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Morphological variation in round goby, *Neogobius melanostomus* (Actinopterygii, Gobiidae) from the Black Sea

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The article is focused on the morphological variation in the round goby, *Neogobius melanostomus* (Pallas, 1814) from the western coast of the Crimean Peninsula (Black Sea). A total of thirty-five plastic and seven meristic characters were measured in similar-sized males of the round goby. On average, gobies from the eastern part of the Karkinitsky Bay (the water area of the Bakalskaya Spit and the Samarchik Bay) were larger than those from the other two areas (SL_{avr} = 109.2±0.9 mm and SL_{avr} = 111.0±1.9 mm, respectively), which probably indicates the best trophic conditions in these areas. Gobies from the Donuzlav Lyman were smaller by the average values of the standard length (SL_{avr} = 87.6±1.3 mm). The differences between average values of the quantitative characteristics of compared samples were statistically significant. It was found that the heterogeneity of the ecological conditions of the habitats made it possible to form various variations of characters in the round goby. It was revealed that at least three population groups of round goby were formed near the western coast of Crimea: one of them was formed by fish from the Donuzlav estuary, the second – by gobies from the Samarchik Bay, the third – by a group of fish from the water area of the Bakalskaya Spit and Yarylgachskaya Bay. As the analysis of the correlations between the plastic characters and the values of the coordinates of the two canonical variables has shown, practically all the studied measurements ensure the discrimination of the samples of the round goby, however, the best discrimination along the first canonical axis (correlation coefficients more than 0.5) is provided by measurements on the body associated with the location of the pectoral, pelvic and anal fins, as well as the parameters of the jaw (length of the upper and lower jaws, distance between the eye and the angle of the mouth, and the width of the mouth). Such differences in the structure of the species population are associated, among other things, with the transformations of the fish population in the eastern part of the Karkinitsky Bay and the Donuzlav Lyman, caused by human economic activity.

Keywords: Round goby, Black Sea, plastic and meristic characters, variability, population.

УДК 597.556.333.1:591.4(262.5)

Морфологическое разнообразие популяции бычка-кругляка *Neogobius melanostomus* (Actinopterygii, Gobiidae) Чёрного моря

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Рассматривается структура популяции бычка-кругляка западного побережья Крымского полуострова. Изучено 35 пластических и 7 меристических признаков у самцов бычка-кругляка сходных размеров. Выявлены статистически значимые отличия в средних значениях признаков между выборками рыб из трёх районов Каркинитского залива и лимана Донузлав. В среднем бычки из восточной части Каркинитского залива (акватория Бакальской косы и залив Самарчик) оказались крупнее, чем на двух других обследованных участках ($SL_{ср}$ = 109,2±0,9 мм и $SL_{ср}$ = 111,0±1,9 мм соответственно), что, вероятно, свидетельствует о лучших трофических условиях в указанных районах. Рыбы из лимана Донузлав оказались по средним значениям стандартной длины мельче ($SL_{ср}$ = 87,6±1,3 мм). Установлено, что неоднородность экологических условий мест обитания позволили сформировать у бычка-кругляка различные вариации признаков. Выявлено, что у западного побережья Крыма сформировались по меньшей мере три популяционные группировки бычка-кругляка: одна из них образована рыбами из лимана Донузлав, вторая – бычками из залива Самарчик, третья – группой рыб из акватории Бакальской косы и Ярылгачской бухты. Как показал анализ корреляционных связей между пластическими признаками и значениями координат двух канонических переменных,

практически все изучаемые промеры обеспечивают дискриминацию выборок бычка-кругляка, однако наилучшую дискриминацию по первой канонической оси (коэффициенты корреляции более 0,5) обеспечивают промеры на теле, связанные с расположением грудного, брюшного и анального плавников, а также параметры челюсти (длина верхней и нижней челюстей, расстояние между глазом и углом рта и ширина рта). Подобные различия в структуре популяции вида связаны в том числе с преобразованиями рыбного населения в восточной части Каркинитского залива и лимана Донузлав, вызванными хозяйственной деятельностью человека.

