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Non-native zoobenthic species of the Crimean Black Sea Coast

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Abstract

More than 40 non-native species have been registered in the zoobenthos of the Black Sea. Only, five alien species, the Crustacea *Rhithropanopeus harrisii* (Gould, 1841) and *Rhithropanopeus harrisii* (Gould, 1841), and the Mollusca *Rapana venosa* (Valenciennes, 1846), *Mya arenaria* (Linne, 1758) and *Anadara kagoshimensis* (Tokunaga, 1906), were recorded in the benthos on the Crimean shelf between 1999 and 2014. The blood-cockle *A. kagoshimensis* has settled on many sites of the Black Sea shelf in the past forty years. The first detection (1999) along the Crimean coast and the temporal variability of this mollusc's population coincides with the variability of the water temperature in the area. The five alien species had spatial aggregation and their occurrence did not exceed 23% in the boundaries of the distribution sites. An increasing trend in their abundance in the last five - seven years was observed. These years were characterized by a temperature rise in the surface layer of coastal waters. Similar patterns have been observed in the interannual variability of the biomass and abundance ratio of aliens to native for all zoobenthic taxonomic groups, i.e. of the dominance index of alien species.The low dominance index of the introduced species is indicative of low impact on the diversity of the benthic communities of the Crimea coast, i.e. at metacommunity scale. With the exception of *R. venosa*, they exhibited lower biomass and abundance along the Crimean coast shelf as opposed to other areas of the Black Sea shelf. Occasionally, the dominance index for the barnacle *Amphibalanus improvisus* (Darwin, 1854) can be high, a fact attributed to the low biomass and abundance of other benthic species.

Keywords: alien zoobenthic species, biomass, abundance, metacommunity, Crimea, Black Sea.

Introduction

The colonization of the Black Sea by Mediterranean species (or Mediterranization) is a natural process, which started after the opening of the Bosporus Strait (Archangelsky & Batalina, 1929). The natural mechanism of sea currents is not the only "supplier" of benthic larvae from the Mediterranean Sea. Anthropogenic transfer of alien species has a significant impact on the benthic community of the entire Black Sea. The development of active navigation and introduction of species for aquaculture expands the geographic distribution of invasive species. Anthropogenic intervention is responsible for the first record of alien species off the coast of the Caucasus and on the north-west shelf of the Black Sea, from the Atlantic or the Indo-Pacific (Zaitsev & Öztürk, 2001; Gomoiu, 2001; Alexandrov *et al*., 2004; Aleksandrov, 2010). Nowadays, more than 40 non-native alien species are registered in the benthos of the Black Sea (Gomoiu *et al*., 2002; Gomoiu & Skolka, 2005; Alexandrov *et al*., 2007). The barnacle *Amphibalanus improvisus* (Darwin, 1854) was one of the first alien species recorded in the Black Sea far back in the 1840s (Gomoiu & Skolka, 1996). It is attached not only to the hard substrata available, but also to the shells of local bivalves in benthic communities. Of the many alien species introduced in the Black Sea, seven zoobenthic species, namely the polychaetes, *Ficopomatus enigmaticus* (Fauvel, 1923), *Streblospio gynobranchiata* (Rice & Levin, 1998) and *Polydora cornuta* (Bosk, 1802), the crustacea, *Rhithropanopeus harrisii* (Gould, 1841), and the molluscs *Rapana venosa* (Valenciennes, 1846), *Mya arenaria* (Linne, 1758) and *Anadara kagoshimensis* (Tokunaga, 1906) are considered invasive. They are known to have changed the structure of benthic communities in the Black Sea over the last 30-40 years (Gomoiu, 1984; Alexandrov & Zaitsev, 2000; Skolka & Gomoiu, 2004; Chikina & Kucheruk, 2005; Surugiu & Feunteun, 2008; Skolka & Preda, 2010; Ivanov, 2013; Radashevsky & Selifonova, 2013; Boltachova *et al*., 2015; Teacă *et al*., 2015).

