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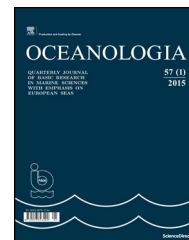
ORIGINAL RESEARCH ARTICLE

Chamelea gallina in the coastal waters of the Anapa bay bar (the Black Sea) as a carbonate sediment producer

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Summary   The paper presents preliminary results of monitoring the population of the bivalve *Chamelea gallina*, which is the main source of biogenic carbonates for the Anapa bay bar beaches (the Black Sea). It is shown that by 2017, the biomass of the clams decreased more than twice compared to 2010, but began to increase in 2018. The average sizes of *C. gallina* are clearly divided in terms "year" — "section" — "age". At the same time, interannual variations of the average size are very strong in all age groups. The average shell length of *C. gallina* significantly increased in 2018 compared to 2016, and especially — to 2017. This may be caused by the population decline of the predator *Rapana venosa* feeding on clams. Geographic differences in the shell length between sections are not directly related to the distribution of biogenic elements (nitrogen and phosphorus). The differences in longevity and shell size between *C. gallina* from the Anapa region and distant populations from the other parts of the distribution area are likely related to its significant negative correlation with the growth rate, which in turn negatively correlates with latitude.

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1. Introduction

The accumulative shores of the World Ocean are unique natural formations of great recreational, economic, and historical value. According to the geological time scales, the modern coasts are of the same age as the Holocene transgression, estimated at 7000—9000 years BP (before present). Immediately after the Holocene transgression, intense changes in the coastal slopes began to occur along the entire coastline of the oceans causing the destruction of abrasion areas and simultaneous formation of accumulative bodies. As the rate of abrasion decreased, the transport of new sediments to accumulative forms declined, and in many cases, the accumulation process was replaced by erosion. The action of some factors, primarily solid river runoff and the entry of biogenic material (shells of benthic mollusks) reduced the erosion rate, but erosion generally increases during the deficit of sediments or during the periods of the ocean level rise (Kosyan and Krylenko, 2014). Flooding of coastal areas, erosion of sandy beaches, and the destruction of harbor constructions became typical on the global and regional scales (Kont et al., 2003; Mimura, 1999; Nicholls and Cazenave, 2010; Nicholls and Mimura, 1998; Peltier, 1999; Zerbini et al., 1996). Biogenic material (shells, supplied by coastal mollusks) is becoming increasingly important. In some areas of the Black Sea, the proportion of shell residues that makes up the beaches reaches 98% (Kosyan, 2018).

During several years, we have been studying the lithodynamics of the Black Sea accumulative shores, the main of which are situated near the Anapa city (Anapa bay bar) (Kosyan et al., 2018, 2011; Kosyan and Krylenko, 2014; Krylenko et al., 2011). According to our data, mass bivalve mollusks *Chamelea gallina* and *Donax trunculus* are the main suppliers of carbonates in the sediments of sandy beaches (Fedorova et al., 2018). The main quantitative contribution belongs to *C. gallina* population whose mass development zone is located at depths of 6—10 m (Kosyan et al., 2012).

Chamelea gallina (Linnaeus, 1758) is a common infaunal bivalve of the Veneridae family inhabiting shallow water sand or mud along the European coasts. It is distributed throughout the Mediterranean and Black Seas as well as in a few localities in the Atlantic, along the southern coast of the Iberian Peninsula as far west as Faro, Algarve (Backeljau et al., 1994). The species is commercially used in the Mediterranean and Atlantic (Froglia, 1975a; Gaspar et al., 2004; Özden et al., 2009). There are a number of papers focused on its population studies in the Mediterranean countries and Portugal (Delgado et al., 2013; Froglia, 1975b; Romanelli et al., 2009), but only fragmentary information exists about its ecology in the Black Sea (Boltacheva and Mazlumyan, 2003; Chikina, 2009; Kiseleva, 1981; Koluchkina et al., 2017a,b,c; Revkov et al., 2014).

To determine the volume of shell material (biogenic carbonates) entering the Anapa bay bar beach and to predict its changes in the coming years it is necessary to know the number and biomass, size and age structure of mollusk populations in the coastal waters, as well as the threats and factors influencing their dynamics such as biogenic nutrients concentration, environmental conditions, and predators. In order to fill the data gap, monitoring of the bivalve *C. gallina* and its predator, the gastropod *Rapana venosa* has been conducted in 2016—2018. The goal of this work is to study the spatial characteristics of the distribution and interannual dynamics of the *C. gallina* populations on the Anapa bay bar coast of the Black Sea. The main question of the data analysis is as follows: are there statistically significant differences between the average shell sizes (in terms of length) depending on the year of observation, age, geographic location, and habitat depth.

2. Material and methods

Samples of mollusks were taken in the area of the Anapa bay bar located in the northeastern part of the Black Sea; this is an open part of the coast with a total length of about 40 km (Fig. 1). The bottom is flat in the offshore part with a pronounced system of underwater bars at depths of up to 6 m. The sampling was carried out along four sections (7, 18, 24, 29) in June 2016, 2017, and May 2018, with stations at depths of 6 and 10 m (Fig. 1 and Table 1). Two samples were taken at each station. The location of sections was determined by the characteristics of the granulometric composition of the sediments. High content of coarse fractions in the sands was previously identified over sections 18, 24, and 29 (Fedorova et al., 2018); it was low on section 7. Samples were taken by divers by means of the bottom frame with a size of 32 cm × 32 cm; the thickness of the sand layer collected under the frame was about 3 cm. Subsequently, the samples were sieved through a sieve with 1 mm mesh. The following characteristics of the collected mollusks were determined: number, weight, length of the shell (maximum distance along the anterior-posterior axis), and age. The age was determined
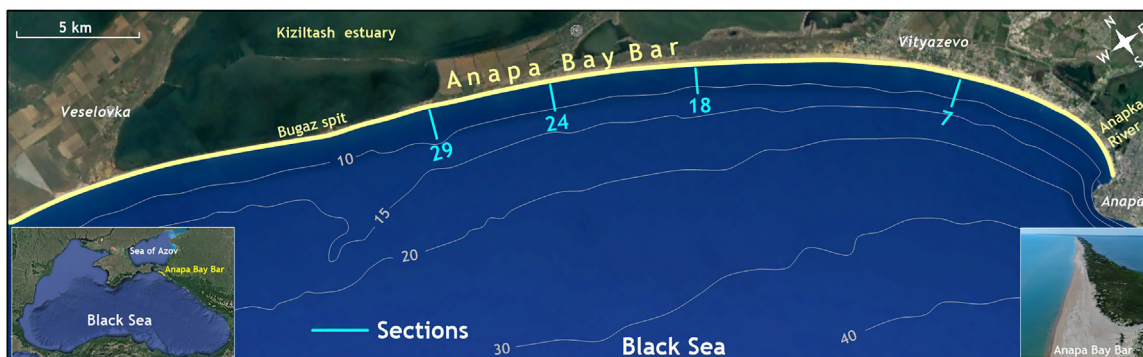

