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EGG SHAPE IN THE TAXONOMY AND PHYLOGENY OF BIRDS OF PREY

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The article investigates the possibility of use of morphological characteristics of eggs as criteria for the solution of questions of systematics and phylogeny of birds of prey. The comparison of systematical dendrograms developed by different authors on the basis of morphology, comparative anatomy and DNA analysis with polynom indexes and factors calculated for 1322 eggs of birds of prey give the grounds to believe that morphological parameters of eggs can serve as an additional criteria in systematics and phylogeny of birds.
Key words: egg shape, systematics, birds of prey, Falconidae, Accipitridae, Pandionidae, Cathartidae.

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INTRODUCTION

The issues of systematic and phylogenetic relations of birds in general and of Falconiformes in particular, still remain valid. In the history of ornithology they were solved in different directions. In the second half of the XX century, Charles Sibley and Jon Ahlquist carried out a fundamental revision of the system of birds with DNA hybridization method (Sibley & Ahlquist, 1990). The originality of the approach and unconventionality of the obtained results caused in due time, on the one hand, a considerable number of critical publications, and on the other – pushed for further research both on the molecular systematics (Harshman, 1994; Gamauf & Haring, 2004; Clarke et al., 2005; Slack, 2012), and in traditional directions: morphological (Sibley & Ahlquist, 1990; Zelenitsky et al., 2012) and comparative anatomy (Barta & Székely, 1997; Kurochkin, 2004; Mayr, 2005; Livezey & Zusi, 2007). Along with the above, in the literature, a number of works devoted solely to the taxonomy of birds of prey (Franzevich, 2010; Wink, Heidrich & Fentzloff, 1996; Wink et al., 1998; Wink & Sauer-Gürth, 2000; Helbig et al., 2005; Lerner & Mindell, 2005; Lerner et al., 2008).

Since the middle of last century there was another direction, that it was still not widespread. We call it conditionally oological, i.e. one that is based on morphological parameters of bird eggs (Kuzyakin, 1954; Mytiai, 2003, 2008; Huynen et al., 2010). Clarification of the possibilities of using eggs oological characteristics as additional information in issue solving of taxonomy and phylogeny of Falconiformes birds is the main motive of this article.

MATERIAL AND METHODS

The material for this article were the measurements and pictures of the eggs from the collections of museums in Ukraine and Russia. Material processing carried out by the previously mentioned procedures (Mytiai, 2003, 2008). To compare the characteristics of the eggs shapes of Falconiformes and eggs of other groups of birds we used seven indices forms: traditional index of elongation - $I_{el} = L / D$ and six indices proposed by us. It if the following indexes: infundibular ($I_{IZ} = r_i / D$), lateral ($I_{lz} = r_l / D$) and cloacal ($I_{sz} = r_c / D$) areas, asymmetry ($I_{as} = r_c / r_i$), the equatorial Ieq = b = L- ($r_c + r_i$) and complementarity index $I_{com} = (r_c + b) (r_i + b)$ bL, where b = L- ($r_c + r_i$), L - length, D - diameter, r_c, r_l, r_i - the radii of the related zones. Also we calculated 4 polynomial indexes. The latter were kindly presented us by L.I. Frantsevich (2010). Basic date obtaining methodology were described by us earlier (Mytiai, 2003; 2008). 1322 eggs of birds of prey were analyzed (Table 1).

Statistical processing of the materials was carried out using software Statistica-6 and Microsoft Excel 2010. Cluster dendrograms were constructed on the basis of seven indices of shapes and four polynomial coefficients.

Table 1. The scope of actual material

Type	n
Accipiter nisus	70
A. gentilis	88
Aquila clanga	10
A. heliaca	11
A. pomarina	47
Buteo buteo	237
B. rufinus	28
Circus pygargus	20
C. aeruginosus	65
Haliaeetus albicilla	16
Hieraaetus pennatus	35
Accipiter nisus	70
Milvus migrans	102
Milvus milvus	48
Neophron percnopterus	14
Pernis apivorus	23
Aegypius monachus	12
Falco cherrug	73
F. eleonorae	12
F. naumanni	23
F. peregrinus	12
Falco subbuteo	36
F. tinnunculus.	138
F. vespertinus	89

RESULTS AND DISCUSSIONS

With respect to the place of Falconiformes, among other orders of birds in the literature there are a lot of conflicting data. The same contradictions are also observed in the subdivision of order in the family and in relations between the representatives of the families and genera among themselves and with other orders. The reason for this is one-sided approach, when based on one or two criteria the judgment is formed as a whole.

