in the vocal recognition, but also estimation of individual differences depends on the method of analysis. We studied pair-specific differences of duets elicited by mating pairs of Siberian crane *Grus leucogeranus*. We quantitatively described the duet structure and compared visual and statistical classification methods of pair identification by duet. Three methods were used: discriminant analysis, method of classification trees and visual classification of spectrogram. We found significant interpair differences. The pairs differ by duet structure that is by the ratio of male- and female-initiated duets and by the ratio of the number of male to female calls; temporal-frequency duet characteristics are pair-specific, too. All methods showed high interpair differences, which exceeded random values significantly. Discriminant analysis stepwise procedure based on 11 parameters resulted in 97.3% of correctly assigned duets. Human observers correctly assigned 80.7% of spectrograms. Our data provide a basis for remote monitoring of this endangered species with a wild population of only 3,000 birds.

Keywords Duet · Vocal individuality · Acoustic monitoring · *Grus leucogeranus* · Vocal communication

Communicated by Peter McGregor

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Introduction

Individual vocal peculiarities were proven for many avian species of different groups (e.g., Falls 1982; Aubin and Jouventin 2002). Vocal recognition was also documented for many species (e.g., Stoddard 1996; Hall and Magrath 2000; Charrier et al. 2001a, b). It may serve for parents-offspring interaction, recognition between mates or neighbors.

Individuality for recognition can be coded by different acoustic traits. Reliability of an individual signature depends on ecological constraints.

For example, penguins constitute extraordinary model for studying individual recognition by acoustic means. They identify their chicks by vocal cues and complexity of vocal signature depends on the methods of care for eggs and chicks (Aubin and Jouventin 2002). Species, which have a nest that is meeting site for pair members and chicks, have a less complex vocal signature than species that have no nest. Nest-building Adélie species *Pygoscelis adeliae* and gentoo penguin *Pygoscelis papua* use frequency values of harmonics and their spectral profile in recognition, resulting in a simple signature system (Jouventin and Aubin 2002). Nest-building macaroni penguin *Eudyptes chrysolophus* uses the tempo given by the successive syllables of the call and the harmonic content of the call, but both features convey enough information to allow recognition on their own (Searby et al. 2004). Non-nesting emperor penguin *Aptenodytes forsteri* and king penguin *Aptenodytes patagonicus* use an analysis of frequency or amplitude modulations over time coupled with a beat analysis based on a precise ‘two-voice’ system and, notably, both components are strictly complementary, as both are necessary for recognition (Jouventin et al. 1999; Aubin et al. 2000; Lengagne et al. 2001).

Two closely related gull species have contrasting manner of chick rearing: nidicolous black-headed gulls *Larus ridibundus* rear chicks in the nest and chicks of nidifugous slender-billed gulls *Larus genei* leave the nest early. Comparison of the acoustic signal structure shows the presence of two fundamental frequencies in the slender-billed gull's call and only one in the black-headed gull's call. For individual recognition, a two-voice signal may constitute an advantage, since receiving birds can rely upon two harmonics series instead of one to identify an individual. Thus, the potential for individuality coding is more in the species where the offspring experiment the greatest constraints to identify their parents (Mathevon et al. 2003).

The strength of the vocal signature may vary not only from a species to another but even between conspecifics. For example, mates and relatives can have different vocal cues for individual recognition. For example, the vocal identification of Subantarctic Fur Seals *Arctocephalus tropicalis* is asymmetrical; that is, mothers mainly use temporal structures to recognize their pups' calls, but pups used both energy spectrum and ascending frequency modulation occurring at the start of each call (Charrier et al. 2003). Both male and female African Wood Owls *Strix woodfordii* are distinguished with a precision of almost 100%, but most parameters of individual identification of males and females differ (Delpont et al. 2002). Male, but not female Pukeko *Porphyrio porphyrio* have individual peculiarities (Claperton 1987). Because of such asymmetry, we suggest that a duet call, that is, a joint call of male and female, may be a way to increase the number of individual features because of the combination of male and female call peculiarities.

Vocal recognition of neighbors was found in passerine and non-passerine birds (Godard 1991; Stoddard 1996; Hardouin et al. 2006). Neighbor-stranger discrimination serves a base for "dear enemy hypothesis". The "dear enemy hypothesis" was first defined by Fisher (1954). It proposes that the level of territorial aggression is higher to strangers and lower to neighbors. Encounters between neighboring males resulted in the social adjustment that reduces the aggressive response of a bird to the songs of its neighbors (Weeden and Falls 1959). "Dear enemy effect" was found in territorial species of all vertebrates classes (see Briefer et al. 2008a) including birds (e.g., Weeden and Falls 1959; Falls 1982; Brunton et al. 2008). This effect depends on pattern of neighbors interaction. In species with high territorial instability, individuals do not respond differently to neighbors versus strangers and in species with intense competition between neighbors they react even more strongly to conspecific neighbors than to distant ones (see Briefer et al. 2008b).