Figure 1   Map of sampling sites.

Table 1 Salinity and N, P and Si concentration in the sea water of Anapa bay bar, May 2018.

Section	Coordinates		Depth [m]	Salinity [‰]	PO_4 [μM/l]	Si [μM/l]	NO_3 [μM/l]	NO_2 [μM/l]	NH_4 [μM/l]
7	37°16′12″	44°57′16″	10[a]	18.20	0.16	3.04	0.21	0.05	1.65
	37°16′12″	44°57′16″	10	17.93	0.09	3.28	0.45	0.07	1.75
	37°16′27″	44°57′27″	6	18.44	0.06	3.04	0.15	0.04	1.33
	37°16′44″	44°57′36″	2	19.59	0.37	3.70	0.75	0.13	2.46
18	37°09′44″	45°00′49″	10[a]	19.06	0.05	2.86	0.17	0.07	1.26
	37°09′44″	45°00′49″	10	18.57	0.41	3.46	0.13	0.18	2.33
	37°09′56″	45°01′02″	6	18.52	0.41	3.52	0.00	0.11	1.45
	37°10′07″	45°01′12″	2	19.82	0.19	2.62	0.11	0.12	1.60
24	37°05′51″	45°02′14″	10[a]	18.52	0.12	2.86	0.33	0.00	1.92
	37°05′51″	45°02′14″	10	18.99	0.44	3.76	0.12	0.14	3.04
	37°05′59″	45°02′31″	6	18.60	0.21	3.28	0.28	0.17	2.18
	37°06′06″	45°02′43″	2	19.59	0.19	3.10	0.00	0.17	1.77
29	37°02′19″	45°03′12″	10[a]	18.23	0.13	2.27	0.08	0.00	2.20
	37°02′19″	45°03′12″	10	19.23	0.12	3.58	1.22	0.08	3.69
	37°02′30″	45°03′35″	6	18.40	0.13	3.52	0.00	0.05	1.32
	37°02′34″	45°03′47″	2	19.11	0.24	3.40	0.00	0.08	2.18

[a] Samples taken in near-bottom layer.

by counting external shell rings (Deval, 2001; Ramon and Richardson, 1992); this method is considered as appropriate for quick estimates of the age (Gaspar et al., 2004).

In addition to *C. gallina*, we sampled *R. venosa*, a carnivorous gastropod predating on bivalves, at the same sections and dates (sampling methods and some results are published in Kosyan (2017)).

Samples of seawater for determining the hydrochemical parameters were taken on all sections at 2, 6, and 10 m depths. At depths of 2, 6, and 10 m, the samples were taken from the boat in the surface layer of the sea into clean polystirol 1 l bottles; additional samples of near-bottom water were taken at a depth of 10 m. The sampling and processing of nitrates, nitrites, ammonium, silicates, and phosphates were performed by standard methods (Grashoff et al., 1999). The measurements were carried out in the Laboratory of Chemistry of the Southern Branch of the Shirshov Institute of Oceanology. Phosphates (P-PO_4) were determined by the modified Murphy and Riley method (Hansen and Koroleff, 1999). Absorbance was measured at 885 nm in a 50-mm cell, the precision of the technique was 0.03 μM. Silicates (Si) were determined colorimetrically according to the blue silicon—molybdenum complex (Koroleff, 1983). Absorbance was measured at 810 nm with a 10-mm cuvette; the precision of the technique was 0.06 μM. Nitrites (N-NO_2) were measured with sulfanilamide and N-1-naphthylethylendiamine dihydrochloride (Hansen and Koroleff, 1999). Nitrate (N-NO_3) was converted to nitrite using Cu-Cd columns. Absorbance was measured at 543 nm in a 50-mm cell; the precision of the technique was 0.02 μM. Ammonium (N-NH_4) was determined by the phenol-hypochlorite reaction (Solorzano, 1969). Absorbance was measured at 630 nm with a 10-mm cuvette; the precision of the technique was 0.06 μM.

The coordinates of the stations are presented in Table 1.

Statistical processing of samples was carried out using the methods of analysis of variance (MANOVA) in the STATISTICA

12 environment. The advantage of this method is the ability to use qualitative variables that form individual samples. The main idea of the method is to search for statistically significant differences between the average values of the parameter of interest, namely: the average values are statistically different if these differences exceed the variances within each sample.

A total of 2124 specimens of *C. gallina*, aged one, two, and three and more years were processed. Unfortunately, the uneven coverage of data by years, sections, and depths does not allow us to use them fully, since the lack of data strongly affects the reliability of the analysis as a whole. As a result, the samples were formed according to the following criteria (categories):

- year: 2016, 2017, 2018;
- age: 1, 2, 3+ years;
- section: 7, 18, 24, 29;
- depth: 6, 10 m.

The shell length is a dependent variable.

