Hydrobiological Journal, 2013, Vol. 49, No. 1

Morphological Differentiation of *Anadara inaequivalves* (Bivalvia, Arcidae) in the Black Sea[†]

N. L. Finogenova[1], A. P. Kurakin[1] & O. A. Kovtun[2]
[1]Odessa Branch
Institute of Biology of the Southern Seas
National Academy of Sciences of Ukraine
Odessa, Ukraine
[2]Odessa State University
Odessa, Ukraine

The morphological variability of the invader *Anadara inaequivalvis* (Bruguiére, 1789) belonging to Bivalvia was studied in three sections of the Black Sea, including Odessa Bay, the shelf of the Zmeiny Island, and the Danube River delta, by the method of discriminate analysis. A valid difference in the morphological parameters of the shells of the studied mollusks was revealed. The determined coefficients of the functions make it possible to identify mollusks in terms of a set of morphological characters with the accuracy of classification of 100%.

KEYWORDS: *Anadara inaequivalvis*, *discriminate analysis*, *morphological variability*, *the Black Sea*.

Introduction

The study of intra- and inter-population variability is one of the perspective approaches to bioindication. The study of phenotypical plasticity of the species-invaders is of particular interest, because their adaptation potential manifests itself primarily in changes in their morphological parameters [6, 7]. The first visible morphological changes in animal body indicative of the formation of a new subspecies are conditioned by changes in the process of metabolism. Changes in the structure of a shell belong to such first visible changes in Bivalvia [3].

The rate of *Anadara inaequivalvis* (Bruguiére, 1789) distribution in the Black Sea and in the Sea of Azov is indicative of a high eurybiotic capability of the mollusk [1, 4, 5]. Thus, the objective

[†] Originally published in *Gidrobiologicheskiy Zhurnal*, 2012, Vol. 48, No. 5, pp. 3–10.

ISSN 0018-8166

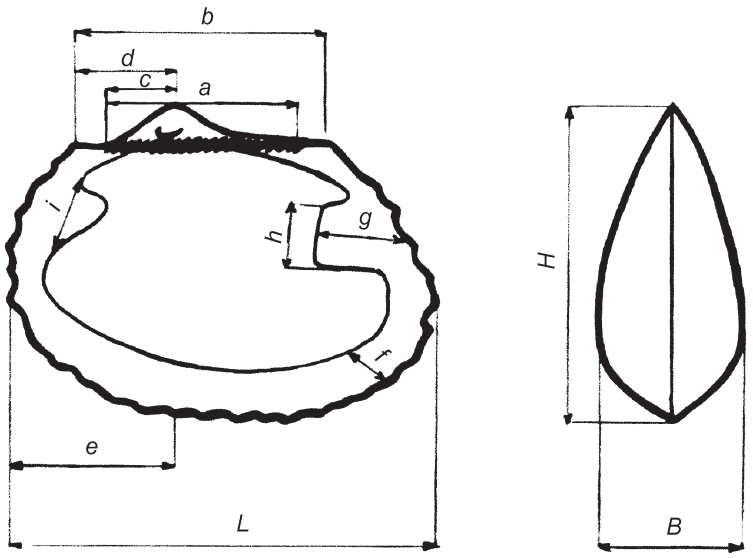

Fig. 1. Scheme of the measurements of the linear characteristics of *A. inaequivalvis* shells: *L* – shell length; *H* – shell height; *B* – shell width; *a* – ligament length; *b* – length of the dorsal margin of the shell; *e* – length from the anterior margin to the apex; *c* – length from the anterior margin of the ligament to the apex; *d* – length from the anterior margin of the shell to the apex; *i* – width of the impress of the anterior obturator muscle; *f* – distance from the margin of the mantle to the margin of the shell; *h* – width of the impress of the posterior obturator muscle; *g* – length of the impress of the posterior obturator muscle. The linear characteristics of the shell were transformed into the indices, which were used in further calculations [9].

of the present work was to reveal the morphological variability of this species in different sections of the northern part of the Black Sea.

Material and Methods

Material for the study included the shells of *Anadara inaequivalvis* (Bivalvia) collected in Odessa Bay (near Cape Maly Fontan) from the depths of 12–15 m (2009–2010, soil – silty sand, 26 sepcimens), in the shelf of the Zmeiny Island from the depth of 15 m (2010, soil – shell rock, 30 specimens), and in the Danube River delta from the depths of 21–24 m (2008, soil – grey silt, shell rock, 30 specimens).

