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SEMI-QUANTITATIVE METHOD OF SONG SIMILARITY ANALYSIS ON AN EXAMPLE OF CHAFFINCH SONGS IN UKRAINE

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Abstract. There are 3 ways of sonogram and wave-form analysis now: visual comparison of sonograms, comparison of numerical characteristics of sound parameters and automatic algorithmic similarity search. Imperfections of these methods are their certain subjectivity or neglect important nuances of song structure. We have worked out the semi-quantitative method of song analysis. It is based on formalized description of song elements. This method intends for research of song elements' and song type variation. It was tested for analysis of Chaffinch songs in Ukraine. First step is the description of any element of sonogram as consecution initial sub-elements by means of parameter marking by letters: first (second, etc.) sub-element is whistle (wh) or trill (t), long (l) or short (sh), wide (w) or narrow (n) etc. "Formula of element", or complete description of element, is the result of this step. Next, all complete descriptions of elements are compared with each other on all sub-elements. Sums of coincident and non-coincident parameters of pairs of elements created matrix table. Sørensen's index was calculated for all pairs of elements. Tree clustering is created by Ward's method (using STATISTICA 5.1). The table of groups of elements is result of this work. Next step is the making of song description in the form of song formula. Song formula is the step by step list of all song elements in the form of enumeration of element alphanumeric code names, with one code to each phrase. It used for comparison of song types.

Key words: bioacoustics, Chaffinch, *Fringilla coelebs*, method, similarity, song type, element.

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Полуколичественный метод анализа сходства песен на примере песен зяблика. - Яблоновская-Грищенко Е.Д. - Беркут. 15 (1-2). 2006. - Существующие на данный момент методы анализа сонограмм имеют ряд недостатков, заметно ухудшающих их эффективность. Это субъективность сравнения элементов и типов песен либо игнорирование тонких нюансов их структуры. Нами предложен уменьшающий влияние таких недостатков полуколичественный метод анализа песни. Этот метод был использован для анализа песен зяблика с территории Украины. Алгоритм применения метода таков. Первый этап – представление каждого элемента песни (графического образа с сонограммы, соответствующего данному звуку) как комплекса субэлементов. Каждый субэлемент описывался словесно жестко зафиксированной последовательностью эпитетов, описывающих его форму (как, например, свист (wh) или трель (t), длинная (l) или короткая (sh) и т. д.). Описание, или формула, элемента представляла собой совокупность описаний всех его субэлементов. Мерой сходства элементов служило количество совпадений эпитетов для каждой сравниваемой пары элементов при последовательном, без перестановок, их сравнении по субэлементам. Группы сходно звучащих элементов выделялись с помощью кластерного анализа. Описание типа песни, или формула песни, получила вид последовательности буквенно-цифровых обозначений всех ее элементов, что позволило сравнивать типы песен не визуально, а через сходство описаний (количество совпадений названий элементов). Дендрограммы сходства элементов и типов песен строились в программе STATISTICA 5.1 по методу Варда с использованием индексов общности Чекановского-Съеренсена.

Wave-forms and sonograms are used to song analysis. Some problems of reliable and unbiased comparison show up at this data processing. There are 3 ways of sonogram and wave-form analysis now: visual comparison of sonograms, comparison of numerical characteristics of sound parameters and automatic algorithmic similarity search. There are some field of competence and disadvantages to everyone method.

The most commonly used method is visual comparison of sonograms and their similarity search by two or several experts. It is used in the most part of studies until recent times (Baptista, 1977; Baptista, King, 1980; Martindale, 1980; Baker, 1983; Austen, Handford, 1991; Böhner, Wistel-Wozniak, 1995; Miyasato, Baker, 1999; Geberzahn, Hultsch, 2004; Kumar, 2004; Leitão et al., 2004; Astakhova, Boeme, 2006, etc.). This is the way of analy-

sis of any acoustic signals including long complicated non-structuring songs. However, its important disadvantage is subjectivity of comparison of graphical images. As experts may use different arbitrary characteristics to elements relation search, the subjectivity of related groups of elements allocation becomes more considerable (Grabovsky, Panov, 1992; Williams, 1993). Sometimes visual comparison may ignore important nuances of song structure and results in mistakes of comparison. Occasionally verbal description of elements is used as the analysis unit (Cunningham et al., 1987). However, element as complex of sub-elements at standard algorithm is not applied in referred study.