Ключевые слова: бычок-кругляк, Каркинитский залив, лиман Донузлав, Чёрное море, пластические и меристические признаки, изменчивость, популяция.

The round goby *Neogobius melanostomus* (Pallas, 1814) is a Ponto-Caspian endemic species; its range includes the basins of the Black, Marmara, Caspian and Azov seas. The round goby is an important commercial species throughout its entire range [1–5]. The round gobies are demersal that prefers brackish coastal waters of seas and estuaries. The species is one of the most common goby species off the coast of the Crimean Peninsula [4, 5]. The high ecological plasticity and invasive potential are characteristic of the species, which actively occupies new habitats. Thus, the round goby has distributed upstream of large European rivers and has established stable populations in new reservoirs; it was also accidentally introduced with ballast waters into the Baltic Sea basin and the Great Lakes in North America [6–12].

Gobiidae are predominantly non-migratory or short-distance migratory fishes that form local morphologically distinct groups [4]. Previously, several studies investigated the population structure of the round goby in both native and introduced habitats [1, 6, 9–12]. For example, the length of the pectoral and pelvic fins, as well as the height of the anal fin are greater in the population of the round goby from the Sea of Azov in comparison with population from the Black Sea, while the height and thickness of the body show the opposite relationship. This is attributable to the nature of nutrition and movement [1]. The caudal peduncle length and the interorbital distance are greater in the round goby from the Dnieper population which indicates rheophily of these fish [1]. The round goby from the Kakhovka Reservoir of the Dnieper has a greater height of the dorsal fins and reduced length and width of the pelvic fin as well as the reduced length of the pectoral, anal and caudal fins in comparison with individuals from the Sea of Azov bays; this difference is associated with the hydrological conditions of the reservoirs [10]. The reduction of the number of fin rays and vertebrae in compare with gobies from the native range was found in the population of the round goby in the Southeast Baltic [12]. At the same time, the reduction of the number of rays in the dorsal and caudal fins was also found in the round goby from the Great Lakes of North America [6].

At the same time, the specific characteristics of the round goby population structure in the Black Sea coast of Crimean Peninsula, especially in the Karkinitsky Gulf and Donuzlav Lyman that have been subjected to an intense anthropogenic stress for more than 50 years, are still poorly known.

The Karkinitsky Gulf is the largest in the Black Sea and the Sea of Azov and has unique hydrochemical and morphological characteristics. The Karkinitsky Gulf is partitioned by the Bakal sandy spit and Bakal shoal into two parts, the eastern shallow part and the deep western part [5, 13]. During the function of the North Crimean Canal until 2014 the eastern part of the gulf was influenced by freshwater discharge, resulting in the reduced salinity in some of its smaller bays (Samarchik and Chatyrlytsky) [5].

As for Donuzlav Lyman, it stands out among the other Black Sea lymans because of its size, configuration and geomorphology. The lyman is separated from the Black Sea by the Belyaus sandy spit. Previously, it was the second largest salt lake in the Crimea, its salinity reaches up to 95‰. However, in 1961, the navigable channel was open in the spit; as a result the salinity of Donuzlav Lyman has substantially dropped. Thus, the modern fish fauna in the Lyman has been formed over the past few decades [14].

Hence, taking into account the high ecological plasticity of the round goby, as well as its ability to form morphologically distinct groups depending on the environmental conditions against the backgrounds of the anthropogenic changes in above mentioned water areas, the goal of this study is to evaluate the morphological variability of the species from different localities of the Crimean coast of the Black Sea using plastic and meristic characters.

Material and Methods

Ninety-eight males of the round goby were collected in November 2015 and July 2017 dur-

ing the expedition of the A.O. Kovalevsky Institute of Biology of the Southern Seas of RAS in the Karkinitsky Gulf (3 samples) and the Donuzlav Lyman (1 sample) (Fig. 1).

In the Karkinitsky Gulf samples were collected in the Samarchik Bay, the water area of the Bakalskaya spit (the region of the settlement of Aurora – the eastern shallow part of the Karkinitsky Gulf) and in the Yarylgach Bay (the western deepwater part of the Karkinitsky Gulf) (Fig. 1). The ichthyological material was collected using shrimp trap "Venter" with a mesh size of 6.5–7.5 mm, where round goby is one of the most common by-catch species [15].