3. Results

3.1. Seawater chemical analysis

The salinity of seawater and concentration of the main biogenic elements are shown in Table 1. The concentration of N, P, and Si insignificantly varied within the selected sections. The average values of total nitrogen were as follows: 1.88 (section 18), 2.23 (section 24), 2.26 (section 7), 2.35 μM/l (section 29); the values of phosphorus were: 0.16 (29), 0.17 (7), 0.24 (24), 0.27 μM/l (18); while that of silica were: 3.12 (18), 3.19 (29), 3.25 (24), 3.27 (7) μM/l. The following trend prevailed over sections 18, 24, and 29: the amount of nutrients in the surface waters increased with

Table 2　Number and biomass of *Chamelea gallina* on Anapa bay bar in 2016—2018.

Sampling period at section	Number at depth [spm/m^2]			Biomass at depth [g/m^2]		
	6 m	10 m	Average for section	6 m	10 m	Average for section
June 2016						
Section 7	365.0	1130.0	505.0	488.0	1616.0	701.7
Section 18	510.0	2725.0	1081.7	363.3	357.0	240.3
Section 24	340.0	220.0	186.7	302.3	29.3	110.5
Section 29	270.0	490.0	383.3	185.5	57.5	209.0
Average for depth	371.3	1141.3	756.3[a]	334.8	515.0	424.9[a]
June 2017						
Section 7	253.0	450.0	351.3	245.0	448.0	346.5
Section 18	310.0	1925.0	1117.5	70.5	261.5	166.0
Section 24	3670.0	295.0	1982.5	325.0	62.5	193.8
Section 29	250.0	780.0	515.0	78.0	145.0	111.5
Average for depth	1120.6	862.5	991.6[a]	179.6	229.3	204.5[a]
May 2018						
Section 7	320.0	60.0	190.0	210.5	30.5	120.5
Section 18	390.0	710.0	550.0	221.5	337.5	279.5
Section 24	150.5	430.0	290.3	103.5	137.0	120.3
Section 29	555.0	1000.0	777.5	649.0	322.5	490.8
Average for depth	353.9	550.0	452.0[a]	296.1	206.9	252.8[a]

[a] Average for all sections and depths.

depth, while in the bottom layer, it was below average. There was no obvious tendency over section 7.

3.2. *Chamelea gallina* number and biomass

Average number and biomass of the clams in 2016—2018 are presented in Table 2. The maximum number (3670 spm/m^2) was observed at section 24 at a depth of 6 m in 2017, the highest biomass (1616 g/m^2) was at section 7 at a depth of 10 m in 2016. The average number was the largest in 2017 (991.6 spm/m^2) mainly due to the small-sized fingerlings; the average biomass in 2016 was 315.4 g/m^2. Comparative literature data on the number and biomass of *C. gallina* from the other parts of the Black Sea in the last 50 years are presented in Table 3.

3.3. *Chamelea gallina* general size and age structure

Shell length frequency distribution is presented in Fig. 2. The lengths of the majority of specimens were 5—7 mm in 2016, 5—9 mm in 2017, and 11—15 mm in 2018. The main problem of the study of *C. gallina* size and age population structure is the uneven distribution of samples within individual categories. Fig. 3 shows the dependence of *C. gallina* average size on their age on different sections. Average shell length of one-year-old clams was approximately the same on all sections: about 5.5—8.6 mm. The largest average shell lengths at the age of 2 and 3 years were of the clams collected at section 7 (probably, due to the proximity of the section to the Anapka River); the shell lengths of clams at sections 18, 24, and 29 were almost similar at the age of 2 years but differed at the age of 3 years so that the clams at section 29 had the

largest average shell length, and the smallest was found at section 24. Thus, the differences in the average sizes became more and more tangible with age.

The age of clams varied within 1—8 years. The largest number corresponded to one-year-old mollusks, the lesser number to two-year-old ones; the one year and two-year-old mollusks comprised 60% of the total biomass. The much lesser number of mollusks aged 3 and more, was observed.

The average sizes are clearly divided in terms "year" — "section" — "age". At the same time, interannual variations of the average size are very strong in all age groups (Figs. 4 and 5). One more important detail can be noted: the average size of clams significantly increased in 2018 compared to 2016 and especially compared to 2017 (Fig. 6). It is true for all age categories with the exception of two-year-old mollusks at 6 m and three-year-old at 10 m at section 7, and one-year-old ones at 10 m at section 24 (Figs. 4 and 5).

Analysis of the significance levels of intra- and intergroup differences suggests that there are significant statistical differences in the average size of mollusks between the categories of samples: age, geographical location (section), year of observation, and depth.

3.4. The role of geographic location and year of observation

We found strong differences in the average size of *C. gallina* from different sections by means of statistical analysis (Figs. 4 and 5). The annual increment of shell length of clams from different sections at different depths is shown in Table 4. The largest annual increment was observed at a depth of 6 m on sections 24 and 29 in the period 2017—2018. Section 24 is interesting in one more aspect: it is the only section, where a

Table 3 Comparative data on number and biomass of *Chamelea gallina* in the northern part of the Black Sea.

Map position	Location	Depth [m]	Number, [spm/m²]	Biomass, [g/m²]	Date	Source
1	Karkinitsky Bay (northern Crimea)	6—26	—	383	1985—2000	Sinegub (2006)
2	Bakal Spit (Karkinitsky Bay, northern Crimea)	4—6	40—2650	34—637	06/2018	Kosyan (2018)
3	Western Crimea, 33.53135°E, 44.6634°N	11	894 ± 85	50—541	2010—2013	Revkov et al. (2014)
4	Crimea		—	138	1960—1970	Kiseleva (1981)
4	Crimea	1—32	—	375	1980—2004	Revkov (2011)
5	Kerch Pre-Strait	5—30	40—70	0—24	2007—2008	Nabozhenko (2011)
6—8	Anapa Bay bar — Gelendzhik	8—25	16—1008	10—389	1962	Kiseleva and Slavina (1965)
6	Anapa Bay bar	6—10	730	520	10.2010	Kosyan et al. (2012)
6	Anapa Bay bar	6—10	756	425	06.2016	Herein
6	Anapa Bay bar	6—10	992	205	06.2017	Herein
6	Anapa Bay bar	6—10	452	253	06.2018	Herein
7	Sukko (south to Anapa city)	5—30	1360	737	2007—2008	Nabozhenko (2011)
9	North-Caucasian coast, Inal Bay	10	9500	800	2001	Koluchkina et al. (2017a)
9	North-Caucasian coast, Inal Bay	10	4400	550	2002	Koluchkina et al. (2017a)
9	North-Caucasian coast, Inal Bay	10	3000	300	2004	Koluchkina et al. (2017a)
9	North-Caucasian coast, Inal Bay	10	<2000	<300	2007—2016	Koluchkina et al. (2017a)
10	Tuapse	20—30	<1500	<200	1968	Kiseleva and Slavina (1972)
10	Tuapse	13	833	54	10/2010	Zagorskaya (2014)
11	Kudepsta	16	3312	244	10/2010	Zagorskaya (2014)