Using numerical characteristics of sound physical properties (audio frequency, sounding time) is the next method of song or song part comparison (Austen, Handford, 1991; Larsen et al., 1997; Baril, Barlow, 2000; Lampe et al., 2004; Mendes, Ades, 2004; Ehrengruber et al., 2006, etc.). This method considered to be the most suitable for analysis of non-song signals or short simple structure songs. It allows assessing some parameters of sound impartially. Loss of song structure nuances and decrease of analyzable parameter complexes are its disadvantages.

In order to decrease of disadvantages influence, both abovementioned methods are used for song analysis (Cunningham et al., 1987; Goretskaya, Korbut, 1998, etc.).

The third method of song analysis is automated recognition of songs or song elements based on image understanding algorithm (Williams, 1993; Avelino, Vielliard, 2004; Chesmore, 2004 et al.), including artificial neuron network use (Aubin et al., 2004). At present time, it is not very widespread because recognition is possible only for some song types or elements. Templates to recognition are selected by researcher (Anderson et al., 1996; Kogan, Margoliash, 1997) and this is an element of subjectivity as in the case of visual comparison method. Another disadvantage of this method is problem of complexity of automated recognition in a case of small differences in comparable elements. This method is destined for recognition of songs or elements rather than for their similarity degree search.

These methods do not answer the purpose of our study. We see as search of similarity of song element formalised descriptions was the first step of unbiased song type comparison. Comparison of sequences of song element descriptions (song formulas) is the best way of song type comparison. We propose new method of formalised description and non-graphical information about song with minimal loss of information. This is the semi-quantitative method of song similarity analysis. Its algorithm is presented below. It decreases song analysis and comparison subjectivity essentially. The method is based on definitely formalised description of song elements, theirs classification using cluster analysis, and song formulas making. Song formula is the formalised description of element consecution in the form of alphanumeric codes. Classification of song formulas is carried out using cluster analysis. This, in fact, is the expert evaluation of graphical image of song by the definitely limited set of characteristic features of the same image. Formalised song formula is the result of the same evaluation. Resembling semi-quantitative analysis of graphical information is used in some another studies. For example, V.N. Grishchenko (1994) used it for analysis of similarity of autumn bird migration in Ukraine on phenological maps.

Formalised song element description and element grouping to similar elements essential distinctions detection are necessary to song formula making. Element description is based on severely fixed list of epithets. It defines all feature complex of element as dichotomic guide list of epithets (Yablonovska-Grishchenko, 2005, 2006).

We investigated Chaffinch (*Fringilla coelebs*) song in our study. It is short, structured, and sharply detached at time. Therefore it is very convenient to approbation of our method.

During 2002–2004, 2286 songs of 244 Chaffinch males from central and northern Ukraine (the Kaniv Nature Reserve, Cherkasy

region; Seym Landscape Park, Sumy region; Kyiv and forests near the Ros river, Kyiv region) were analysed to develop epithet list and element descriptions.

We recorded songs using digital camcorder Sony TRV 110 E with external microphone. Sound files were saved in Wave-format. Sound data were not compressed. Sonograms were generated using Sonic Foundry Sound Forge 5.0 and Syrinx 5.2s (John Burt, http://www.syrinxpc.com).