The shell of *A. inaequivalvis* is inaequivalve (its left shell is somewhat larger as compared to the right shell). The shell significantly varies in its form, height, and width. On the whole, 12 morphological parameters of each right shell were analyzed with the accuracy of 0.1 mm (Fig. 1).

The following formula was used in performing calculations:

Table 1

Limits of variability of the indices of morphometric characters of *A. inaequivalvis* shell in the Black Sea

Values	Indices										
	*H_i	B_i	a_i	b_i	c_i	d_i	e_i	f_i	g_i	h_i	i_i
Odessa Bay (near Cape Maly Fontan)											
min	0.93	0.88	0.72	0.82	0.35	0.53	0.67	0.44	0.50	0.40	0.46
max	0.96	0.94	0.81	0.88	0.49	0.62	0.74	0.50	0.58	0.55	0.56
$M \pm m$	0.93 ± 0.002	0.91 ± 0.003	0.76 ± 0.004	0.86 ± 0.003	0.44 ± 0.006	0.57 ± 0.004	0.70 ± 0.003	0.47 ± 0.004	0.53 ± 0.004	0.50 ± 0.007	0.52 ± 0.005
CV, %	0.86	1.47	2.42	1.95	7.44	4.47	2.20	3.91	3.64	6.82	5.15
Shelf of the Zmeiny Island											
min	0.94	0.89	0.72	0.84	0.34	0.52	0.67	0.25	0.49	0.39	0.37
max	0.98	0.95	0.84	0.89	0.61	0.65	0.77	0.49	0.62	0.56	0.58
$M \pm m$	0.96 ± 0.002	0.92 ± 0.003	0.79 ± 0.005	0.87 ± 0.002	0.86 ± 0.002	0.60 ± 0.005	0.73 ± 0.004	0.40 ± 0.007	0.56 ± 0.005	0.51 ± 0.007	0.53 ± 0.0.008
CV, %	1.30	1.69	3.43	1.27	11.73	4.50	2.67	10.51	4.92	7.15	7.93
Danube River delta											
min	0.91	0.85	0.72	0.81	0.28	0.47	0.66	0.64	0.62	0.55	0.61
max	0.97	0.90	0.86	0.86	0.46	0.57	0.73	0.74	0.76	0.67	0.76

Table 1 *(continued)*

Limits of variability of the indices of morphometric characters of *A. inaequivalvis* shell in the Black Sea

Values	Indices										
	*H_i	B_i	a_i	b_i	c_i	d_i	e_i	f_i	g_i	h_i	i_i
$M \pm m$	0.94 ± 0.003	0.88 ± 0.003	0.76 ± 0.004	0.84 ± 0.003	0.39 ± 0.008	0.51 ± 0.004	0.70 ± 0.003	0.69 ± 0.005	0.68 ± 0.005	0.62 ± 0.006	0.68 ± 0.006
CV, %	1.59	1.61	3.25	1.78	11.40	4.72	2.31	3.73	4.26	5.47	5.23
Generalized data over the studied sections of the Black Sea											
min	0.91	0.85	0.72	0.81	0.28	0.47	0.66	0.25	0.49	0.38	0.37
max	0.98	0.95	0.86	0.89	0.61	0.65	0.77	0.74	0.76	0.68	0.76
$M \pm m$	0.95 ± 0.002	0.90 ± 0.002	0.77 ± 0.003	0.86 ± 0.002	0.44 ± 0.007	0.56 ± 0.005	0.71 ± 0.002	0.52 ± 0.014	0.59 ± 0.008	0.54 ± 0.007	0.58 ± 0.009
CV, %	1.71	2.61	3.60	2.05	14.51	8.26	3.31	24.67	11.78	11.89	13.98

* Here and in Table 2, the designations of morphometric characters are given in Figure 1.

Table 2

Results of multi-factor dispersion analysis of the indices of morphometric characters of *A. inaequivalvis* shell in Odessa Bay, in the shelf of the Zmeiny Island, and in the Danube River delta

Influencing factors	*F* – dispersion ratio										
	H_i	B_i	a_i	b_i	c_i	d_i	e_i	f_i	g_i	h_i	i_i
Section of the sea	6.33	2.41	4.14	0.21	18.96	6.44	11.10	49.80	4.23	4.81	2.45
Type of bottom sediments	1.17	0.73	1.26	0.00	0.75	0.44	2.34	2.70	2.65	0.07	3.26
Depth	2.31	0.40	1.11	1.04	2.85	1.54	2.18	4.01	1.17	0.01	0.31

Note. The underlined values were obtained with $p > 0.05$.

$$C_x = \frac{\ln X}{\ln L},$$

where C_x – index of the linear parameter X; L – shell length. The index L_1 was calculated by the formula:

$$L_i = \frac{l}{L} - l.$$

Discriminate analysis was used in revealing morphological characteristics responsible for infraspecific difference in the shells of *A. inaequivalvis* occurring in various sections of the Black Sea.