decrease in the average shell length was observed (6 m depth, 2016—2017). The period 2016—2017 may be considered as a critical one for all other age groups as well, since its annual increment has been less than the increment in 2017—2018, with the exception of section 18 at 6 m depth.

3.5. Depth influence

The collected material allows us to estimate the dependence of the linear dimensions of the mollusk shells on the depth. Fig. 6 shows the average sizes of shells found at different depths in different years, regardless of their age and sex

(i.e., for the entire population). We note the main features: (1) the average length of the shells decreases with increasing depth (away from the shore); (2) this trend is increasing from year to year. In 2016, the size reduction was observed at the level of statistical (including instrumental) errors, then in 2018, mollusk populations at depths of 6 and 10 m form separate samples with almost non-overlapping confidence intervals for medium sizes. The average length of shells at a depth of 10 m is by 3.5% less than at a depth of 6 m.

If we take into account the age categories (Fig. 7), these statistical properties are found mainly in adults (three years old and older). We also note that the overall decrease in the
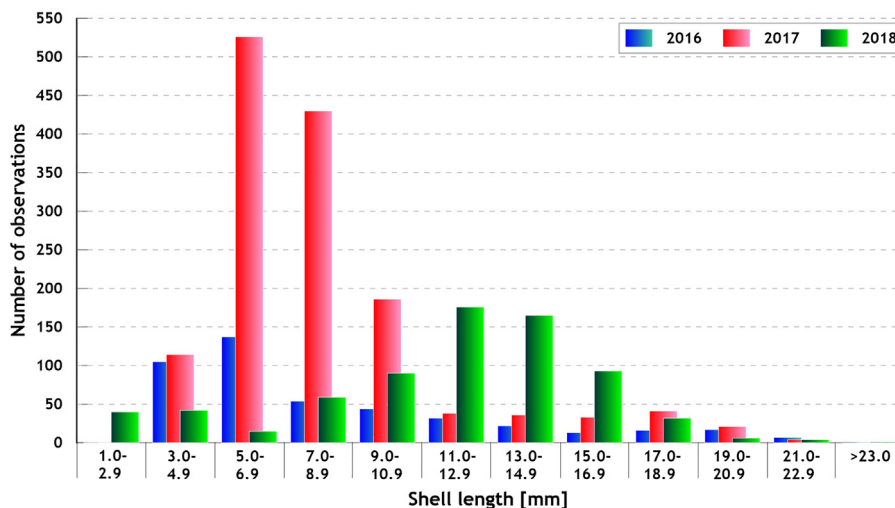
Figure 2   Shell length frequency distribution of *Chamelea gallina* at Anapa bay bar in 2016—2018.
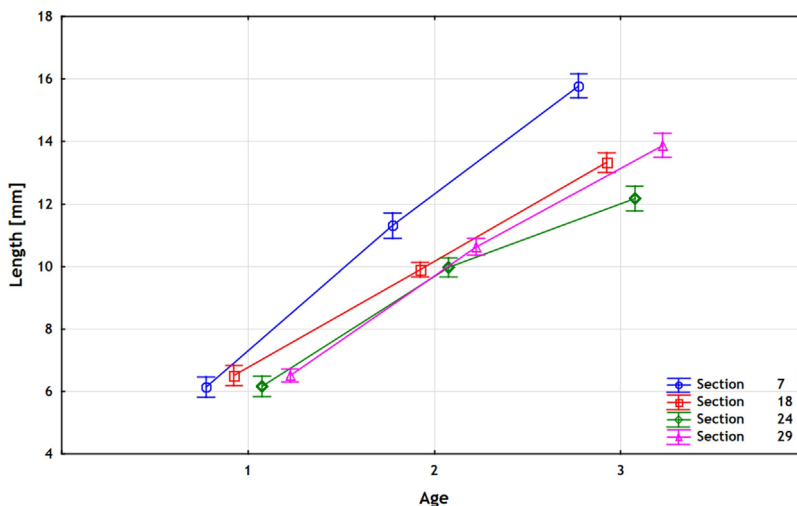

Figure 3   Geographic differences in average sizes of *Chamelea gallina*, sampled in 2016—2018. Hereinafter, vertical bars denote 0.95 confidence intervals.

average size of the mollusk shells over the entire study site, regardless of the depth, observed in 2017 (Fig. 6), is caused by a decrease in the average size of two-year-old individuals in the same year (Fig. 7).

The lack of differences at depths of 6 m and 10 m in 2016—2017 compared to 2018 might be caused by the peculiarities of wind waves responsible for transport, crushing, and redistribution of benthic animals in the sand layer resulting in mixing of mollusks from different depths. To check this assumption, we used a regularly updated database of wind wave parameters over the entire Black Sea based on the simulations using the DHI MIKE SW spectral wave model covering the period from 1979 to the present (Divinsky and Kosyan, 2017). The time step of the calculated parameters (wave heights, periods, directions of propagation, etc.) was 1 h.