Cranes display strong territorial behavior (Meine and Archibald, 1996). Particularly, Siberian cranes are territo-

rial both during the breeding season (Germogenov et al. 2009) and sometimes on winter grounds (Sauey 1985). One of the functions of the crane duet is territorial (Archibald 1976a). Thus, it would be useful for neighbor notification to have individual differences in loud territorial calls. So, we suggest that Siberian crane duets may be pair-specific and used as labeling for the territory of a mating pair.

The Siberian crane is one of the rarest crane species. The IUCN Red List of Threatened Species status is CR A3bcde+4bcde (<http://www.iucnredlist.org>). The species is divided into three populations. All but a few belong to the Eastern population. These birds breed in north-eastern Siberia (Yakutia) and winter in China (Meine and Archibald 1996). The Eastern population's breeding grounds in Yakutia are in lowland tundra. Siberian crane as well as other cranes is monogamous (Flint 1987; Degtyarev and Labutin 1999). Cranes form pair bonds within flocks of non-breeding birds or outside of the breeding season within mixed flocks; it is considered that pair bonds typically remain until one bird dies (Meine and Archibald 1996). Nevertheless, divorces when both mates remained alive were recorded for sandhill (Littlefield 1981; Nesbitt 1989; Hayes 2005) and sarus (Sundar 2005, cited by Hayes 2005) cranes. According to Nesbitt (1989), low reproductive success resulted in a divorce of all three observed pairs. However, Hayes found no correlation between divorce rate and reproductive success (Hayes 2005).

There are many methods for studying vocal individuality. Examples include discriminant analysis (Terry et al. 2005; Volodin et al. 2005), cross-correlation (Lessells et al. 1995; Terry et al. 2001), neural networks (Reby et al. 1998; Terry and McGregor 2002), visual classification of sound by human observers (Janik 1999; Terry et al. 2001), cluster analysis (McCowan 1995), and hidden Markov models (Reby et al. 2006). We used discriminant analysis, classification trees, and classification of sound by human observers, i.e., two statistical and one visual method to compare pattern recognition abilities of the human brain with statistical methods (Janik 1999). Visual classification of spectrograms is one of the simplest techniques for studying individuality because it does not require special bioacoustics, computer, or statistical knowledge. It would be very useful for bioacoustic monitoring of the endangered Siberian crane if human brain is able to distinguish spectrograms of different pairs.

Here, we aimed (1) to describe quantitatively the structure of Siberian crane duet; (2) to investigate an ability to classify correctly duets using the discriminant analysis and the classification trees method; and (3) to compare statistical classification methods and accuracy of visual classification.

Materials and methods

Sound recording

We recorded duets from 11 captive mating pairs of Siberian cranes at the Oka Crane Breeding Center, Ryazan region, Russia in 2003, 2004, and 2006. Sex of the birds was determined by karyotypic and PCR analysis before our study. Some birds were individually marked with foot rings; others had peculiarities of ornamentation and coloration that enabled individual recognition. Most recordings were obtained during the breeding seasons (May-July). Each pair had a separate open enclosure (area 100 m²) with a covered area. Neighboring pairs could hear each other. The birds were 2-28 years old (Table 1). Pairs 1, 2, and 4-10 bred before the start of our study. The first breeding of pair 3 took place in 2003, which was the first year of the study. Pair 11 was formed in year 2004.

All recordings were made outdoors from a distance of 5-50 m to the birds. This distance range is quite suitable for recording of loud crane duet as Klenova et al. (2008) found the high pair specificity of the red-crowned crane duets which were recorded from the distance 8-800 m.

Crane elicited duets in response to humans approaching and intruding into their enclosures, which is how we recorded most duets. In 2006, we provoked cranes by

using playbacks. We broadcast a pair’s own duet or duet of other pairs to the focal pair, one-three duets per playback session. Members of the focal pair could see us during playback.

We used a professional tape-recorder Marantz PMD 222 (D&M Professional, Kanagawa, Japan) and Sennheiser K6-MKH 67 (Sennheiser Electronic, Wedemark, Germany) shotgun condenser microphone. Frequency band of the whole system was 40-20,000 kHz. Playback procedure was made using the Marantz PMD-222 with a Creative TravelSound 400 dynamic (Creative Labs., Dublin, Ireland). Digitizing, spectrogram plotting both for statistical methods and visual classification was made using Avisoft SASLab Pro v. 4.38 software (Avisoft Bioacoustics, Berlin, Germany).

We digitized sounds with a sampling rate of 22.05 kHz and precision of 16 bit. For both statistical and visual analysis, we took duets with high signal-to-noise ratios and without background noise.