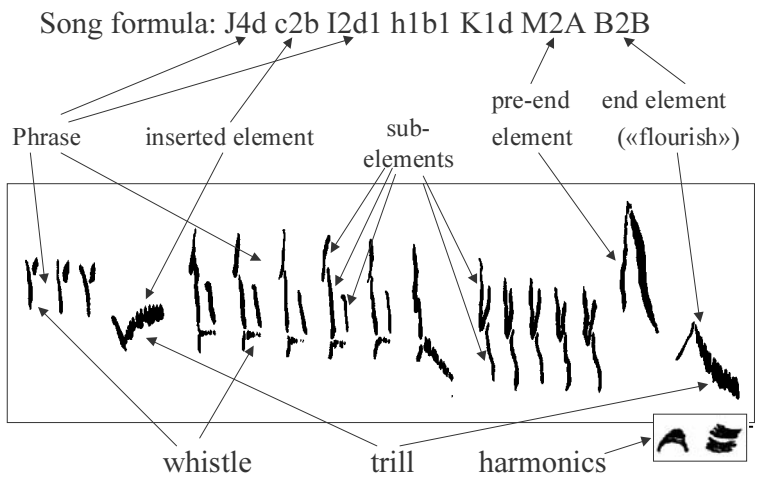

Fig. 1. Used terms.
Рис. 1. Используемые термины.

As a result, 101 elements were found in all song types of analysed sonograms. All elements were registered in the element catalogue. New elements from another study sites were added to the catalogue later.

Every song element was defined as a graphical image from the sonogram. It was described as complex of some parts or sub-elements (Fig. 1).

The first step of the study was selection of characteristic list for description of any element. They look like epithets – graphical image of sub-elements descriptions. There are three sound types, including whistle (it looks like line in sonogram), trill (looks like "brush"), harmonic (some lines, one above other) (Fig. 1) and their graphical image characteristics – long or short, horizontal or vertical and so on (Table). They were fall into groups. There is a certain only one epithet of group for every sub-element. Description by epithet list was making for every sub-element of element (there are 1–6 sub-elements in an element). It looks like list of epithet codes of all sub-elements of element from Table (to 45 positions) with descriptions of sub-element types and their epithet lists. This is the work element formula (Fig. 2).

The next step is the search of similar element groups. All element formulas were compared with each other. As a result, we got matrixes of epithet number coincidence for element pairs in element groups – for trill, whistle and harmonic elements.

Comparison was made in the following way:

1. Whistles, harmonics, and trills are compared separately. Identical epithets use to whistle and trill, or harmonic and trill do not consider coincidence.

2. Epithet comparison of all sub-elements is made one after another (first and last sub-elements of one element do not compare with last and first sub-elements of another). Only next way of comparison is allowable (W – whistle, T – trill):

1 element T W W or T W W
↕ ↕ ↕
2 element W W T W W T,

depending on epithet coincidence number prevalence (trills or whistles coincidence is higher). Higher coincidence number is chosen.