We estimated the characteristics of the waves at a point located on section 18 (Fig. 1) at a depth of 15 m. Considering

the wave parameters only at one point is quite justified in our research, since the shelf slope is characterized, in general, by the lack of large bathymetric features, the coastline is slightly curved (in our study site), and the isobaths are almost parallel to the coast (Fig. 1). We formed three sample periods from the database: June 2015—May 2016, June 2016—May 2017, and June 2017—May 2018, covering the periods between the mollusk collection expeditions. The sample periods are characterized by three parameters: significant wave heights (the use of these heights is most common in marine engineering practice), the direction of propagation, wave power. The power of the waves, proportional to the square of the height of the waves and the characteristic period of the waves, can be considered as some kind of integral characteristic of the waves. For further analysis, we restricted ourselves to the sector of strongest waves in the range from 135° to 270°, since the waves of these directions determined the main
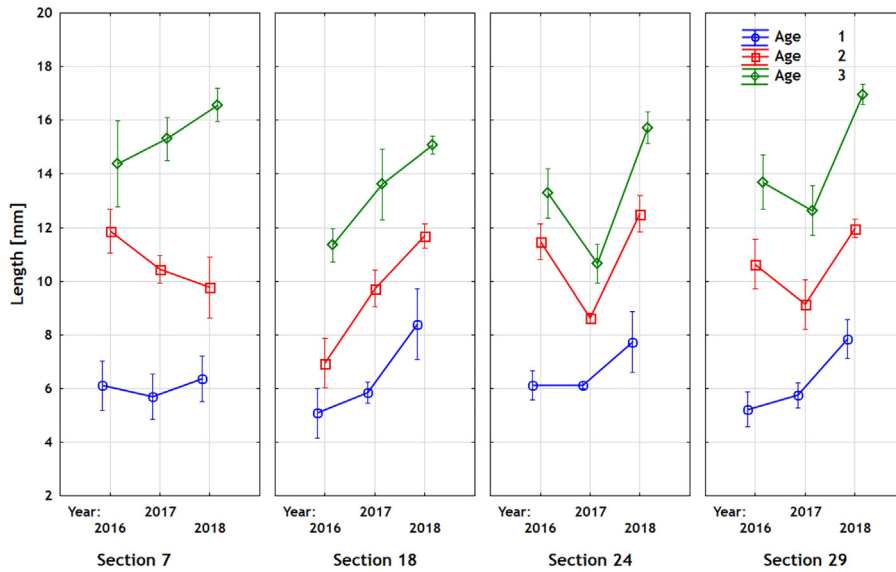
Figure 4 *Chamelea gallina* shell length dynamics at the depth of 6 m in 2016—2018.
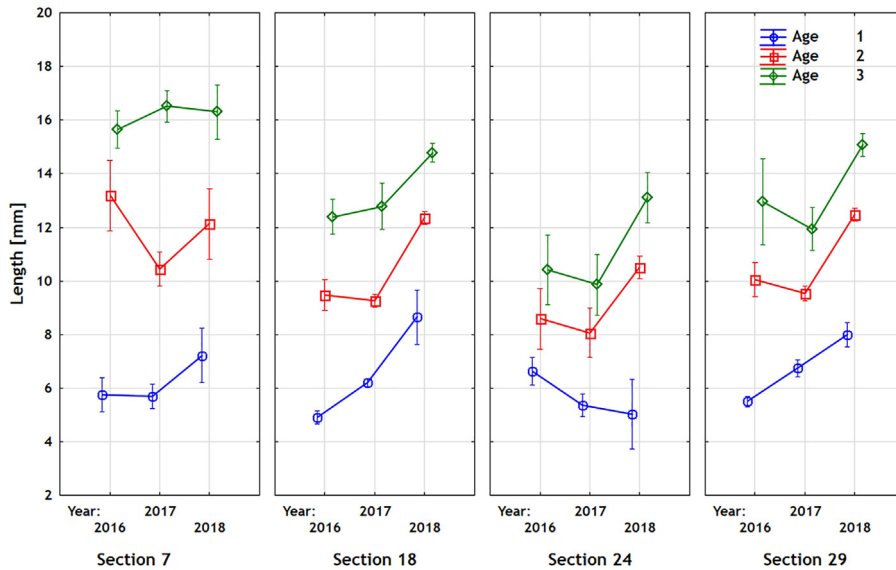

Figure 5 *Chamelea gallina* shell length dynamics at the depth of 10 m in 2016—2018.

lithodynamic load on the shelf zone of the Anapa bay bar (alongshore and transverse motions of the bottom sediments). Fig. 8 shows the average values of significant wave heights and wave powers for periods 06.2015—05.2016, 06.2016—05.2017, 06.2017—05.2018. As follows from Fig. 8, the seasons in 2015—2016 and in 2016—2017 were characterized by the surface waves with the average heights, which were by 15% higher than the average wave heights in the 2017—2018 season (Fig. 8a). As for the power of wind waves (Fig. 8b), the season in 2015—2016 exceeded the season 2017—2018 by almost 20%, and the season 2016—2017 by 40%. Based on the above mentioned facts, we can conclude that the wave forcing on the shelf slope of the Anapa bay bar in 2015—2016 and in 2016—2017 was much stronger than in the season of 2017—2018.

Thus, the average sizes of clams on the Anapa bay bar are different at different sections and depths. These differences, minimal for one-year-old clams, become more pronounced with age.