Sound measuring

For statistical analysis, we took duets recorded in 2003-2006 from 11 pairs, 10-52 duets per pair (Table 1). The total number of duets was 375. Pairs 8 and 11 included the same female. During the winter of 2003-2004, male 8 died,

Table 1 Year of birth, year of pair formation and number of analyzed duets for experimental Siberian cranes

Pair	Birth year	Year of pair formation	n duet			
			2003	2004	2006	Total
1	m1 1986 f1 1986 m2 1996	1987		13	21	34
2	f2 1996 m3 2001	2001	14	6	18	38
3	f3 1997 m4 1986	2002	16	19	12	47
4	f4 1994 m5 ?	1999	23	10	19	52
5	f5 1992 m6 1987	1995		5	9	14
6	f6 1991 m7 1980	1994	5	10	20	35
7	f7 1981 m8 1989	1988	20	8	20	48
8	f8 1989 m9 1980	1990	10			10
9	f9 1986 m10 1978	1990	12	15	21	48
10	f10 1996 m11 2003	1999		9	20	29
11	f11 1988	2004			20	20
Total			100	95	180	375

Male 5 was captured as a wounded bird in the wild

and his female settled with male 11. We considered these pairs as two different pairs. We made a sampling frequency conversion to 10.0 kHz. Spectrograms were created with a Hamming window, FFT-length 512 points, frame 75%, and overlap 93.75%, providing a time resolution of 3.2 ms and a frequency resolution of 20 Hz. We considered a duet as a sequence of syllables and each syllable consists of one male and one female call (Fig. 1). Frequency parameters of female calls are significantly higher than the male ones (see “Structure of Siberian crane duet” section) so it is easy to distinguish between male's and female's calls during a duet.

In the syllable, we measured a set of frequency and temporal parameters with the standard marker and free reticule cursors of Avisoft SASLab Pro. Fifteen parameters were measured for descriptive statistics: F_{peak_m} —the male call peak fundamental frequency, F_{peak_f} —the female call peak fundamental frequency, F_{min_m} —the male call minimum fundamental frequency, F_{min_f} —the female call minimum fundamental frequency, F_{max_m} —the male call maximum fundamental frequency, F_{max_f} —the female call maximum fundamental frequency, F_{st_m} —the male call start fundamental frequency, F_{st_f} —the female call start fundamental frequency, F_{end_m} —the male call end fundamental frequency, F_{end_f} —the female call end fundamental frequency, the male call frequency modulation, the female call frequency modulation, Dur_m —the male call duration, Dur_f —the female call duration, Dur_syll_m —syllable duration as the distance from one male call start to the next male call start. In addition, for descriptive statistics, we measured the duration of entire duets using duets recorded from the start until the end ($n=152$). We used 11 parameters (Fig. 2) in the procedure of analysis of variance (ANOVA), discriminant analysis and method of classification trees: F_{min_m} , F_{min_f} , F_{max_f} , F_{st_m} , F_{st_f} , F_{end_m} , Dur_m , Dur_f , Dur_syll_m , Dur_syll_f —syllable duration as the distance from one female call start to the next female call start, $T_{min-Tst_f}$ —duration from the female call start to the minimum female call fundamental frequency.

We measured 10 syllables of high quality in each duet. If a duet did not have 10 syllables, we measured all syllables. For duets with more than 10 syllables, we measured equal parts of syllables from the start and the end of a duet. For

Fig. 1 Spectrogram of the Siberian crane duet: introduction and main part. In this duet, a female calls more often than a male

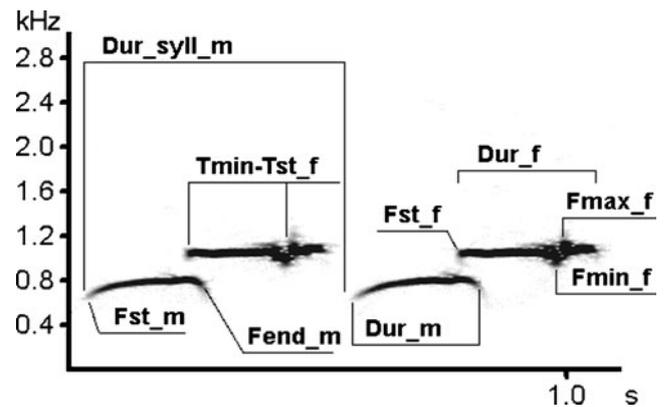
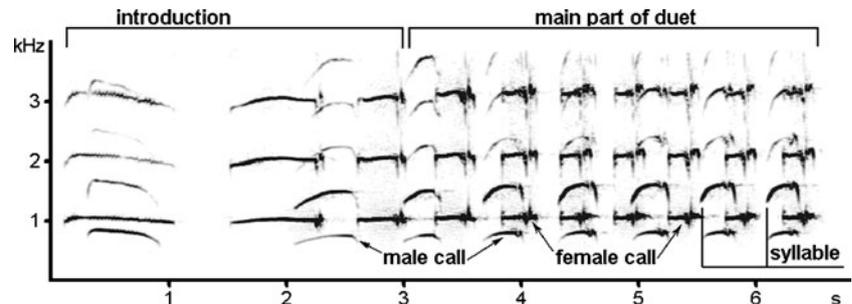