Different spatial scales of ecological processes are characterized by linkages and contingent spatio-temporal boundaries in the Black Sea. Zoobenthos, as an indicator, reflects the spatial and temporal variability and the scales of these ecological processes on the sea shelf. At local level, benthic communities change significantly because of the changing local hydrological conditions that are reflected in the interannual variability of the species and the age structure of zoobenthos (Shalovenkov & Ryabtsev, 2003, 2004). On the scale of the entire Crimean shelf, the structure of benthic communities is relatively constant and has the distinctive features of other Black Sea regions (Zernov, 1913; Kiseleva & Slavina, 1963, 1964, 1965; Nikitin, 1964; Kiseleva, 1981). Here, the absence of alien mollusca for many years after their settlement in the Black Sea is an indication of the particularities and the elative "isolation" of regional benthic communities. At the same time, the water masses of the coastal shelf of the Crimea are characterised by regional peculiarities of the hydrophysical fields and relatively stable hydrological fronts on the borders (Zats *et al*., 1966; Blatov *et al*., 1984; Blatov & Ivanov, 1992; Artamonov *et al*., 2012). Therefore, we consider the Crimean shelf community to be a regional metacommunity, one of the several local zoobenthic communities that replace each other and overlap on the whole coastal shelf. The Western and Deep-sea hydrological fronts and the hydrological structure before the Kerch Strait in the east are conditional borders (ecological barriers) for the benthic metacommunity on the coastal shelf of the Crimea (Fig. 1).

The aim of this study is to assess the biological characteristics (biomass and abundance) of non-native macrozoobenthic species and the temporal trends on the shelf of Crimea. The applicability of the aliens/invasive species ratio is also tested as a potential impact indicator.

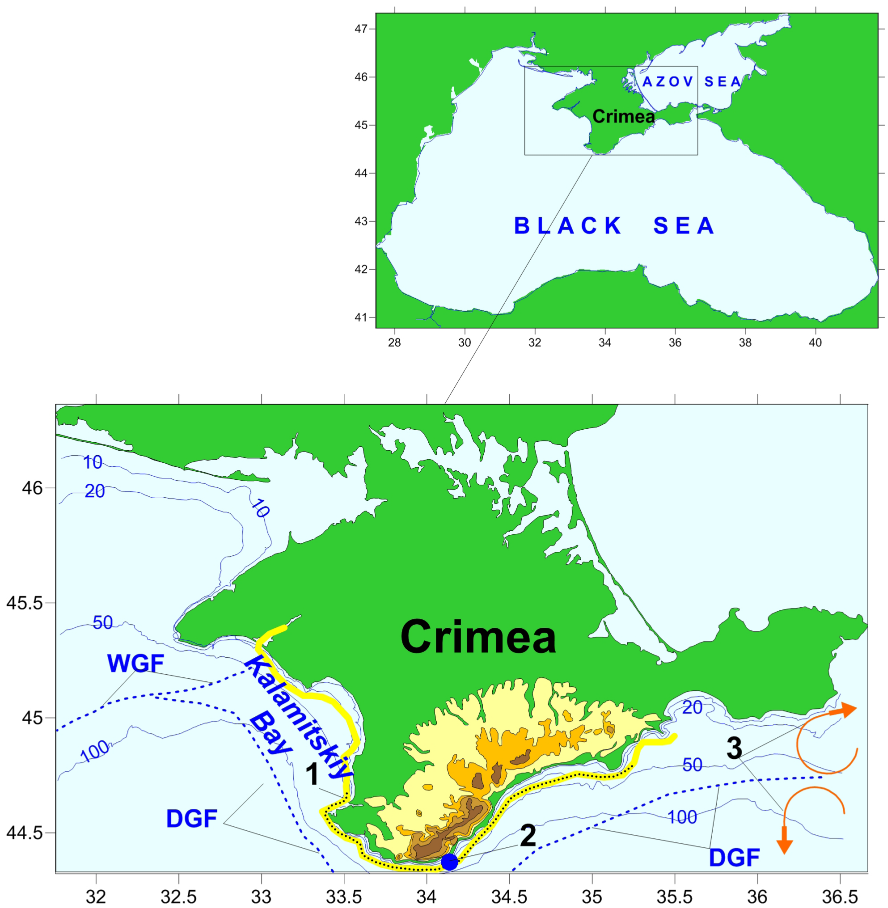

Fig. 1: Study area (60 sites, solid yellow line) and area of recording (dotted brown line) of the alien mollusc *A. kagoshimensis* along the Crimean shelf. Conditional borders (dashed blue line) of the Western (WGF) and Deep-sea (DGF) hydrological fronts. 1 - Western boundary of recording of the mollusc on the shelf; 2, label ● - example of one local investigated site (Table 1); 3 - structure of hydrological circulation before the Kerch Strait.