The mature males of similar age (2+ and 3+) and similar size were selected for the morphometric studies to exclude a possible factor of sexual and age variation. All samples of the round goby were fixed with 4% formaldehyde solution until further morphological analysis. In addition, the material (deposit No. AB-1248) from the Center of joint usage "The Collection of Hydrobionts of the Oceans" of the A.O. Kovalevsky Institute of Biology of the Southern Seas of RAS, was used.

A total of 35 plastic and seven meristic characters of *N. melanostomus* were measured. The round goby body measurements (Fig. 2) were evaluated using the callipers with an error of +0.1 mm [11, 16]. Rations relative to the standard length (*SL*) and head length (*HL*) were also calculated.

The statistical analysis was performed with STATISTICA 10.0 software packages. The normality of the sample's distribution was verified using the Shapiro-Wilk criterion [17]. The differences were supposed to be reliable at the confidence level of 5% ($p < 0.05$). The basic and multivariate statistical methods such as correlation analysis, discriminant and cluster analyses were performed. The significance of the differences between the means was evaluated using Student's test [18]. To assess the diversity in the complexes of characters the gobies from different regions, the Kullback-Leibler's information criterion (*D*) was used [19].

Fig. 1. Map of the studied area

Results and Discussion

According to the obtained data, gobies from the eastern part of Karkinitsky Gulf (the Bakalskaya spit and Samarchik Bay) were larger than gobies from two other regions (SL_{avr} = 109.2±0.9 mm and SL_{avr} = 111.0±1.9 mm respectively), which could indicate better feeding conditions in these areas. The difference is provided at $t > 2.677$ between standard length of gobies from the studied areas. The standard length of the fishes from the Donuzlav Lyman was smaller (SL_{avr} = 87.6±1.3 mm) than the standard lengths of the gobies collected in the Karkinitsky Gulf.

The measurements of the fish in the samples varied insignificantly. The highest variability ($Cv > 10$) was noted for (percentage of *SL*) *ih* for the round goby from the Samarchik Bay and the Yarylgach Bay and *pl* for the round goby from the Bakalskaya Spit. The head parameter (percentage of *HL*) *io* was the most variable ($Cv > 10$) among the samples from three studied regions, excluding Samarchik Bay. The most variability among meristic characters ($Cv > 5$) was noted for the round goby from the Bakalskaya Spit.

The differences between several characters of the round goby from four regions of the Black Sea coast of Crimea are statistically significant resulting according to the Student's test. In such a manner, the significant differences in most of characters (at $t > 2.677$) were observed between samples from Karkinitsky Gulf and Donuzlav Lyman. Hence, the samples of round goby from geographically distant Samarchik Bay and Donuzlav have significant differences in 25 plastic and four meristic characters. The samples from the Bakalskaya spit and the Donuzlav Lyman had differences in 22 plastic and two meristic parameters. In turn, the round goby from the Yarylgach Bay and Donuzlav Lyman had significant differences in 19 plastic and one meristic character.

The geographical distance between the Donuzlav Lyman and three other studied water areas, feeding conditions and the history of the formation of the round goby population in these