3.6. *Rapana venosa* biomass

Our preliminary results show that the average shell length of rapa whelks on the Anapa bay bar (Fig. 9c) increased by 10% in 2017 (the condition index remained unchanged), then it decreased by 4% in 2018 (condition index also decreased by 10%, Fig. 9d). The average biomass was the largest at all sections in 2016, decreasing from 20% to 50% in 2017 and from 30% to 85% (compared to 2016) in 2018 (Fig. 9b). The weakening of the rapa whelk's pressure on the *Chamelea*
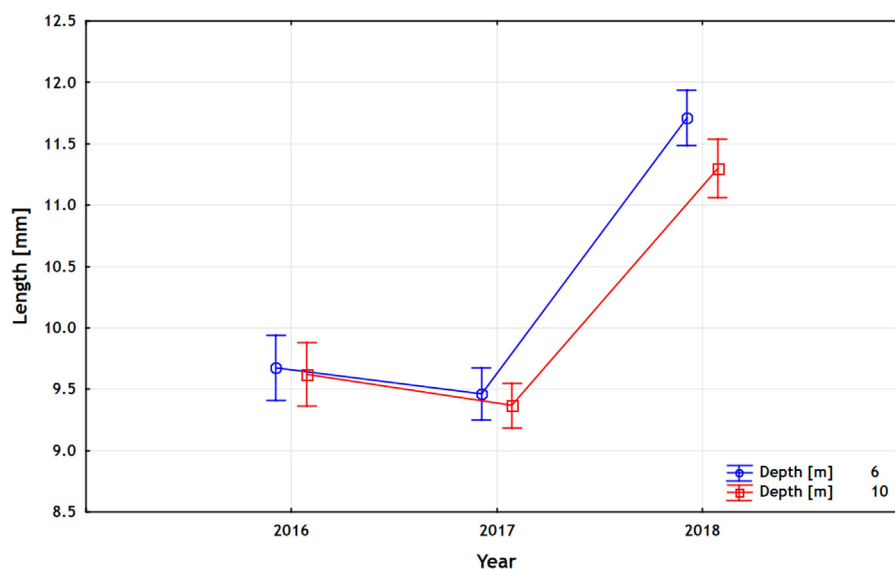
Figure 6   Shell length dynamics of *Chamelea gallina* at 6 and 10 m depths.

Table 4   Annual increment of *Chamelea gallina* shell length [mm] on Anapa bay bar in 2016—2018.

Depth [m]	6 m		10 m	
Time period	2016—2017	2017—2018	2016—2017	2017—2018
Section				
One-year-olds				
7	4	4.5	4.5	6
18	4	6	4	6
24	2.5	6	2	4.5
29	4	6	4	6
Two-year-olds				
7	3	5	3.5	6
18	7	5	3	5.5
24	1↓	8	2	5
29	2	8	2	5

community by 2018 might have led to an increase in clam biomass and average shell sizes.

4. Discussion

4.1. Biogenic nutrients concentration

We assumed that one of the factors contributing to the difference in growth rate on Anapa bay bar coast is related to the food supply. Hence, in 2018, we performed a chemical analysis to determine a rough assessment of the content of nutrients. However, these estimates should be treated with caution, as one measurement over three years is not representative, and the concentration of nutrients in the surface seawater can change rapidly.

Venerida mollusks are planktotrophic and sestonophagous, feeding on planktonic algae and suspended organic matter (Froglia, 1975b). The planktonic algae need nutrients for growth, first of all, nitrogen and phosphorus. It is known

that an increase in the concentration of nitrogen sharply stimulates the growth of microalgae, which are the main sources of organic matter in the marine ecosystems; at the same time, an excess of phosphorus inhibits their growth (Eberly, 1967). The highest biomass of mollusks in 2018 was observed at section 29 (Table 2) (which is consistent with these data) where the maximum amount of nitrogen was recorded but a minimum of phosphorus was observed. This is also seen over section 18, where the maximum amount of phosphorus was found but a minimum of nitrogen. Intermediate, almost identical values of nitrogen (2.23 and 2.26) and more variable values of phosphorus (0.24 and 0.17) were recorded at sections 24 and 7, respectively, where intermediate values of biomass were also found. It can be assumed that under the conditions of the Anapa bay bar, phosphorus has a lesser effect than nitrogen on the development of the algae biomass and consequently on the development of mollusks. The analysis of nutrient concentrations on the Bakal Spit (Kosyan, 2018) provided nearly the same results for P and N, but the silica concentration several times
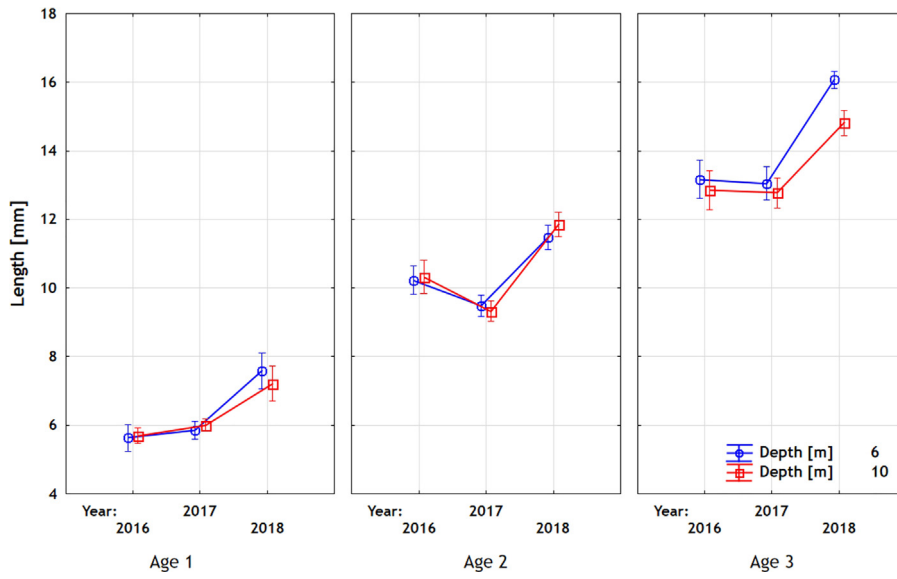
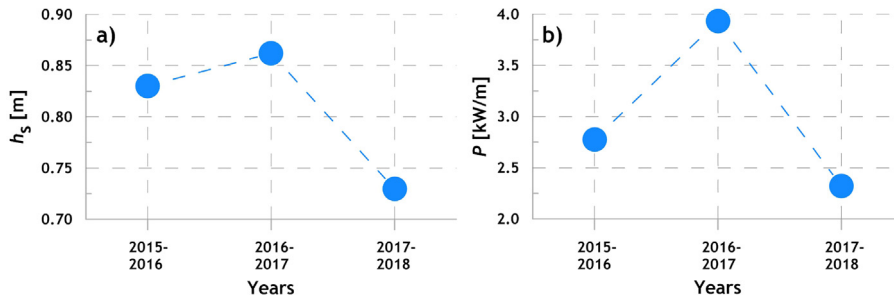**Figure 7** Shell length dynamics of *Chamelea gallina* of different age groups at 6 and 10 m depths.