For example, the search for similarity of eggs of Falconiformes and other representatives of the class of birds in one of the mentioned eleven parameters gave the following results. According to the index of cloacal area close to Falconiformes values have Ciconiiformes, Galliformes, Cuculiformes, Procellariiformes, Anseriformes and Piciformes. According to the index of the lateral area the group includes: Piciformes, Columbiformes, Coraciiformes and Strigiformes. According to the index of infundibular area: Coraciiformes, Apodiformes, Piciformes, Cuculiformes, Passeriformes and Galliformes (Fig. 1).

According to the index of elongation: Piciformes, Galliformes, Strigiformes and Coraciiformes. According to the index of asymmetry: Piciformes. According to the index of complementarity: Columbiformes, Galliformes and Piciformes. According to equatorial index daytime predators stand apart from other birds. A similar picture is observed for the coefficients of the polynomial. According to the coefficients of polynomial of the first degree the similarities are shown by the followings: Coraciiformes, Podicipediformes, Procellariiformes, Piciformes and Pelecaniformes. According to the coefficient of the second degree: Pelecaniformes, Gaviiformes, Strigiformes and Anseriformes. According to the coefficient of the third degree: Piciformes, Ciconiiformes, Anseriformes and Cuculiformes. A more generalized information obtained using cluster analysis under 11 parameters (Fig. 1).

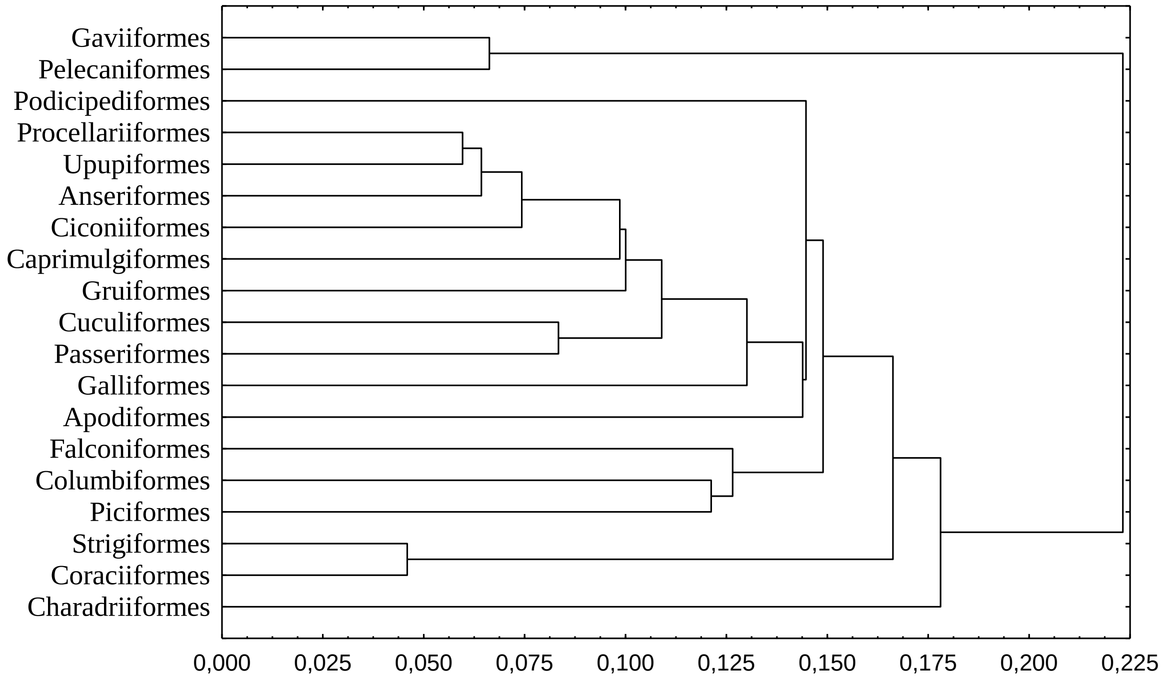

Fig. 1. Birds ranks allocation under egg shapes

In the diagram there is a clear distinction of shapes of eggs between mentioned birds orders. In this respect, the most common is the opinion that the close relatives of the birds of prey are Ciconiiformes and Pelecaniformes (Mayr & Clarke, 2003). For G.P. Dementiev (1951) and A.P. Kuzyakin (1954) reality of these relations was not clear. On this issue, one of them (Kuzyakin, 1954) proposed suggestion that by oological features there is very distant similarity observed only between small predators such as *Falco* and *Circus cyaneus* with a *Ixobrychus minutus* and *Ciconia ciconia*. Our analysis of the shape of eggs of 32 species of birds of mentioned groups did not identify (Fig. 2).