Fig. 2 The measured parameters. F_{st_m} , F_{end_m} are male call start and end fundamental frequencies, respectively; F_{st_f} , F_{min_f} , F_{max_f} are female call start, minimum, maximum fundamental frequencies respectively; Dur_m , Dur_f —male and female call durations respectively, Dur_syll_m —syllable duration as the distance from one male call start to the next male call start; $T_{min-Tst_f}$ —duration from the female call start to the minimum female call fundamental frequency. Male call minimum fundamental frequency F_{min_m} coincides with F_{st_m} ; syllable duration as the distance from one female call start to the next female call start Dur_syll_f was not shown

example if a duet consisted of 20 syllables, we measured 2, 4, 6, ...20th syllables. The total number of measured syllables from 375 duets was 3,070.

Statistics

We used the Wilcoxon matched pairs test to compare male and female call parameters; one-way ANOVA with “pair” as the grouping variable to investigate inter- and intrapair variance of frequency and temporal parameters; discriminant analysis and method of classification trees; chi-square test to compare the average percent of correctly assigned duets with random value in the procedure of visual classification.

All statistical analyses were carried out in STATISTICA v. 6.0 (StatSoft, Inc., Tulsa, OK, USA).

Discriminant analysis

All 11 parameters were tested for normality by the Kolmogorov-Smirnov and Lilliefors test. As some of the

parameters did not have a normal distribution, we found the decadic logarithm of all parameters.

Randomization of discriminant analysis results was done according to the Solow method, which was designed for the discriminant analysis of correlated parameters (Solow 1990). Procedure of randomization was coincided with Klenova et al. 2008.

For validation and corroboration of results, we used cross-validation procedure. We divided our sample in two in a random manner, and discriminant functions obtained from one part were used for classification of another part (Volodin et al. 2005).

Method of classification trees

The method of classification trees is intended to substitute discriminant analysis if the data set is too small and its distribution differs from the normal one (Feldesman 2002). We used this method as another way to validate results of the discriminant analysis stepwise procedure, so we included the same 11 parameters.

Visual classification of spectrogram

For visual analysis, we used duets recorded in 2006 from nine pairs (pairs 1-4, 6, 7, 9-11), 10 duets per pair. Therefore, we analyzed 90 duets. For spectrogram creation, we made sampling frequency conversion to 8.0 kHz. We used a Hamming window, FFT-length 512 points, frame 50%, and overlap 93.75%, providing a time resolution of 4 ms and a frequency resolution of 16 Hz. Each duet corresponded to one 4-s spectrogram, and the start of a spectrogram coincided with the start of a male call. As the duration of a syllable was 0.508±0.055 s (Table 2), a 4-s

spectrogram included seven to nine syllables. We printed each spectrogram on a separate sheet and gave them a random number from 1 to 90. Nine human observers participated in visual classification as volunteers. None of them was a professional biologist and nobody was experienced in bioacoustics research. We prepared special instructions for volunteers. The instructions included the definition of a spectrogram as the relationship between frequency and time and brief information about the syntax of a Siberian crane’s duet. We asked volunteers to pay no attention to echo, sound intensity, or noise as these features depend on conditions recording. The goal of each volunteer was to divide the 90 spectrograms into nine groups.

Results

Structure of Siberian crane duet

The syntax of the male and female parts of the duet is the same, but frequency parameters give the opportunity for reliable sex identification of a mate.

A duet of the Siberian crane begins with an introduction, which is a protracted call of the male or female (Fig. 1). In total, we recorded 165 duets from the start; 77 duets (46.7%) were started by a female and 88 (53.3%) by a male, but this ratio was pair-specific. Males more often started a duet in pairs 1, 4, 11; females in pairs 2, 5, 7, 9 (Table 3).