3. Comparison of elements of one type is made in a similar manner:

Sub-element description list Список описаний субэлементов

Whistle – Wh	Trill – T	Harmonic – H
(Begins) from above – A	(Begins) from above – A	(Begins) from above – A
In the middle – M	In the middle – M	In the middle – M
From below – B	From below – B	From below – B
Left tilt – Lt	Left tilt – Lt	Left tilt – Lt
Right tilt – Rt	Right tilt – Rt	Right tilt – Rt
Vertical – Vr	Vertical – Vr	Vertical – Vr
Horizontal – Hr	Horizontal – Hr	Horizontal – Hr
Down-up – DU	Down-up – DU	Down-up – DU
Up-down – UD	Up-down – UD	Up-down – UD
Very long – Vl	Very long – Vl	Thick – Tk
Long – L	Long – L	Thin – Tn
Short – Sh	Short – Sh	
Very short – Vs	Very short – Vs	Joins from above – Ja
	Middle – Md	Joins in the middle – Jm
		Joins from below – Jb
Straight – S	Straight – S	
Curved to the right – Cr	Curved to the right – Cr / Curved downward – Cd	
Curved to the left – Cl	Curved to the left – Cl / Curved upward – Cu	
Double bend – S	Double bend – S	
Double bend mirroring – 2	Double bend mirroring – 2	
Narrow – N	Narrow – N	
Wide – W	Wide – W	
Very wide – Wv		
Wide from above – Wa	Wide from above or in the beginning – Wa /Wn	
Wide from below – Wb	Wide from below or in the end – Wb/We	
Wide in the middle – Wm	Narrow in the middle – Nm	
Strongly curved – Cs	Strongly curved – Cs	
Feebly curved – Cf	Feebly curved – Cf	
Far to horizontal – Hf	Far to horizontal – Hf	
Near to horizontal – Hn	Near to horizontal – Hn	
Far to vertical – Vf	Far to vertical – Vf	
Near to vertical – Vn	Near to vertical – Vn	
Joins from above – Ja	Joins from above – Ja	
Joins in the middle – Jm	Joins in the middle – Jm	
Joins from below – Jb	Joins from below – Jb	
Joins from the right – Jr	Joins from the right – Jr	
Joins from the left – Jl	Joins from the left – Jl	
“Hook” from the right – Kr	Close – Ct	
“Hook” from the left – Kl	Infrequent – It	
“Hook” from above – Ka	Left-dislodged angle – Al	
“Hook” from below – Kb	Right-dislodged angle – Ar	
	Symmetrical angle – As	
Wide “hook” – Kw		
Narrow “hook” – Kn	Sharp angle – Ap	
	Wide angle – Aw	

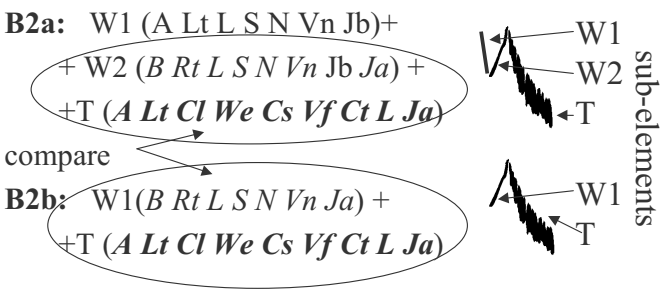

Fig. 2. Example of element formulas description and theirs comparison.
Рис. 2. Пример записи и сравнения формул элементов.

1 element W1 W2 W3 W1 W2 W3
↕ ↕ or ↕ ↕
2 element W1 W2 W3 W1 W2 W3,

depending on epithet coincidence number prevalence. Higher coincidence number is chosen. Comparison is allowed in case of one sub-element is ignored; because new elements can generate by means of sub-element disappear.

However, cross compare way:

1 element W1 W2 W3
↕ ↕
2 element W1 W3 W2

is inadmissible, because this comparison way indicates similarity of sub-elements, not elements.

4. Higher coincidence number is chosen in any case. Sub-element consecution without gaps is chosen in case of equal coincidence number.

1 element W1 W2 W3 W1 W2 W3
↕ ↕ or ↕ ↕
2 element W1 W2 W3 W1 W2 W3.

In this case we choose the first variant.

To element groups affinity search we used cluster analysis. To pair of elements similarity degree search we used Chekanovsky-Sørensen index as the most adequate to comparable lists similarity dimension (species, types, etc.) and arcwise connected with absolute similarity measure (Pesenko, 1982). Similarity element groups were obtained by Ward method (method of intraclass dispersion minimization) in STATISTICA 5.1, because one is the best cluster polythetic method (Pesenko, 1982) and the most sensitive to comparison of matrixes with small index differences. Its results are the most adequate to biological interpretation.

We analysed whistle and trill elements separately (Fig. 3). Every group was marked by letter, every sub-group was marked by number. Elements in sub-group were marked by letters in alphabetical order. Code name of element looks as A1a, B2c, I3d etc.