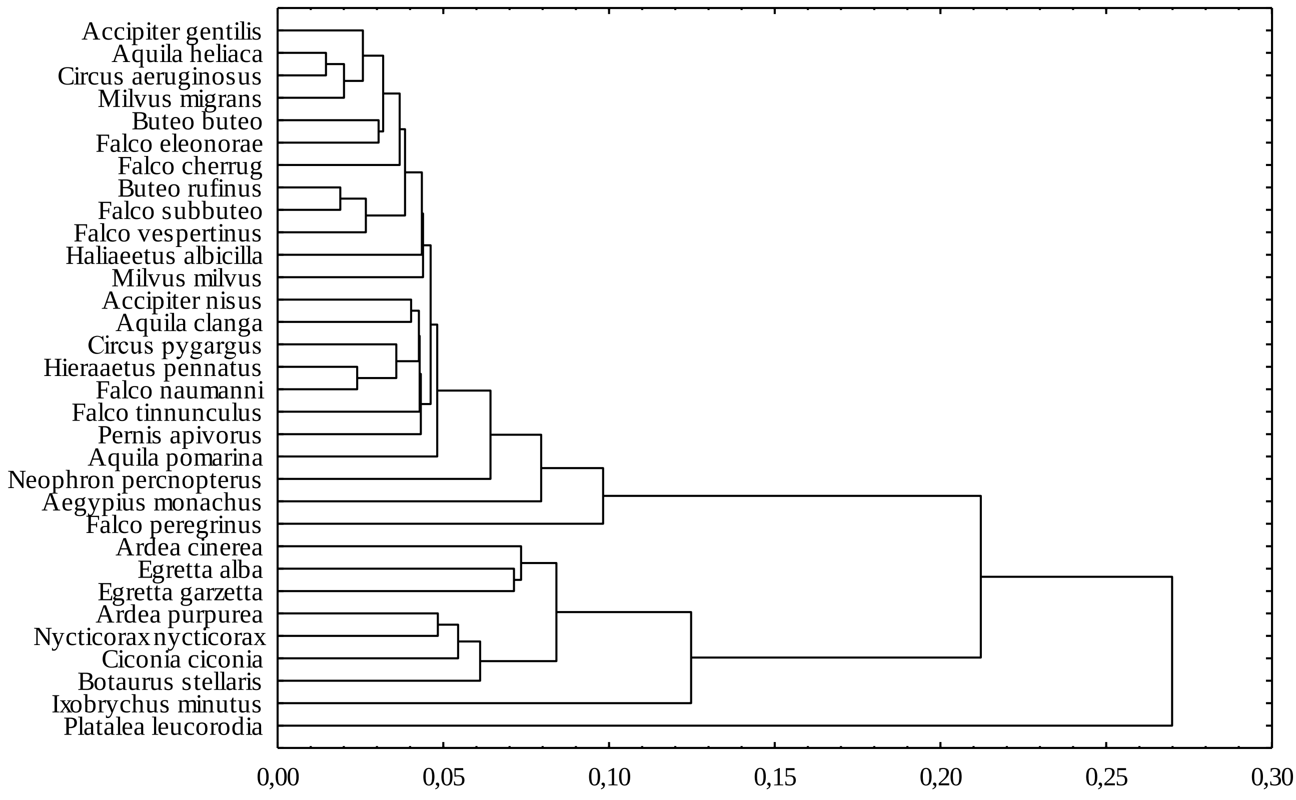

Fig. 2. Dendrogram of egg similiarity of Falconiformes and Ciconiiformes

Similarity is observed only on the coefficients of the polynomial of the third degree. The latter is connected with a slight change in the lateral part of the egg, but strongly asymmetrical affects the shape of the subpolar sector. Indeed, the radii of infundibular and cloacal areas of eggs vary greatly. The birds of prey (n = 1322) I_{iz} = 0.464 ± 0.0001 and I_{sz} = 0.331 ± 0.0003, while Ciconiiformes have another values: (n = 477) I_{iz} = 0.409 ± 0.0004 and I_{sz} = 0.312 ± 0.0006. Moreover, Falconiformes eggs are shorter (I_{el} = 1.265 ± 0.0004), than Ciconiiformes (I_{el} = 1.397 ± 0.0005). It should be noted that the eggs of Falconiformes for most parameters significantly differ from the eggs of representatives of other orders. Therefore, describing the similarity, we mean its relative character, i.e. more similar eggs have those orders that are the most closer to each other. In all these orders observed shape close to spherical. Elongation indices of Falconiformes, Strigiformes and Coraciiformes are very close in value, constituting, respectively, 1.265, 1.224, 1.224. The reasons for this phenomenon are different. For this case, there is an opinion (Amaral & Jorge, 2003), that the sphere-like eggs are most suitable in the clutches of one or two or more of the five eggs. According to the complex of features the greatest similarity in form eggs of these birds observed with Strigiformes and Coraciiformes and a little less - to Galliformes and Piciformes (fig. 3).