After the introduction, the partners commenced to call by turn in the main part of a duet. Female and male calls can overlap to a varying extent; Figure 1 shows both simultaneous and consecutive calls of partners. On average, the number of male and female calls is equal. The ratio of male to female

Table 2 Descriptive parameters of Siberian crane duets

Parameter		Mean±SD	Wilcoxon matched pairs test
Fpeak, kHz, n=3,070	♂	0.86±0.08	T=463.0, Z=16.5, p<0.0001
	♀	1.06±0.08	
Fmin, kHz, n=3,070	♂	0.81±0.07	T=148.0, Z=16.7, p<0.0001
	♀	1.00±0.07	
Fmax, kHz, n=3,070	♂	0.89±0.09	T=610.0, Z=16.5, p<0.0001
	♀	1.10±0.07	
Fst, kHz, n=3,070	♂	0.81±0.07	T=102.0, Z=16.7, p<0.0001
	♀	1.00±0.06	
Fend, kHz, n=3,070	♂	0.86±0.08	T=138.0, Z=16.7, p<0.0001
	♀	1.10±0.07	
frequency modulation, kHz, n=3,070	♂	0.08±0.06	T=24341.0, Z=5.0, p<0.0001
	♀	0.09±0.04	
call duration, ms, n=3,070	♂	216.7±45.7	T=16223.0, Z=9.1, p<0.0001
	♀	194.6±34.8	
Dur_syll_m, s, n=3,070		0.508±0.055	
duet duration, s, n=152		11.1±5.2	

Table 3 The percentage of male- and female-started duets and the ratio of call number

n of male- and female-started duets						The ratio of the number of male to female calls in a duet			
Pair	Male		Female		Total	Year			Average
	Number	%	Number	%		2003	2004	2006	
1	9	81.8	2	18.2	11		0.96	0.98	0.97
2	3	21.4	11	78.6	14	0.94	0.99	1.02	0.98
3	11	61.1	7	38.9	18	0.98	0.99	1.00	0.99
4	31	77.5	9	22.5	40	1.02	1.15	1.23	1.13
5	1	16.7	5	83.3	6		0.76	0.81	0.78
6	7	38.9	11	61.1	18	1.04	1.15	1.08	1.09
7	3	15.8	16	84.2	19	0.76	0.80	0.76	0.77
8	1	50.0	1	50.0	2	0.98			0.98
9	4	25.0	12	75.0	16	0.94	0.98	0.98	0.97
10	5	62.5	3	37.5	8		0.99	1.01	1.00
11	13	100.0	0	0.0	13			0.98	0.98

call numbers is 0.97 ± 0.15 (SD), $n=350$ duets, but this value varied between the pairs (Table 3). Females called significantly more often in pairs 1 (Wilcoxon matched pairs test: $T=38.5$, $n=30$, $p<0.01$), 5 ($T=0$, $n=12$, $p<0.01$), 7 ($T=0$, $n=47$, $p<0.001$), and 9 ($T=51$, $n=46$, $p<0.01$); males called significantly more often in pairs 4 ($T=50$, $n=51$, $p<0.001$) and 6 ($T=36.5$, $n=32$, $p<0.001$). In pairs 2, 3, 8, 10, and 11 the number of calls does not differ significantly between the sexes ($p>0.001$).

Fpeak, Fmin, Fmax, Fst, Fend of female calls are significantly higher than the male ones (Table 2). The difference between the average values of frequency parameters between males and females is 0.19–0.24 kHz, i.e., 23–28%. The difference in call duration is also significant, but the overlap interval is very big (Wilcoxon matched pairs test: $T=16,223.0$, $n=3,070$, $p<0.0001$), and call duration does not provide reliable information on bird sex.

ANOVA

ANOVA showed highly significant interpair differences for all 11 parameters analyzed. The biggest F ratio had the male call start fundamental frequency Fst_m ($F_{1,10}=133.4$, $p<0.0001$), the male call minimum fundamental frequency Fmin_m ($F_{1,10}=129.3$, $p<0.0001$), the male call duration Dur_m ($F_{1,10}=83.6$, $p<0.0001$), and the male call end fundamental frequency Fend_m ($F_{1,10}=77.4$, $p<0.0001$). F ratio for the female call minimum fundamental frequency Fmin_f was $F_{1,10}=66.8$, $p<0.0001$, for the female call start fundamental frequency Fst_f $F_{1,10}=65.7$, $p<0.0001$, for the duration from the female call start to the minimum female call fundamental frequency Tmin-Tst_f $F_{1,10}=62.2$, $p<$

0.0001, for the syllable duration as the distance from one male call start to the next male call start Dur_syll_m $F_{1,10}=61.2$, $p<0.0001$, for the female call maximum fundamental frequency Fmax_f $F_{1,10}=60.4$, $p<0.0001$, for the syllable duration as the distance from one female call start to the next female call start Dur_syll_f $F_{1,10}=57.8$, $p<0.0001$, for the female call duration Dur_f $F_{1,10}=44.2$, $p<0.0001$.

Discriminant analysis

Of the total number of 375 duets, 97.3% were assigned correctly, that is significantly higher ($p<0.01$) than the random value 21.4 ± 1.6 (SD). Percent of correct assignment varied from 90.0 (one pair) to 100.0 (four pairs). Three parameters of main contribution to discrimination in descending order are Fst_m, Fmax_f, Fst_f: 83.5% of duets were assigned correctly using them. As mentioned above, the same female was a member of pairs 8 and 11. Nevertheless, not a single duet of pairs 8 and 11 was wrongly assigned.