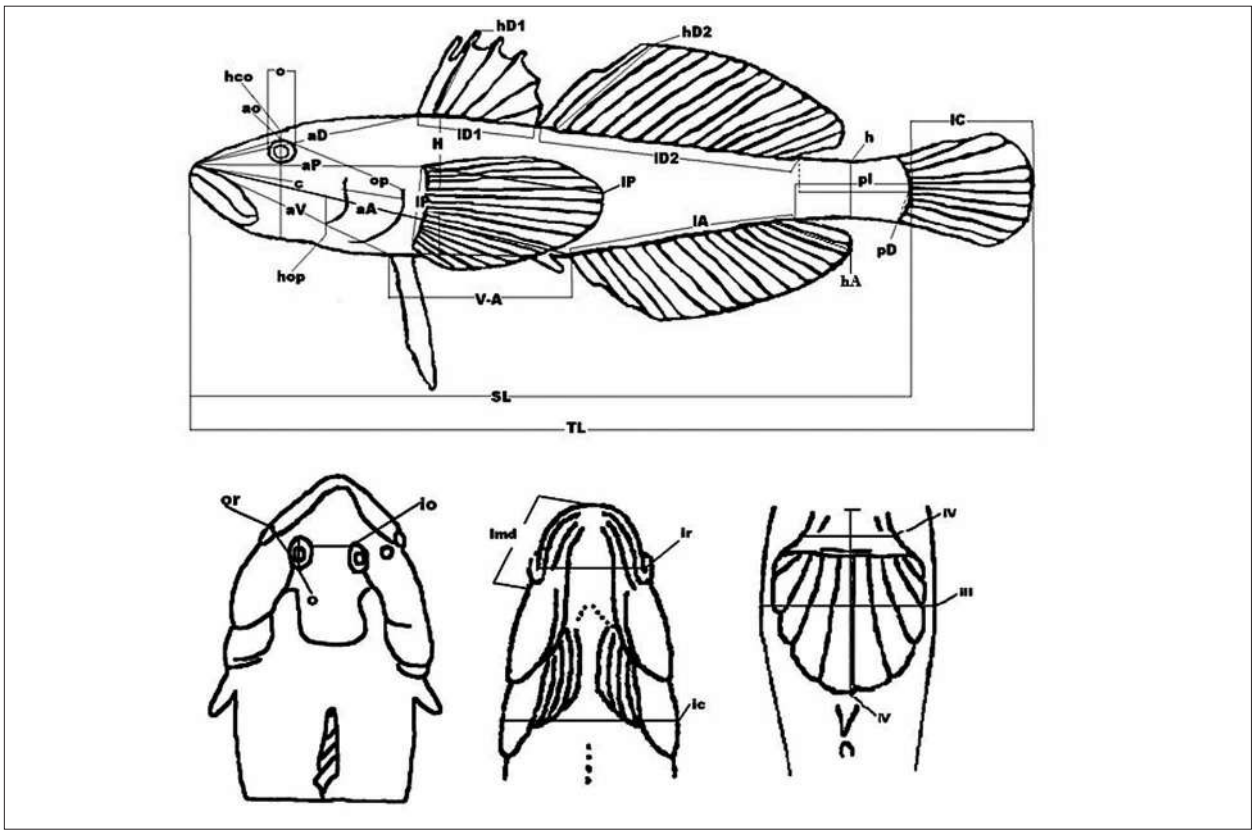

Fig. 2. Scheme of the round goby measurements [11, with additions]
Morphometric measurements of body: *TL* – total length; *SL* – standard length; *H* – maximum body depth; *h* – caudal peduncle depth; *iH* – maximum body width; *ih* – caudal peduncle width; *aD* – predorsal distance; *pD* – postdorsal distance; *aP* – prepectoral distance; *aV* – prepelvic distance; *aA* – preanal distance; *V-A* – pelvic-anal distance; *pl* – caudal peduncle length; *lD1* – length of first dorsal fin base; *hD1* – first dorsal fin depth; *lD2* – length of second dorsal fin base; *hD2* – second dorsal fin depth; *lA* – length of anal fin base; *hA* – anal fin depth; *lP* – pectoral fin length; *iP* – width of pectoral fin base; *lV* – pelvic fin length; *iV* – width of pelvic fin base; *lC* – caudal fin length; *HL* – head length.
Morphometric measurements of head: *ic* – head width; *ao* – preorbital distance; *o* – horizontal eye diameter; *op* – postorbital distance; *io* – interorbital distance; *lm* – upper jaw length; *lmd* – lower jaw length; *or* – distance between eye and corner of mouth; *hop* – cheek depth; *ir* – mouth width; *hco* – head depth through middle of eye.
Meristic characters: *D1* – number of first dorsal fin spines; *D2* – number of second dorsal fin rays; *A* – number of anal fin rays; *P* – number of pectoral fin rays; *C* – number of caudal fin rays; *squ* – number of transverse rows of scales

water areas could be a reason for identified differences. As shown in [20], the formation of the round goby population in the Karkinitsky Gulf was significantly affected by the invasion of fish fauna from the Dnieper River faunistic complex during the functioning of the North Crimean Canal, while in the Donuzlav Lyman the Black Sea group of the round goby was historically formed.