Maximum differences with respect to the parameters of eggs of Falconiformes (without Cathartidae) observed by Gaviiformes, Pelecaniformes and Podicipediformes. The representatives of these groups have the most elongated eggs of all birds. Their index of elongation is, respectively 1.602, 1.592, 1.482. Significant differences are peculiar to complementarity index: 1.078, 1.098, 1.082. For Falconiformes is equal to 1.285. This means that the curvature of their cloacal area isless.

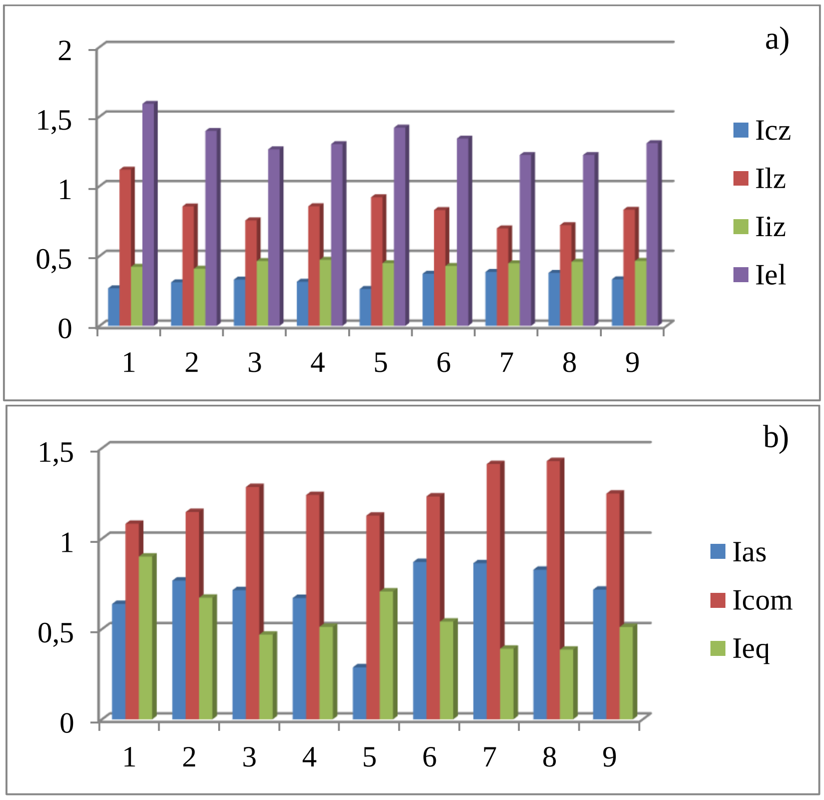

Fig. 3. Diagrams of egg shape similarity of the Falconiformes to other orders:
1) Pelecaniformes, 2) Ciconiiformes, 3) Falconiformes, 4) Galliformes, 5) Gruiformes, 6) Columbiformes, 7) Strigiformes, 8) Coraciiformes, 9) Piciformes

No less important is the issue of the relationships within the order of diurnal birds of prey. In the literature there are equally as mentioned above, contradictory information. We analyze some of them using the same procedure. Based on a number of considerations, A.P. Kuzyakin believes that the monotypic family of Pandionidae is close, on the one hand, to Accipitridae, and on the other, to the most primitive of birds of prey - Cathartidae. In this regard, the right thing to put them between the accipitrides and Falconiformes. Our dendrograms this kind takes place after the Falconidae and Accipitridae, closer to *Gyps fulvus*, *Aegypius monachus* and *Gypaetus barbatus* (Fig. 4).