For the cross-validation procedure we obtained discriminant functions from the first half of the sample (learning sample, $n=188$) and applied them to the second half of the sample (test sample, $n=187$). In the learning sample, 96.8% of duets were assigned correctly; stepwise discriminant analysis of the test sample with discriminant functions from the learning sample resulted in 95.7% of duets being correctly classified. Then we swapped the learning sample with the test one, and 98.9% of duets were assigned correctly by stepwise discriminant analysis of the test sample; analysis of the learning sample with discriminant functions from the test sample resulted in 95.7% of duets being correctly classified.

Method of classification trees

From 375 duets, 92.5% were assigned correctly. Three parameters of main contribution to discrimination in descending order were Fmax_f, Dur_syll_m, Fmin_m. Therefore, the female call maximum fundamental frequency played an important role both in discriminant analysis and the method of classification trees, but other parameters differed.

We conducted tenfold cross-validation. Learning ($n=188$) and test ($n=187$) samples were the same as for discriminant analysis. Cross-validation analysis resulted in 86.1% of duets being correctly assigned.

Visual classification of spectrograms

The average for correctly assigned duets was 80.7 ± 11.7 (SD), but this was pair- (68.9-97.8%) and volunteer-dependent (64.4-95.6%, Table 4). The random value of correct assignment for nine groups in such type of analysis is 100% divided by 9=11.1%. Thus, the average percent of correctly assigned duets was significantly more than the random value, chi-square test: $\chi_1^2=490.9$, $p < 0.0001$. Figure 3 shows interpair differences in male and female call configuration and the character of frequency modulation in duets of different pairs.

Discussion

We found significant pair-specific differences in the duet of the Siberian crane. Pairs differed by both duet structure and temporal-frequency parameters of the duets. There are pair-specific differences in the ratio of male and female calls; the pairs differed by the start of a duet.

Both statistical and visual analyses show pair-specific differences of duets. All methods, that are discriminant analysis, method of classification trees, and visual classification, resulted in high-expressed interpair differences, but discriminant analysis was the best predictor.

Individual vocal cues

We used six frequency and five temporal parameters of Siberian crane duets for analysis of individual features. Frequency parameters had more potential for the vocal recognition. The biggest F ratio had the male call start fundamental frequency (Fst_m), the male call minimum fundamental frequency (Fmin_m) and the male call duration (Dur_m); the main contribution to discriminant analysis made the male and the female call start fundamental frequencies (Fst_m, Fst_f) and the female call maximum fundamental frequency (Fmax_f). The male call duration (Dur_m) had a big F ratio too, but other temporal parameters contributed to the discrimination less than frequency ones. It appears that the frequency domain is more important than the temporal one but both are essential for the pair-specific identification.

Classification of red-crowned crane duets with procedure of discriminant analysis also shows high pair-specific differences of duets (Klenova et al. 2008). Most syllables of red-crowned crane duet consist of one male and two female calls. It was shown that three parameters contributed the most in discrimination in order of decreasing importance were the first female call maximum fundamental frequency (Fmax_F1), the male call maximum fundamental frequency (Fmax_M), and the male call duration (Dur_M). According to ANOVA, Fmax_F1, Dur_M and the second female call maximum fundamental frequency (Fmax_F2) were the most pair-specific parameters (Klenova et al.

Table 4 Number of correctly assigned duets per pair per volunteer. Ten duets were taken from each pair, so percent of correctly assigned duets= number x 10

Pair	Volunteer									Average number of correctly assigned duets	Average% of correctly assigned duets
	1	2	3	4	5	6	7	8	9		
1	9	10	3	4	9	10	10	9	10	8.2	82.2
2	6	4	8	7	6	7	8	9	9	7.1	71.1
3	6	6	8	9	9	6	8	10	9	7.9	78.9
4	7	10	10	10	10	10	10	10	10	9.7	96.7
6	5	7	4	7	8	6	8	10	9	7.1	71.1
7	9	10	10	10	9	10	10	10	10	9.8	97.8
9	3	5	9	5	8	10	9	9	10	7.6	75.6
10	6	4	5	4	6	9	10	9	9	6.9	68.9
11	7	8	7	9	9	6	10	10	10	8.4	84.4
average	64.4	71.1	71.1	72.2	82.2	82.2	92.2	95.6	95.6	8.1	80.7