The pairwise comparison of round goby from the water area of Bakalskaya spit, Samarchik Bay and Yarylgach Bay showed reliable differences between the first and second regions and between the first and third regions by 10 plastic characters. At the same time, the gobies from distant regions of Karkinit Gulf, Yarylgach Bay and Samarchik Bay differ reliably only by five plastic and four meristic characters. The nature of the latter differences requires further research.

The degrees of similarity between regions were estimated using a cluster analysis based on the Kullback-Leibler divergence index (*D*).

As shown in Figure 3, the round gobies from the Samarchik Bay and the Yarylgach Bay are united by both plastic and meristic characters at the lowest level of divergence and are clustered with gobies from the Bakalskaya Spit. In turn, the gobies from the Donuzlav Lyman form a cluster separate from three water regions of the Karkinitsky Bay.

The discriminant canonical analysis was carried out to compare round gobies from 4 above mentioned regions. The distribution of individu-

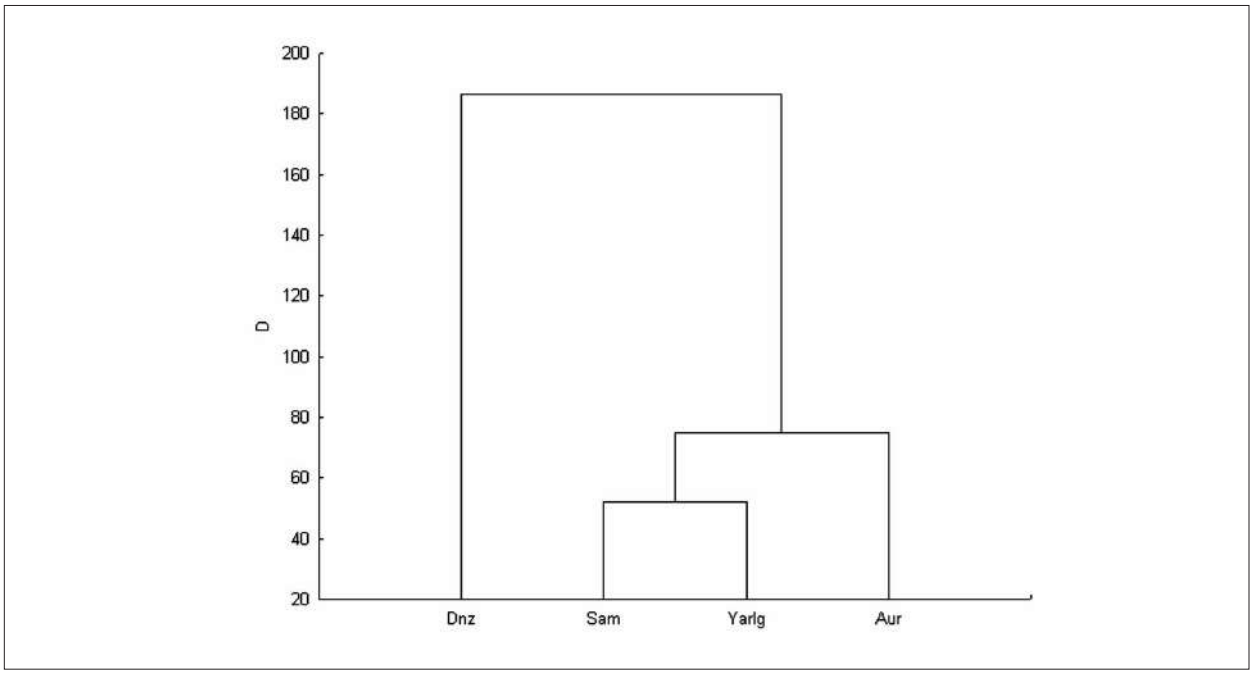

Fig. 3. The results of a cluster analysis based on a complex of all studied characters of the samples of the round goby from 4 regions of the Black Sea: Dnz – Donuzlav Lyman, Sam – Samarchik Bay, Yarlg – Yarylgach Bay, Aur – Bakalskaya Spit