Figure 8 Mean values of significant wave heights (a) and wave powers (b) for the periods between sampling of mollusks.
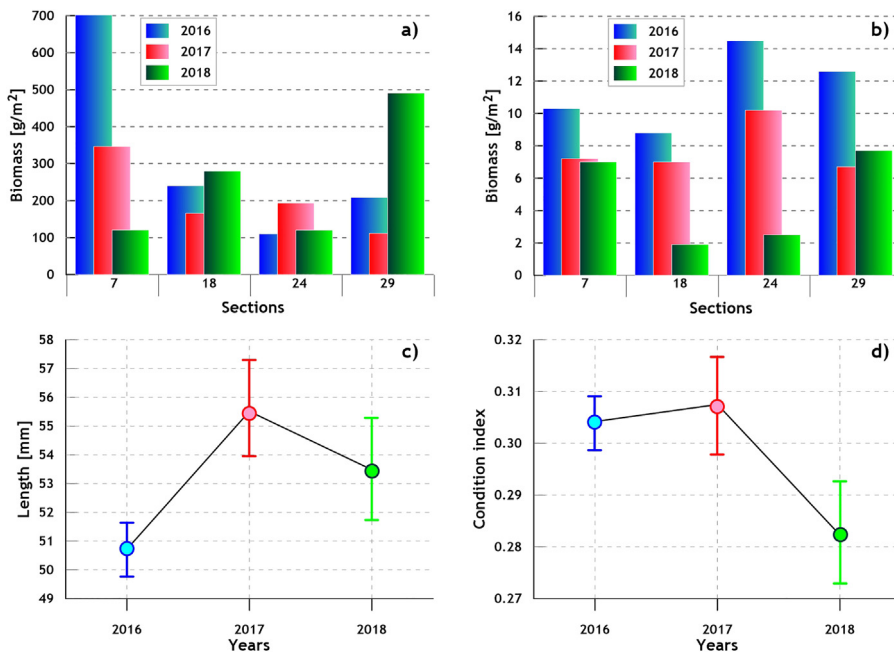

Figure 9 Biomass [g/m^2] dynamics of *Chamelea gallina* (a) and *Rapana venosa* (b) at different sections at the Anapa bay bar; dynamics of shell length (c) and condition index (d) of *Rapana venosa*, collected at 6—10 m on 7, 18, 24 and 29 sections.

exceeded that in the Anapa bay bar waters. Though the concentrations of nutrients do not indicate clear downward trends between sections 7 and 24 (Table 1), we presume that the following situation might take place. One of the important sources of nutrients is the Anapka River (Fig. 1), which is located close to section 7; here, the highest biomass and average population shell length of *C. gallina* was detected in 2016—2017 (Table 2). As the distance from the river increases, the amount of nutrients and organic matter decreases, and by section 24, it appears to be minimal. The improvement of the situation on section 29 is probably related to the fish passage channel located in the mullet farm 4 km to the north, dug in the Bugaz Spit, which connects the Kiziltash estuary with the sea. Although in spring and summer this channel is closed to the passage of fish, partial water exchange and the influx of nutrients from the estuary can have a positive effect on the marine biocenoses located nearby. Similarly to the Anapa bay bar, the biomass of clams on different sections of the Bakal Spit was also different (Kosyan, 2018). The highest biomass of *Chamelea* was observed near the Bird Island separated from the end of the spit and populated by large colonies of sea birds. The island is probably a source of biogenic nutrients, causing high mollusk productivity.

It was shown previously, that the concentration of stable isotope ^{13}C in live *C. gallina* shells, collected on the Anapa bay bar at various depths, was different: the concentration of ^{13}C at 5 m was 19.55‰, while at 10 m it was 20.29‰ (Antipushina, 2012). This means that the diets of clams on different depths could also differ and could be one of the causes of growth differences. Strong wind waves mix shells from different depths, and this trend is manifested only in relatively quiet years, as it was shown in Section 3.

4.2. Dynamics of abundance and biomass of mollusks

At the end of the 20th and beginning of the 21st century, significant changes occurred in the composition and abundance of Bivalvia, a key group of macrozoobenthos at depths of 10—30 m in the northern part of the Black Sea. As a result of anthropogenic eutrophication and introduction of alien species in 1999—2005, there was a significant decrease in species diversity, and fluctuations in the abundance and biomass of bivalve mollusks started to occur (Chikina, 2009; Kucheruk et al., 2002). *C. gallina* prefers sandy grounds, and sand silting is a major factor determining the differences in the modern structure of the northern Black Sea macrozoobenthos (Koluchkina et al., 2017c). The highest densities and biomasses were observed at sandy coasts of Crimea and northern part of the Caucasian coast (Table 3). *Chamelea* biomass in 2010 was approximately the same as the highest values observed in 1962 (Table 3), and then they gradually decreased up to 2017, when it decreased more than twice despite high density The number of specimens (density) was high while the biomass was low due to the decrease in the mean size of the individual clams. The 1.3 times biomass increase in 2018 was determined, mainly owing to the unusually high biomass of clams at sections 29 and 18 (Fig. 8a). In the southern part of the North-Caucasian coast (Inal Bay) (Table 3), a decrease in *Chamelea* biomass from 800 to

300 g/m² was observed in 2001—2004, but in 2007—2016, it varied only within 100—300 g/m² (Koluchkina et al., 2017b). The authors assumed that the system was unbalanced at the end of the twentieth century and then the system entered a new stationary state (Chikina, 2009) close to the one that was observed in the second half of the twentieth century before the eutrophication period. The same tendency seems to be true on the Anapa bay bar and vicinities, but longer monitoring is necessary to fully reveal it.