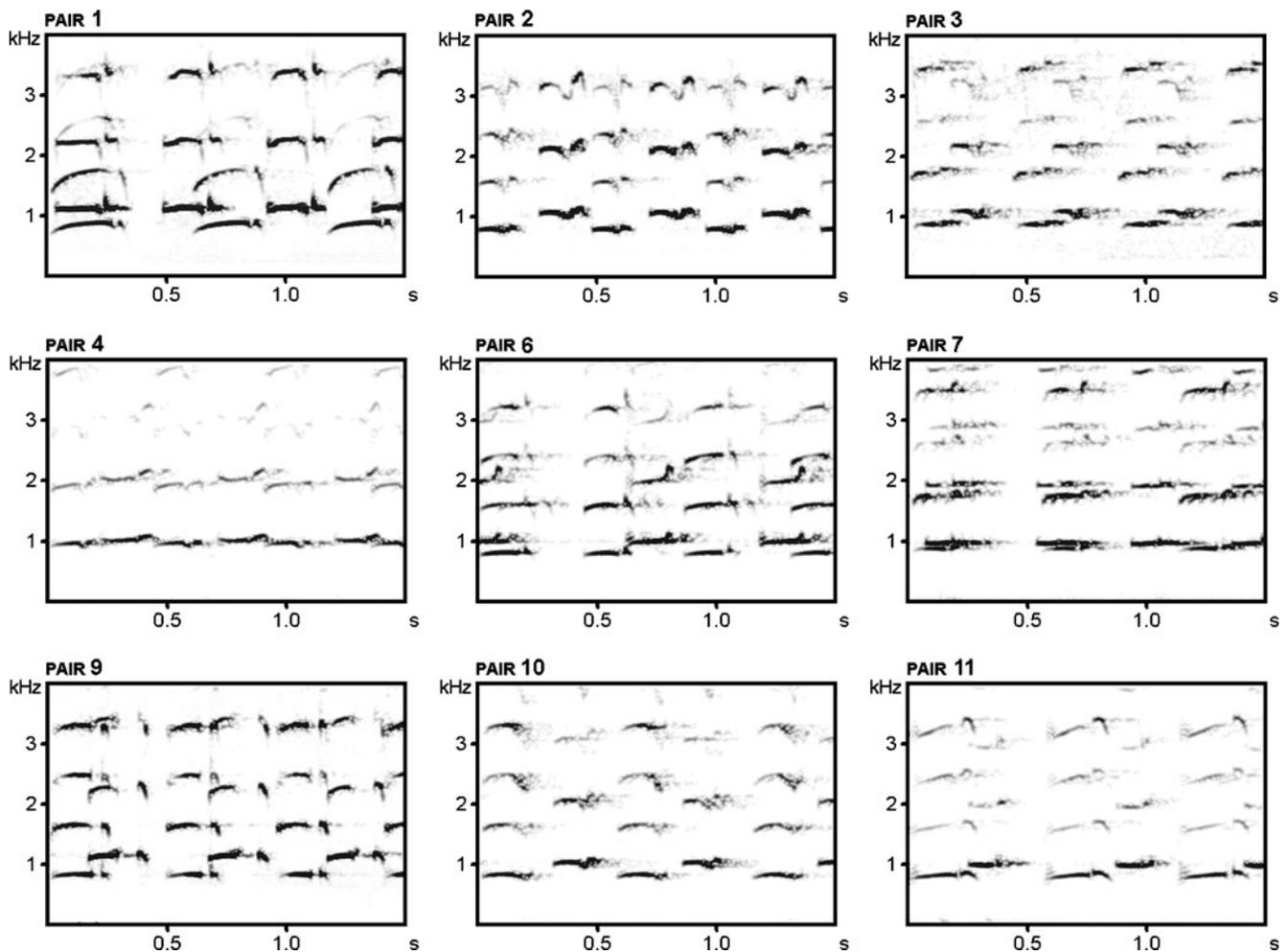


Fig. 3 Duet spectrograms of nine pairs. Interpair differences consist in frequency and temporal parameters, character of frequency modulation, rate and extension of male and female call overlapping

2008). It seems that frequency parameters contributed more to pair identity of red-crowned as well as of Siberian crane. However, temporal parameters mattered also.

Temporal, frequency or spectral parameters may contribute to individual recognition more or less in dependence on species and its ecology. In the most species, individual discrimination is provided by combination of some parameters. Analysis of the contact call of greater flamingo *Phoenicopterus ruber* revealed that most individual features of the calls were frequency ones: the first frequency of the spectrum and the frequency with the highest energy. However, the spectrum width, the principal portion of the spectrum, the call duration and the slow amplitude modulation were also informative (Mathevon 1997). In two seabirds, Yelkouan shearwater *Puffinus yelkouan* and the Mediterranean Cory's shearwater *Calonectris diomedea*, the individual signature was mainly supported by temporal features, particularly the duration of call parts. However, fundamental frequency values of Mediterranean Cory's shearwater, and energy spectrum features of both

sexes Yelkouan shearwater and Mediterranean Cory's shearwater female, were also relevant in the vocal individual signature (Curé et al. 2009). Macaroni penguins *E. chrysolophus* use the tempo given by the successive syllables and the harmonic content of the call. Thus, individual signature is provided by spectral and temporal parameters (Searby et al. 2004). Non-nesting penguins, emperor penguin *A. forsteri* and king penguin *A. patagonicus* use 'two-voice' system, but emperor penguin couple 'two-voice' system with temporal parameters and king penguin couple it with frequency ones (for review, see Aubin and Jouventin 2002).