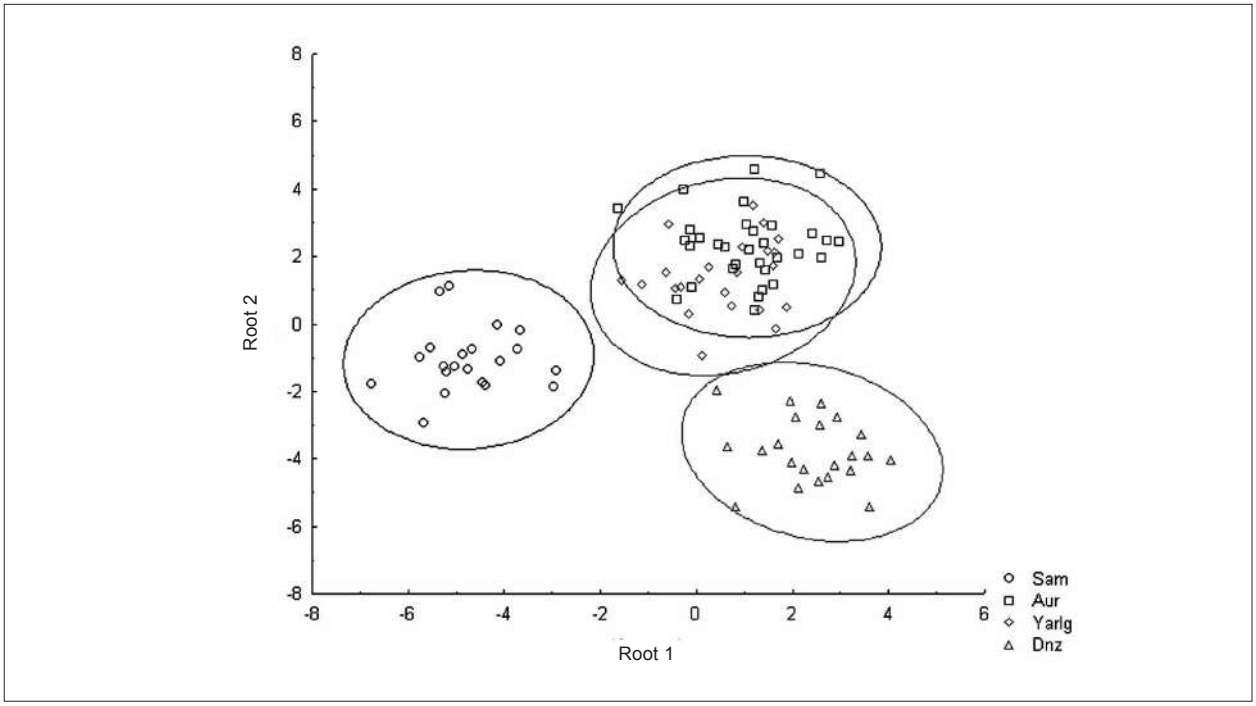

Fig. 4. Scatterplot of canonical scores for body dimensions of round goby from 4 regions of the Black Sea (results of discriminant analysis): Dnz – Donuzlav Lyman, Sam – Samarchik Bay, Yarlg – Yarylgach Bay, Aur – Bakalskaya Spit

als within the two canonical axes according to the plastic characters is shown on Figure 4. As illustrated (Fig. 4) the studied individuals are distributed among three groups along the Root 2: gobies from the Samarchik Bay; gobies from the Donuzlav Lyman; and the third group combine into one the gobies from the Bakalskaya spit and the Yarylgach Bay. In turn along the Root 1 the individuals from the Donuzlav Lyman, the Bakalskaya spit and the Yarylgach bay are united, while the goby individuals from the Samarchik Bay form a separate group. The

largest value of the square Mahalanobis distance of (58.6) was obtained for Samarchik Bay and Donuzav Lyman, and the smallest (27.7) for the Bakalskaya Spit and the Yarygach Bay.