Discriminate analysis is a reliable tool in studies of variability. It can be used in describing geographic variability [2, 8].

The influence of the depth, character of bottom sediments, and localization of the sampling station on the morphology of mollusk shell was determined using the multi-factor dispersion analysis. Calculations were carried out using the Statgraphics *Plus* applied programs for Windows.

Results and Discussion

Variability of the studied characteristics of the shell of *A. inaequivalvis* occurring in the Black Sea varied over a narrow range. However, the value of the coefficient of variation (*CV*) for the value *f* (the distance from the margin of the mantle to the margin of the shell) was more than 20, which is indicative of the significance of this index in studies of the morphology of the species. The highest values of the coefficient of variation were registered in mollusks occurring in the shelf of the

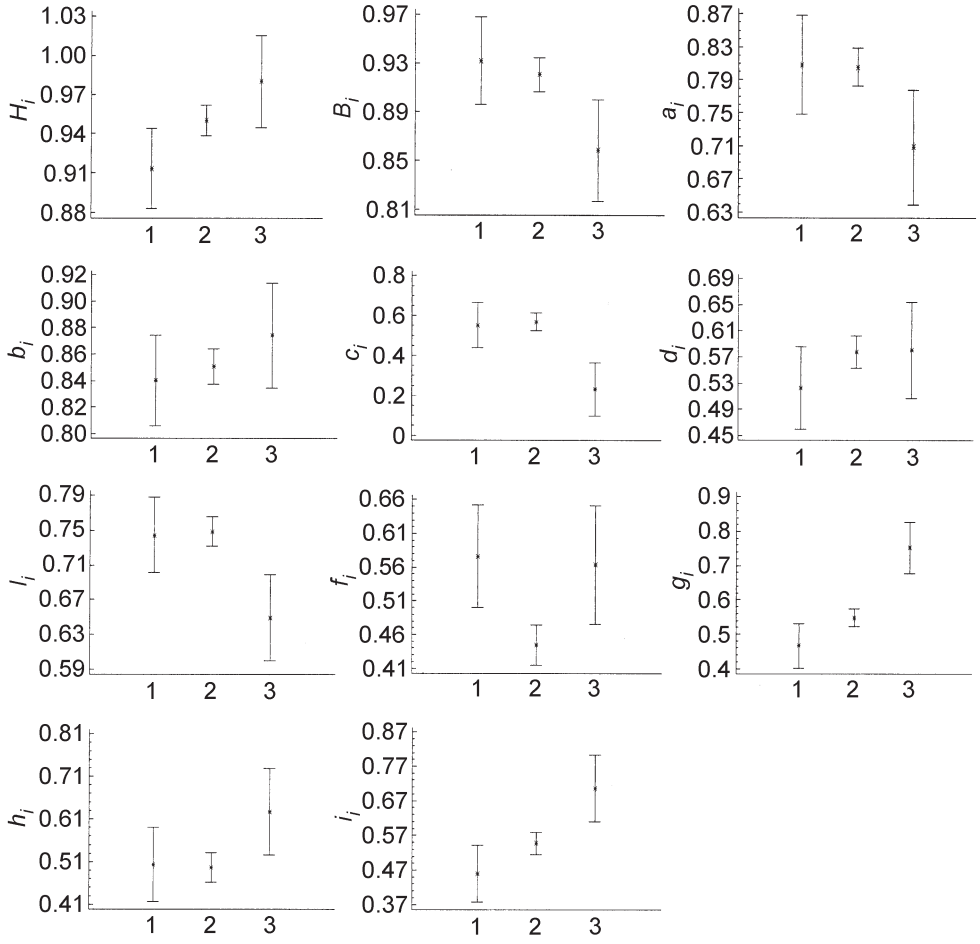

Fig. 2. Results of multi-factor dispersion analysis of the indices of morphometric characters of *A. inaequivalvis* shell. Here and in Figure 3, *1* – Odessa Bay; *2* – shelf of the Zmeiny Island; *3* – the Danube River delta.

Zmeiny Island (Table 1), which is probably determined by unstable environmental conditions in this region. The distribution of mollusks over bottom sediments depends not only on their morphological and functional peculiarities, but also on the surrounding biota and bionomic character of the habitat conditioned primarily by such factors as temperature, salinity, and the intensity of water movement (waves) [3].