Functions of Siberian crane duet

Duets were described for 222 bird species of 44 families (Farabaugh 1982). Avian duets may have various functions (see Hall 2004 for review). All 15 crane species, including the Siberian crane (Bragina and Beme 2007), have very loud duets suitable for recording from a distance (Archibald

1976b, Klenova et al. 2008). The crane duet contains both sexual and threat functions (Archibald 1976a). Sexual functions include pairing, sexual stimulation and synchronization, intrapair and interpair sexual functions, and pair bond maintenance. Threat functions are connected with territorial defense and the threat between pair members (Archibald 1976a, b).

Individual and interpair differences of avian duets are poorly studied. Male song in duets was highly individual in duets of Steere's liocichla *Liocichla steerii* (Mays et al. 2006). Playback experiments in Australian magpie-larks *Grallina cyanoleuca* showed that individuals are able to discriminate between neighbors and strangers by their duets (Hall and Magrath 2000). Among cranes, three species were shown to have interpair differences. The gray-crowned crane *Balearica regulorum gibbericeps* (Budde 2001), Eurasian crane *Grus grus* (Wessling 2000) and red-crowned cranes *Grus japonensis* (Klenova et al. 2008) duets were shown to be suitable for discrimination of mated pairs. Our data show pair-specific differences of the Siberian crane duet. Thus, the loud duet has a potential to serve as a marker of a mating pair's territory. We hypothesize that neighboring pairs may recognize each other with help of duets and maintain territory boundaries thereby according to the "dear enemy" hypothesis. Further research with playbacks of neighbor and stranger duets has to be done to determine the marker function of Siberian crane duet.

Possibility of bioacoustic monitoring

Our volunteers who classified spectrograms visually had no experience in bioacoustics research in connection with applied importance of pair identification. We aimed to develop an easy way for pair identification without special bioacoustics knowledge. Besides, experienced and non-experienced volunteers did visual classification of fantail warbler *Cisticola juncidis* and great bittern *Botaurus stellyaris* sounds with the same accuracy (Terry et al. 2001).

Results of visual classification vary depending on the species. Visual classification of fantail warbler and great bittern sounds resulted in poorer accuracy than discriminant analysis (Terry et al. 2001). At the same time, visual classification was better than three computer methods for classification of bottlenose dolphin *Tursiops truncatus* whistles (Janik 1999) as the human brain is able to estimate the similarity of whistle contours despite extension or compression relative to the time axis.

Ability of inexperienced human observers to assign duets correctly is very important for monitoring and conservation of the Siberian crane. The wild population of the Siberian crane is estimated at ca. 3,000 birds (Meine and Archibald 1996), so constant monitoring is a must.

Distant duet recording and the following identification gives the possibility to avoid disturbing the cranes. Bioacoustic monitoring of wild bird populations is applied to eagle owl *Bubo bubo* (Grava et al. 2008), corncrake *Crex crex* (Peake and McGregor 2001; Terry and McGregor 2002), great bittern (Gilbert et al. 2002), African wood owl (Delport et al. 2002), scops owl *Otus scops* (Galeotti and Sacchi 2001) and other species, either nocturnal or living in dense vegetation. We showed the potential of Siberian crane duet for this method. Duet of the Siberian crane may be used for population censuses and monitoring of mating pairs for some years. It is possible to determine the number of pairs, number of raised chicks for several years and other aspects of Siberian crane biology with this method.

Acknowledgments We thank I. A. Volodin for his huge help with data processing. We thank the staff of the Oka Crane Breeding Centre of the Oka Biosphere State Nature Reserve, especially T.A. Kashentseva, K.A. Postelnykh, T.V. Postelnykh, and E.V. Antonyuk for providing the possibility for research and for their all around help during data gathering. We appreciated A.V. Klenova for her help with the duet recording. N.S. Chernetsov and A.V. Klenova made helpful comments. We thank M. and D. Banin for improvement of English. We thank anonymous reviewers for useful advice and comments on earlier versions of the manuscript. During our work, we adhere to the "Guidelines for the treatment of animals in behavioral research and teaching" (Anim. Behav. 65: 249–255) and the laws of the Russian Federation where the research was conducted. This study was supported by the Russian Foundation for Basic Research (grant 07-04-00609).

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