4.3. Biological factors influencing *Chamelea gallina* shell size and growth rate

According to Deval (2001), the largest observed specimen in the Marmara Sea was 34.3 mm long, and only 2.2% of the sampled specimens were larger than 30 mm indicating a rather high level of anthropogenic effect in the area. On the Anapa bay bar, we observed a further decrease in size: the largest *C. gallina* was 23.8 mm long and 2.3% of specimens were larger than 19 mm. Since the situation with water pollution and precipitation in the Anapa bay bar region is the most favorable (less polluted and silted) compared to the other areas of the northeastern coast of the Black Sea (Koluchkina et al., 2017a), it can be assumed that the decrease in size is due to another cause. The clams are not an object of fishery in Russia, but the effect of *R. venosa* (similar to anthropogenic load) influences the clams by selective elimination of the largest specimens (Kosyan, 2016). According to Nakaoka (2000), even the presence of chemical signals of a predator in water reduces the growth rate of *Mercenaria mercenaria* (Linnaeus, 1758), a member of the same family as *Chamelea*. Thus, *Rapana* can probably inhibit the growth of clams only by its presence. This is indirectly confirmed by the observation (Kosyan, 2018) that the average shell lengths of the clams from the Bakal Spit are larger than those from the Anapa bay bar, despite the same age (2 years). Unlike Anapa bay bar, live specimens of rapa whelks were not found during our studies in the Bakal Spit, only dead shells were found, despite findings of *Rapana* in the other parts of Karkinitsky Bay (Boltacheva et al., 2016). Kiseleva and Slavina (1966) noted, that in the northern part of the Caucasian coast (from Zhelezny Rog Cape to Gelendzhik city), the average shell lengths of *C. gallina* were 12—18 mm, while on the coast between Gelendzhik and Batumi they were 5—12 mm long. The authors also connect this observation with the effect of existence of predators *R. venosa*.

Another probable cause of different sizes of *C. gallina* of the same-age is population density. In a number of studies, both in the experiment (Olafsson, 1986; Peterson, 1982; Peterson and Beal, 1989) and in the natural conditions (Mills et al., 1993), the negative effect of the sestonophagous bivalves population density on their growth rate was noted. The average *C. gallina* shell lengths from different sections differ both within the regions of the Bakal Spit (Kosyan, 2018) and the Anapa bay bar (Figs. 4 and 5). At the same age group, the samples with the highest population density and the lowest average population weight had smaller average sizes of the shells (Figs. 4 and 5, Table 2). The longer lifespan was of *C. gallina* from the Anapa bay bar (8 years, single specimens reached 4—5 years on the Bakal Spit) and can also be associated with the slower growth (Ridgway et al., 2011).

4.4. Geographic factor influencing *Chamelea gallina* shell size and longevity

Longevity and maximum shell size of *C. gallina* are subject to significant variability. The maximum *Chamelea* life span in the Anapa bay bar coast was 8 years and its shell length was 23.8 mm, whereas in the northwestern Crimea (Bakal Spit) it was 5 years with a size of 23.5 mm (Kosyan, 2018).

Maximum longevity and shell length in the Black Sea was estimated at an age of 9 years, while the maximum length was 30 mm (in the southwestern Crimea; Boltacheva and Mazlumyan, 2003) versus formerly reported 43 mm (Scarlato and Starobogatov, 1972). Geographically distant populations along the Mediterranean and the Atlantic reveal even stronger differences. Due to the local environmental conditions, eastern populations of *C. gallina*, from the Marmara Sea and Adriatic, have greater longevities than the western populations in the Mediterranean (Spanish coast) and in the Atlantic (Algarve coast) (Gaspar et al., 2004). Thus, similarly to the Anapa clams, the longevity of *C. gallina* from Ancona (Italy) was reported as 8 years with a shell length of 49 mm (Polenta, 1993), from the northern Marmara Sea: 7 years and 34.3 mm shell length (Deval, 2001). The longevity of *C. gallina* from the South Adriatic, Spain, and Portugal usually did not exceed 5 years and 40 mm shell length (Cano and Hernández, 1987; Gaspar et al., 2004; Massé, 1971; Poggiani et al., 1973; Ramon and Richardson, 1992; Royo, 1984). The marked difference between the longevity maxima of *C. gallina* of approximately the same length from the distant populations may be explained by its significant negative correlation with the growth rate (Ridgway et al., 2011). Growth rate decreases, and lifespan increases, with latitude, both across the group as a whole and within well-sampled species (Moss et al., 2016). The greater longevity of the northern populations may, therefore, be related to reduced energy expenditure for growth and greater energy utilization for shell and tissue regeneration to sustain homeostasis (Ziuganov et al., 2000).

5. Conclusions

Comparative studies of quantitative parameters of *C. gallina* population show that its biomass in 2010 was approximately the same as the highest values observed 50 years earlier in 1962. Then it eventually decreased more than twice, up to 2017, despite high density: the mean size of the individual clams also decreased. The 1.3 times biomass increase in 2018 was determined, mainly by unusually high biomass of clams at particular sections. Our results show that the average sizes of clams on the Anapa bay bar differ at different sections and depths. These differences, minimal for one-year-old specimens, become more pronounced with age. One of the factors influencing shell length and age is the presence of carnivore gastropods *R. venosa* eliminating the largest specimens and probably inhibiting the growth of the other clams of the *C. gallina* population. The concentration of the main nutrients does not reveal a direct correlation with either the shell size or the density, but it must be taken into account that these data should be interpreted with great caution and more sampling is needed during a longer time period. Slightly longer shells at a depth of 6 m compared to 10 m may be explained by different diets at different depths. Wind waves, responsible for the transport and redistribution of benthic animals in the sand layer, result in mixing of mollusks from different depths and leveling of these differences. Comparison with the long-term monitoring results of the macrozoobenthos in Inal Bay (southern part of the North-Caucasian coast) reveals that similar processes might take place at the Anapa bay bar: after fluctuations in the abundance and biomass of bivalve mollusks, the ecosystem entered a new stationary state, close to that observed in the second half of the twentieth century.

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