The peculiarities of the formation of morphological characteristics of *A. inaequivalvis* shells taken from different sections of the Black Sea were revealed by the method of multi-factor dispersion analysis. It has been found that the region of sampling significantly influences the fromation of mollusk shell (Table 2).

Table 3

Results of discriminate analysis

Characteristics	Canonic variables	
	1	2
Own values	90.16	9.84
Explained dispersion, %	33.43	3.65
Canonic correlations	0.99	0.89
Standardized (in parentheses) and non-standardized coefficients of canonic variables for the characters		
L_i	18.06 (0.83)	10.17 (0.46)
a_i	0.29 (0.01)	14.67 (0.35)
bi	2.18 (0.03)	–5.95 (–0.08)
c_i	–2.41 (–0.11)	2.56 (0.12)
d_i	–3.07 (–0.08)	1.98 (0.05)
l_i	–60.73 (–1.05)	2.55 (0.04)
f_i	26.79 (0.83)	–16.80 (–0.52)
g_i	12.76 (0.33)	26.52 (0.69)
h_i	11.66 (0.41)	–1.15 (–0.04)
i_i	2.60 (0.09)	4.01 (0.14)
H_i	6.25 (0.08)	58.27 (0.72)
B_i	–41.43 (–0.59)	–57.99 (–0.84)
constanta	34.70	–28.34

Valid difference was revealed in the ratio between the thickness and height of the shell and its length in mollusks collected from different sections of the Black Sea. Relationship between the height of the shell and its length increases with increasing the intensity of siltation of bottom sediments, whereas relationship between the thickness and length – decreases. Valid difference was reveealed between the following indices of the shell of mollusks (a_i – ligament length, b_i – length of the dorsal margin of the shell, c_i – length from the anterior margin to the apex, and d_i – length from the anterior margin of the shell to the apex) taken from Odessa Bay and from the Danube River delta, and also from the shelf of the Zmeiny Island and from the Danube River delta. The highest values of F were obtained for the index f_i (distance from the margin of the mantle to the margin of the shell). Valid difference in this index was observed in the mollusks taken from Odessa Bay and in those collected from the shelf of the Zmeiny Island, and also in the mollusks taken from the shelf of the Zmeiny Island and from the Danube River delta. Valid difference in the indices g_i (length of the

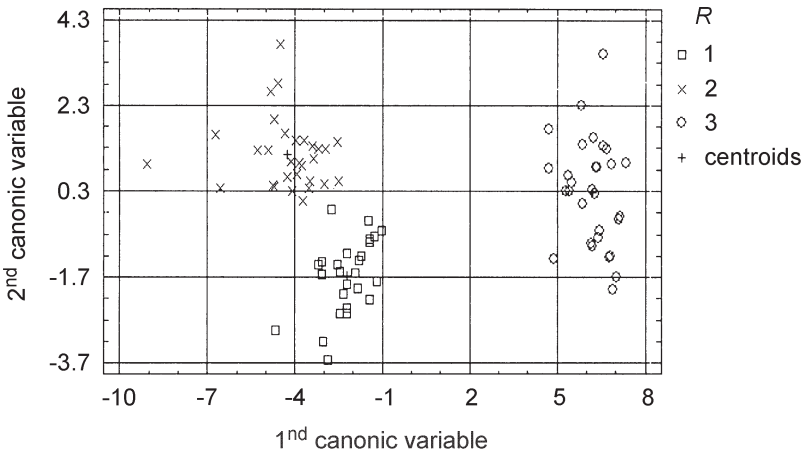

Fig. 3. Results of discriminate analysis of the morphometric characters of *A. inaequivalvis* shell.

impress of the posterior obturator muscle) and i_i (width of the impress of the anterior obturator muscle) was revealed in the shells of mollusks taken from all the studied sections. Valid difference in the index h_i (width of the impress of the posterior obturator muscle) was observed in mollusks taken from Odessa Bay and from the Danube River delta, and also in mollusks occurring in the shelf of the Zmeiny Island and in the Danube River delta (Fig. 2).

Valid difference between the mollusks taken from three various sections of the Black Sea was revealed as a result of discriminate analysis ($\lambda = 0.006$; $F = 395.91$; $df\,1 = 22$; $df\,2 = 10$; $p < 10^{-4}$) (Table 3). Discriminate functions, including variation and co-variation of 12 indices of conchiological measurements of the shell, made it possible to separate the sample of mollusks with the accuracy of 100%.

Based on the values of the standardized discriminate functions it can be concluded that the following characteristics contributed significantly to the morphological difference in mollusks: distance from the margin of the mantle to the margin of the shell (f_i), ratio between the length of mollusk and the length from the anterior margin of the shell to the apex (L_i), ratio between the thickness of mollusk and its length (B_i), and also ratio between the height of mollusk and its length (H_i).