Every group and sub-group was characterized by some basic traits. They are present in any element of sub-group. New elements' group belonging determines by these traits. For example, ascending by frequency whistle and descending trill are basic traits of B2 sub-group. New element position in sub-group is found by its similarity with other elements of sub-group. It named using number after last letter, if its position is in the middle of group (B2b1 after B2b), and it named using next letter alphabetically if its position is in the end (B2d after B2c). We see, the code name of element is its structural description.

Next step is the making of song description in the form of song formula. Song formula is the step by step list of all song elements in the form of enumeration of element alphanumeric code names, with one code to each phrase. Way of letter writing is significant to formula self-descriptiveness increase. Phrase element code is A1a, inserted element code is a1a, end or pre-end element code is A1A (Fig. 3). Terminal element "kit" we did not analyse because it was found in any song type. However, this element was used as the song end marker at new song type description time.

Song type is definitely limited stable sound consecution with phrase structure. Terms "phrase" and "note" are specified by V.D. Illichev (1971). This consecution is invariable,

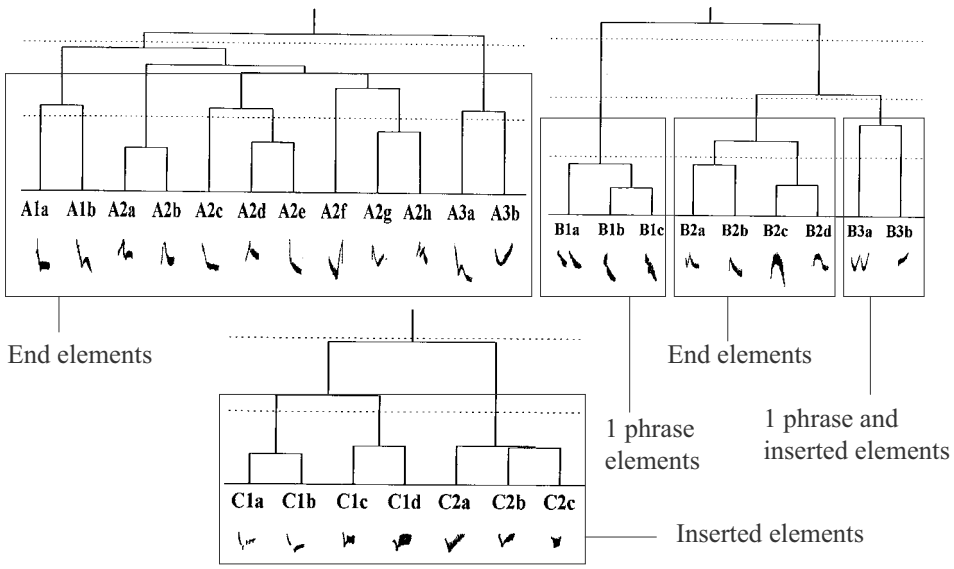

Fig. 3. Element similarity (trills). Рис. 2. Дендрограмма сходства элементов (трели).

but individual phrase sounds may replace by other similar sound sometimes. Song sub-type is described in this case. Element number in phrase may change both by one bird and by different birds, but phrase consecution in type is constant.

Song formula has the following form – K2b c2d N3c L2e N2B B2B; B3a c1a M2d L2d H1B A1A; H4b I2b J4a H3C etc (Fig. 4).

Any new song type was recorded in the following way: its song formula was described with its time-code in its sound file in data base record and its sound was copied to file with name look like its sing formula in song type catalogue.