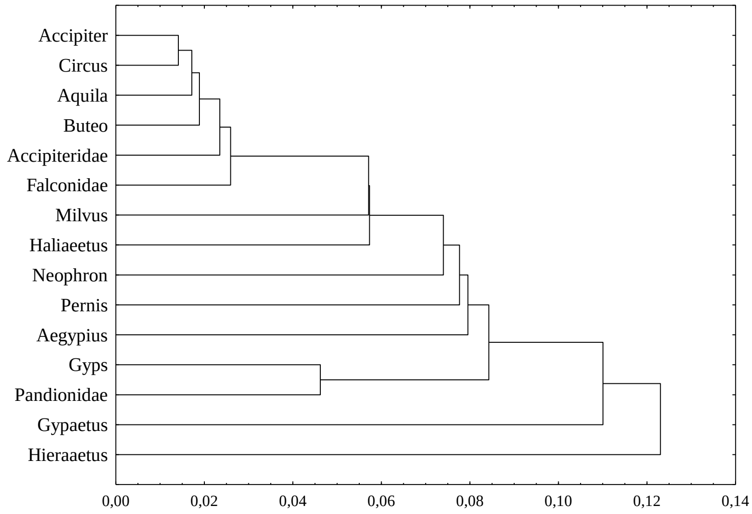

Fig. 4. The relationship of the families and genera of Falconiformes.

According to quantitative index of form *Pandion haliaetus* has the longest egg (I_{el} = 1.335) among the Falconiformes. They also have the biggest equatorial index (I_{eq} = 0.553) and index of the lateral zone (I_{lz} = 0.836). As for the American vultures, their similarity with the *Pandion haliaetus* is reflected by the analysis of the geometric profiles of eggs. Abovementioned schemes of real eggs also allow to identify the degree of similarity between the remaining families within the entire order of Falconiformes (Fig. 5).

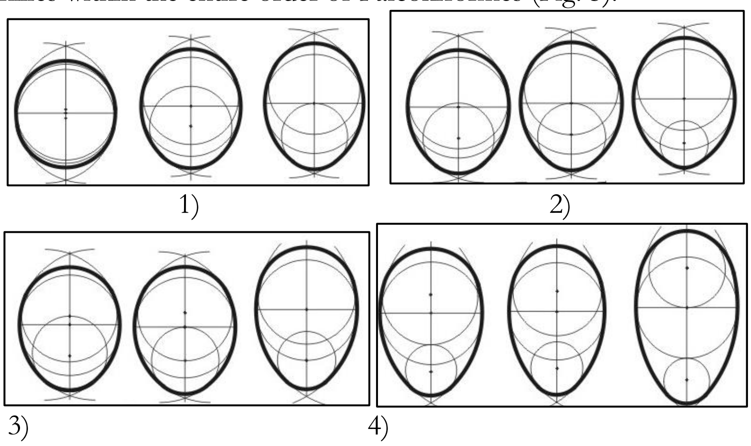

Fig. 5. Geometrical scheme of eggs of order Falconiformes families:
1) Falconidae, 2) Accipitridae, 3) Pandionidae, 4) Cathartidae

Among the " Falconidae – Accipitridae – Pandionidae – Cathartidae " the shortest eggs are indicative for Falconides and Accipitrides. Their families have the same index of elongation (I_{el} = 1,267). The differences observed on the index of complementarity (1.297 and 1.285) and the polynomial coefficients k_1, k_2, k_3 (0.063, 0.016, 0.044, and 0.050, –0.034, 0,056).

Comparison of egg shapes of *Aegypius* of the Old and New World forms under quantitative indexes have shown their complete difference (Fig. 6, 7). Cathartidae Eggs are significantly longer (1.523 vs. 1.292), the arc radius of the cloacal area they have less (0.259 vs. 0.307), and the equatorial index is more (0.846 vs. 0.539).