A region-based discrimination is provided by both canonical axes for almost all measurements. However, the best discrimination along the first canonical variable (correlation coefficients more than 0.50) is provided by the parameters such as *TL, SL, aP, aV, aA, iP, iV, HL, ic, lm, lmd, or, ir* and *hco*. Discrimination along the second canonical variable is ensured by characters as *TL, SL, H, iH ih, aD pD, aP, aV, aA, VA, lD1, hD1, lD2, hD2, hA, lP, iP, lV, iV, lC, HL, hcz, ic, ao, o, op, io, lm, lmd, or, hop, ir* and *hco*.

In this case, the noted differences between the round goby from the studied areas are associated with body sizes (*TL, SL*) and with characters correlate with size. As a result, the gobies from Samarchik Bay are discriminated along both canonical axes.

It is known that variation of morphological characters in fish can be connected to the peculiarities of nutrition, movement and reproduction [21]. The observed differences between round goby samples from the 4 areas of the Black Sea may also be connected with the specific habitat conditions. So, the increasing of the anterior part of the body (*H, iH, H, aD, H*), as well as the caudal peduncle width (*ih*) and depth (*h*) of the round goby from the the Bakalskaya spit might be linked to the overall larger fish size from this area. It is also possible that the gobies from the water area of the Bakalskaya spit have increased load on the anterior part of the body and the caudal fin due to the greater water flow rate in the area. In addition, gobies from the Bakalskaya spit had larger head length (*HL*) and characters expressed inpercentage of *HL* (head width (*ic*), preorbital distance (*ao*), postorbital distance (*op*), and interorbital distance (*io*) in comparison with gobies from other water areas.

The caudal peduncle was longer in the round goby from the Donuzlav Lyman than in gobies from three other areas (characters *pl* and *pD* was increased), which also indicates a greater load on this part of the body, for example, during foraging movement.

The values of *aP, aV, aA* and *V-A* in the round gobies from Samarchik Bay are larger than in gobies from other localities. According to [21], the values of mentioned characters can considerably vary during the formation of gonads.

The increased values of the depth of the first and second dorsal fins (*hD1* and *hD2*), as well as the length of the pelvic fin (*lV*) and pectoral fin (*lP*) were recorded in the round gobies from the Donuzlav Lyman in comparison with other localities. However, the increase of these measurements may be associated with the spawning changes in goby males, because the material was collected in the summer [1].

Measurements that centre around the size of the mouth (the upper (*lm*) and lower (*lmd*) jaws length, mouth width (*ir*) and distance between eye and corner of mouth (*or*)) were larger in the gobies from Samarchik Bay, and were the smallest in the gobies from the Donuzlav Lyman. This is possibly connected with the overall larger size and greater food availability for round gobies in the Samarchik Bay.

Conclusions

Thus, at least three distinct intrapopulation groups of the round goby were identified at the western coast of the Crimean Peninsula: first includes the gobies from the Donuzlav Lyman; second incudes the gobies from Samarchik Bay, whereas third incudes fishes from the Bakalskaya Spit and the Yarylgach Bay. Almost all studied measurements (with exception of *ih* along the first canonical axis) had significant role in discrimination among the groups, as it was shown by the result of our investigation.

It is our point that two major reasons may be responsible for the observed differences. The round gobies from different habitats may have differences in average body sizes under various trophic conditions in diverse water areas, as well as under different stoking densities of individuals. In such an event, the observed differences in size of the gobies from different habitats represent the modification variability.

However, it seems to be more likely that such differences may be associated with the history of the fish population forming in the studied areas. So, the Black Sea group of round gobies was historically formed in the Donuzlav Lyman, while in the Karkinitsky Bay, the formation of the round goby populations was influenced by the invasion of the species representatives of the Dnieper faunistic complex during the functioning of the North Crimean Canal. Thus, the observed differences may be related to the fact that at least two populations of round goby exist in these regions.

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