The distribution of mollusks within the space of two canonic variables has shown that the first canonic variable makes it possible to separate the specimens occurring in the Danube River delta from the other ones (they are characterized by higher values of this variable). In this case, mollusks occurring in Odessa Bay differ from those registered in the shelf of the Zmeiny Island in terms of the second canonic variable (Fig. 3).

A subsequent decrease in the number of the least significant variables with the minimum contribution to the identification of mollusks somewhat influences the quality of separation (96–98%). At the same time, a consideration of four most significant indices (L_i , f_i, H_i and B_i) results in a high quality of separation – 100% ($\lambda = 0.01815$; $F = 326.72$; $df\,1 = 8$; $df\,2 = 3$; $p < 10^{-4}$).

Conclusion

Individual morphological variability was revealed in *A. inaequivalvis* occurring in different sections of the Black Sea. It has been found that mollusks registered in different sections of the Black Sea distinctly differ in the complex of morphometric characters. The following characters of mollusks differed most of all: distance from the margin of the mantle to the margin of the shell (f_i), ratio between the length of mollusk and the length from the anterior margin of the shell to the apex (L_i), ratio between the thickness of mollusk and its length (B_i), and ratio between the height of mollusk and its length (H_i). Valid difference was established between the morphometric characters of the shell of *A. inaequivalvis* occurring in three different sections of the Black Sea.

Analysis of variability of the morphometric characters of the shell of *A. inaequivalvis* (Bivalvia) is indicative of high ecological plasticity of this eurybiotic species. It can be assigned to eurytopic species occurring on soft silty-sand and sandy-silt bottom sediments.

Literature Cited

1. Anistratenko, V.V. & I.A. Khaliman. 2006. *Anadara inaequivalvis* (Bivalvia, Arcidae) in the northern section of the Sea of Azov: final stage of colonization of the basins of the Black Sea and of the Sea of Azov. *Vestnik Zoologii* **40**(6): 505–511. [Rus.]
2. Dzeverin, I.I. & Ye.I. Lashkova. 2006. Possibilities and limitations of some algorithms of discriminate analysis in identifying related species on the example of forest mice *Sylvaemus* (Rodentia, Muridae). *Vestnik Zoologii* **40**(1): 63–69. [Rus.]
3. Skarlato, O.A. 1981. *Dvustvorchatye mollyuski umerennykh shirot zapadnoy chasti Tikhogo okeana.* (Bivalvia of temperate latitudes of the western part of the Pacific Ocean.) Leningrad, Nauka Press. 480 pp. [Rus.]
4. Finogenova, N.L. 2008. Influence of the environmental conditions on the morpho-functional characteristics of *Anadara inaequivalvis* (Bivalvia). Pp. 309–311 in: *Ekologicheskiye problemy Chernogo morya. Tezisy dokladov mezhdunarodnoy nauchno-prakticheskoy konferentsii, 30–31 oktyabrya, Odessa.* (Ecological problems of the Black Sea. Abstracts of reports of the International Scientific and Practical Conference, 30–31 October, Odessa.) [Rus.]
5. Finogenova, N.L. 2010. Spatial and temporal dynamics of the mass and dimensional characteristics of *Anadara inaequivalvis* in the Black Sea and in the Sea of Azov. *Naukovi Zapysky Ternopilskogo Pedagogichnogo Universytetu. Seriya Biologiya* 3(44): 296–299. [Ukr.]
6. Shmalgauzen, I.I. 1940. *Faktory evolyutsii.* (Factors of evolution.) Moscow & Leningrad, AN SSSR Press. 396 pp. [Rus.]
7. Yablokov, A.V. 1980. Population morphology as a new direction in evolution morphology. Pp. 65–73 in: *Morfologicheskiye aspekty evolyutsii. K 90-letiyu so dnya rozhdeniya B.S. Matveyeva. MOPI. Sektsiya zoologii.* (Morphological aspects of evolution. Devoted to the 90th anniversary of B.S. Matveyev. MOPI. Section of zoology.) Moscow, Nauka Press. [Rus.]
8. Jolicoeur, P. 1959. Multivariate geographic in the wolf *Canis lupus* L. *Evolution* **13**(3): 283–299.
9. McDonald, J.H., R. Seed & R.K. Koehn. 1991. Allozymes and morphometric characters of three species of *Mytilus* in the Northern and Southern Hemispheres. *Mar. Biol.* **111**: 323–333.