New type recorded in case of more than two phrase differences or in a case of appearance of new phrase (except inserted or pre-

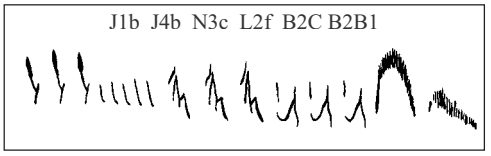

Fig. 4. Song in sonogram and its song formula.
Рис. 4. Формула песни и ее сонограмма.

end elements) (for example, types A2f I2e L1c N2B I3B and J1c A2f I2e L1c N2B I3B). Sub-types were recorded in case of 1 or 2 phrase differences. Although, different types often have more than tree differences, and differences between types and sub-types are good marked.

Study of Chaffinch song dialects in Forest and Forest-steppe zones of Ukraine and in the Ukrainian Carpathians was conducted using this semi-quantitative method in 2002–2006. Some results have been published (Yablonovska-Grishchenko, 2005; Yablonovska-Grishchenko, Grishchenko 2005; Yablonovska-Grishchenko et al., 2006).

Proposed method may be used for study of species with structured and sharply detached element orders or songs (similar with Chaffinch song). It may be used to template selection in automated recognition of elements and song types as complexes of elements.

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REFERENCES

Anderson S.E., Dave A.S., Margoliash D. (1996): Template-based automatic recognition of birdsong syllables from continuous recordings. - J. Acoust. Soc. Am. 100 (2): 1209-1219.

Astakhova O., Boeme I.R. (2006): [Typological organization of Chaffinch (*Fringilla coelebs*) song in Courish Spit population]. - [Population ecology of animals. Matherials of International conference "Problems of population ecology of animals" in memory of academician I.A. Shilov]. Tomsk: Tomsk University. 207-208. (In Rus.).

Aubin T., Mathevon N., Da Silva M.L., Vielliard J.M.E., Sebe F. (2004): How a simple and stereotyped acoustic signal transmits individual information: the song of the White-browed Warbler *Basileuterus leucoblepharus*. - Ann. Braz. Acad. Sciences. 76 (2): 335-344.

Austen M.J.W., Handford P.T. (1991): Variation in the songs of breeding Gambel's White-crowned Sparrows near Churchill, Manitoba. - Condor. 93: 147-152.

Avelino M.F., Vielliard J.M.E. (2004): Comparative analysis of the song of the Rufous-collared Sparrow *Zonotrichia capensis* (Emberizidae) between Campinas and Botucatu Sao Paulo State, Brazil. - Ann. Brazilian Acad. Sciences. 76 (2): 345-349.

Baker M.C. (1983): Sharing of vocal signals among Song Sparrow. - Condor. 85: 482-490.

Baptista L.F. (1977): Geographic variation in song and dialects of the puget sound White-crowned Sparrow. - Condor. 79: 856-870.

Baptista L.F., King J.R. (1980): Geographic variation in song and song dialects of mountain White-crowned Sparrow. - Condor. 82: 267-284.

Baril C.T., Barlow J.C. (2000): Pacific coast and Southwest interior populations of the Hutton's Vireo differ in basic song parameters. - Condor. 102: 911-914.

Bцhner J., Wistel-Wozniak A. (1995): Chaffinch *Fringilla coelebs* song in western and southern Poland: Song types, repertoire sizes, and the terminal element "kit". - Acta Ornithol. 30: 107-115.

Chesmore D. (2004): Automated bioacoustic identification of species. - Ann. Brazilian Acad. Sciences. 76 (2): 435-440.

Cunningham M.A., Baker M.C., Boardman T.J. (1987): Microgeographic song variation in the Nuttall's White-crowned Sparrow. - Condor. 89: 261-275.

Ehrengruber M.U., Pasinelli G., Egli T. (2006): Gesangsvariabilität der Rohrammer *Emberiza schoeniclus* in der Schweiz. - Orn. Beob. 103: 87-96.

Geberzahn N., Hultsch H. (2004): Rules of song development and their use in vocal interactions by birds with large repertoires. - Ann. Brazilian Acad. Sciences. 76 (2): 209-218.