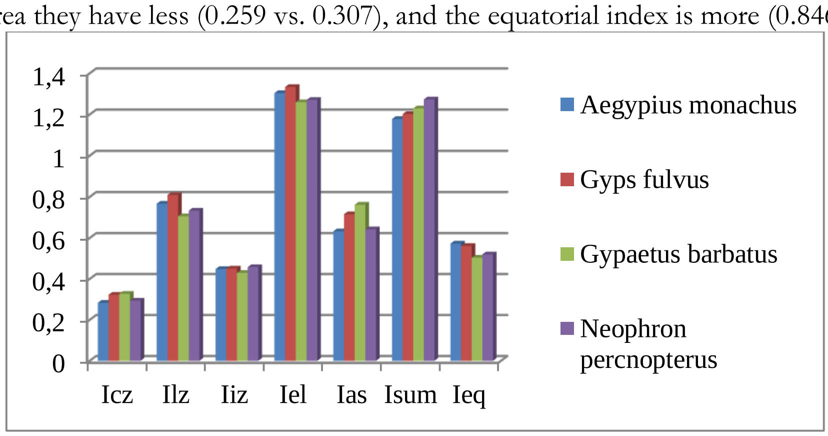

Fig. 6. Shape indices of vultures eggs of the Old World

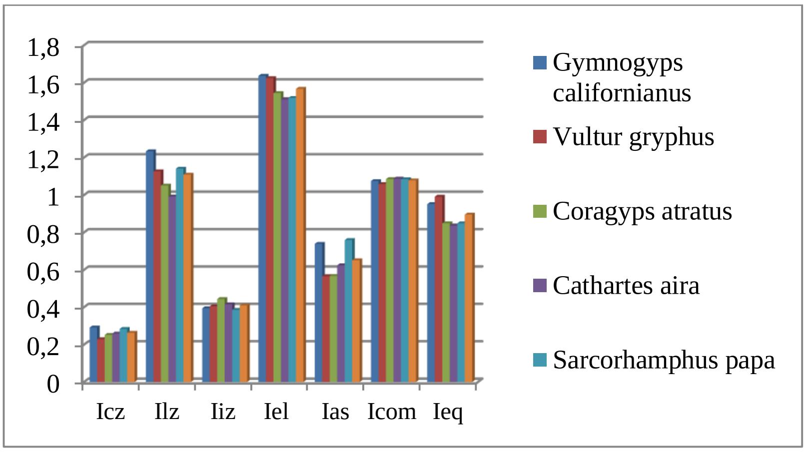

Fig. 7. Shape indices of Cathartidae eggs

The above-mentioned values of Cathartidae form are exceeded by all indeces other representatives of Falconiformes. At the same time, both in form and in its quantitative indicators, the eggs of these species are the closest to the Pelecaniformes (Phalacrocoracidae) and Gaviiformes that clearly confirmed by the diagram (Fig. 8, 9).

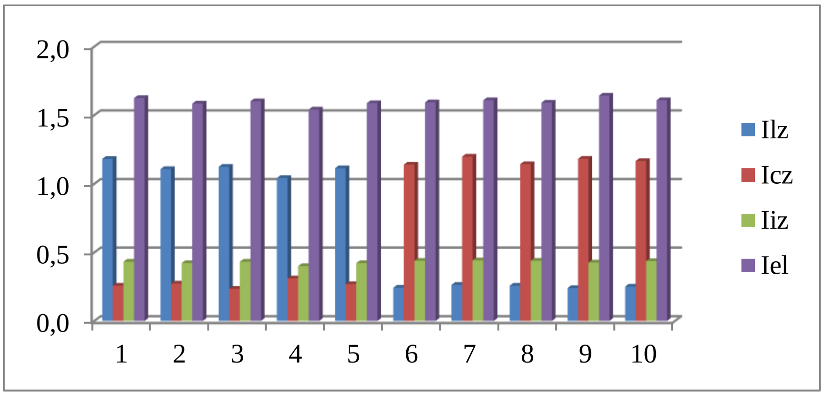

Fig. 8. Shape indices of Pelecaniformes eggs: 1) *Phalacrocorax pelagicus*, 2) *Phalacrocorax carbo*, 3) *Phalacrocorax aristotelis*, 4) *Pelecanus onocrotalus*, 5) Pelecaniformes; and Gaviiformes: 6) *Gavia immer*, 7) *Gavia stellata*, 8) *Gavia pacifica*, 9) *Gavia adamsii*, 10) Gaviiformes