Goretskaya M.Ya., Korbut V.V. (1998): [Structural-functional features of Willow Warbler song]. - Ornitologiya. Moscow. 28: 46-51. (In Rus.).

Grabovsky V.I, Panov E.N. (1992): [Song convergence in Pied Wheatear *Oenanthe pleshanka* and Black-eared Wheatear *Oenanthe hispanica* in repeated contact zones]. - Zool. zhurnal. 71 (4): 75-84. (In Rus.).

Grishchenko V.N. (1994): [Phenological regularities of autumn migrations of birds in territory of Ukraine]. - Diss. … kand. biol. sci. Kyiv. 1-230. (In Ukr.).

Illichev V.D. (1971): [Lectures on bioacoustics]. Moscow. 1-191. (In Rus.).

Kogan J.A., Margoliash D. (1997): Automated recognition of bird song elements from continuous recordings using dynamic time warping and hidden Markov models: A comparative study. - J. Acoust. Soc. Am. 103 (4): 2185-2196.

Kumar A. (2004): Acoustic communication n the Red-vented Bulbul *Pycnonotus cafer*. - Ann. Brazilian Acad. Sciences. 76 (2): 350-358.

Lampe H.M., Dabelsteen T., Larsen O.N., Pedersen S.B. (2004): Degradation of song in a species using nesting holes: the Pied Flycatcher *Ficedula hypoleuca*. - Ann. Brazilian Acad. Sciences. 76 (2): 264-266.

Larsen O.N., Dabelsteen T., Pedersen S.B., Bang-Mшller M., Nogales M. (1997): Competitive release of song in the Tenerifean robin, Erithacus rubecula superbus. - Advances in Ethology. Contributions to the XXV Intern. Ethological Conference, Vienna, Austria, 20–27 August, 1997. Suppl. to "Ethology". 32: 117.

Leitro A., van Dooren T.J.M., Riebel K. (2004): Temporal variation in chaffinch *Fringilla coelebs* song: interrelations between the trill and flourish. - J. Avian Biology. 35: 199-203.

Martindale S. (1980): A numerical approach to the analysis of Solitary Vireo songs. - Condor. 82: 199-211.

Mendes F.D.C., Ades C. (2004): Vocal sequential exchanges and intragroup spacing in the Northern Muriqui *Brachyteles arachnoides hypoxanthus*. - Ann. Brazilian Acad. Sciences. 76 (2): 399-404.

Miyasato L.E., Baker M.C. (1999): Black-capped chickadee call dialects along a continuous habitat corridor. - Animal behav. 57 (6): 1311-1318.

Pesenko Yu. A. (1982): [Principles and methods of quantitative analysis in fauna researches]. Moscow: Nauka. 1-287. (In Rus.).

Williams J.M. (1993): Objective Comparisons of Song Syllables: A Dynamic Programming Approach. - J. Theor. Biology. 161 (3): 317-328.

Yablonovska-Grishchenko E.D. (2005): [Catalogue of Chaffinch songs in Kaniv Nature Reserve]. - Nature Reserves in Ukraine. 11 (1): 39-45.] (In Rus.).

Yablonovska-Grishchenko E.D. (2006): [Typological system of elements in Chaffinch (*Fringilla coelebs*) songs]. - Materials of XII International ornithol. Conference of Northen Eurasia. Stavropol. 592-594. (In Rus.).

Yablonovska-Grishchenko E.D., Grishchenko V.N. (2005): [Catalogue of Chaffinch songs in Seym Regional Landscape Park]. - Nature Reserves in Ukraine. 11 (2): 24-30. (In Rus.).

Yablonovska-Grishchenko E.D., Grishchenko V.N., Skilsky I.V. (2006): [Chaffinch (*Fringilla coelebs*) song type comparison in Chernivtsi and Kyiv cities]. - Naukoviy Visnyk Chernivetskogo Universitetu. 298: 286-293. (In Ukr.).