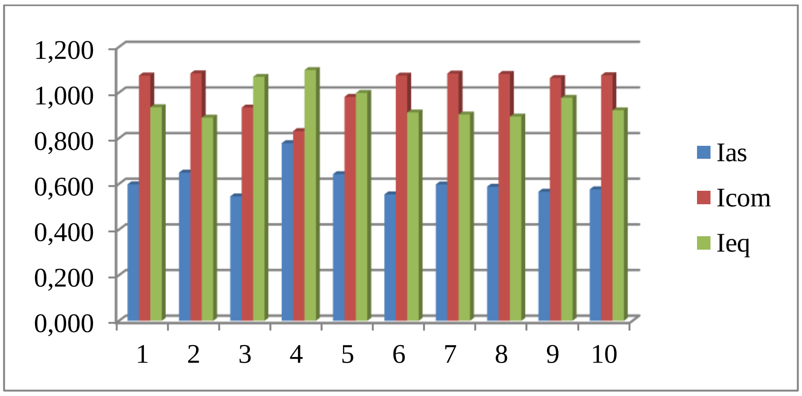

Fig. 9. Shape indeces of eggs (I_{as}, I_{com}, I_{eq}) Pelecaniformes (1-5) and Gaviiformes (6-10) birds (indication is the same as on the fig. 11)

With regard to Falconiformes and Strigiformes A.P. Kuzyakin (1954) notes that a considerable affinity between harriers and owls, can hardly be explained only with random (or converged) similarity. Talking about the relative affinity of *Circus* and *Accipiter* to *Otus*, the author continues, we do not in any way deny the independence of Falconiformes and Strigiformes as orders (Fig. 10).

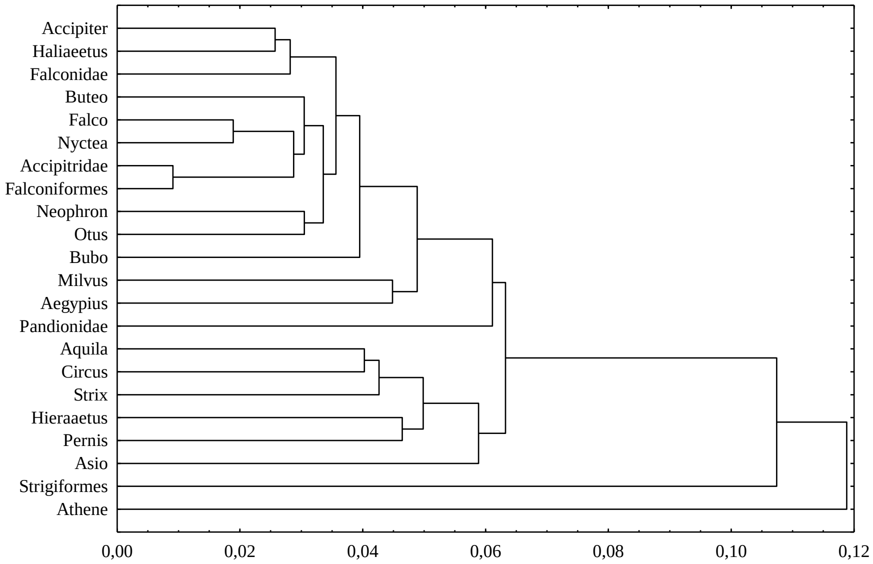

Fig. 10. Dendogram of egg similiarity of Falconiformes and Strigiformes

Among Strigiformes on the elongated shape of eggs and the matte surface of the shell, perhaps the closest to birds of pray is the family of Tytonidae, however, very far from them on the morphology of adult birds. For the *Asio flammeus* and *A. otus*, *Bubo bubo*, *Nyctea scandiaca*, *Strix aluco*, *Athene noctua*, and *Otus brucei* almost spherical eggs with a smooth glossy shell are indicative is very similar to these signs with eggs of *Merops apiaster*, *Alcedo atthis* and other Coraciiformes. Said similarity is also observed for all parameters egg shapes of diurnal Falconiformes and Strigiformes (Fig. 10).

DISCUSSION

Our results clearly show that the shape parameters of bird eggs show a stable attachment to certain types of Falconiformes and complex traits are species-specific. Dendrograms and diagrams built on quantitative values of these signs, exhibit significant similarity with the dendrogram constructed based on morphological, comparative anatomy, paleontology and molecular criteria for adult birds. This allows to conclude the possibility of using the morphological parameters of the eggs as additional information in dealing with taxonomy and phylogeny of birds.

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