Materials and Methods

The macrozoobenthic studies were carried out on the Crimean shelf from the West to the East, along steppe and mountain coasts, during the period between 1999 and 2014. Sixty sites were studied along the coast of Crimea, 3 to 5 new sites per year (Fig. 1, yellow line). About 800 benthic stations were sampled during the study period. Within each site, the locations of the stations (ranging from 12 to 21) were determined according to bottom landscape features and depth gradient. At each station, three random samples of bottom sediment were collected by divers (at depths of 2 - 30 m) and by Petersen grabs (at depths of 30 - 85 m) with a coverage area of 0.1m^2. The samples were sieved through a 1 mm mesh size sieve and preserved in 75% alcohol for subsequent sorting, identification and enumeration of macrozoobenthic organisms (up to species level) at the laboratory. Total biomass - wet weight - was measured for each species.

The analysis and statistical calculations were performed only for sites where the zoobenthic alien species were recorded. The biomass and abundance data are presented as mean values and standard error. The dominance index "D_i" of alien species was derived by applying the equation (Balogh, 1958):

$$Di = \frac{ni}{N} * 100$$

where: n_i – the abundance or biomass of individuals of the i-th species, N - the total abundance or biomass of all species in the same taxonomic group. The alien/native ratio of abundance and biomass was used for estimating the impact of biological invasions on the zoobenthos and for analyzing temporal trends.

The autocorrelation coefficient "r_1" of the first-order series levels (1 year) was calculated by the formula:

$$r_1 = \frac{\sum_{t=2}^{n}(y_t - \bar{y}_1)\cdot(y_{t-1} - \bar{y}_2)}{\sqrt{\sum_{t=2}^{n}(y_t - \bar{y}_1)^2 \cdot \sum_{t=2}^{n}(y_{t-1} - \bar{y}_2)^2}}$$

where: $\bar{y}_1 = \frac{\sum_{t=2}^{n} y_t}{n-1}; \quad \bar{y}_2 = \frac{\sum_{t=2}^{n} y_{t-1}}{n-1}.$

t - time periods, 1,2,3,4,…n (year)

y_t и y_{t-1}- values taken at different time periods

The autocorrelation coefficients of the second and higher orders were calculated similarly.

Statistical analysis of the zoobenthic data, including long-term linear trends and temporal autocorrelation, was carried out using the STATISTICA software package. The time-series observations were not equally spaced in time. However, the series was not completed by interpolating missing values, as the selection of a time series model was not the aim of this study. Kriging interpolation was applied for graphic representation of the studied parameters in the spatial distribution using the Golden Software Surfer program.

Results

Five invasive species; the crustaceans *Amphibalanus improvisus* and *Rhithropanopeus harrisii*, and the molluscs *Rapana venosa, Mya arenaria* and *Anadara kagoshimensis* were recorded in the benthos during the study period.

Anadara kagoshimensis was scattered throughout the coastal shelf of the Crimea from east to west: from the Kerch Strait to Kalamitskiy Bay. As regards Kalamitskiy Bay (Fig. 1), the alien mollusc has not been recorded yet. *Rapana venosa* and *Rhithropanopeus harrisii* were recorded on the whole shelf of the Crimea, while *Mya arenaria* presented a very limited distribution.

In the investigated local areas (Fig. 1, label "2"), alien species had an aggregated distribution and occupied small sites of the seabed (Fig. 2 a-d). They had low abundance and occurrence at local scale. At the same time, the biomass of these alien species exceeded, several times, the total biomass of all native species of zoobenthos (Table. 1). Besides, relative (%) biomass and abundance of the alien species, or dominance index, was high only on a very small area of the sites (Fig. 3 a,b).

At regional scale, the occurrence of the alien zoobenthic species was also low with the exception of the barnacle *A. improvisus*. Out of the 60 investigated shelf areas, the crab *R. harrisii* was recorded at 22% of the sites, the mollusc *R. venosa* occurred at 38% and the mollusc *A. kagoshimensis* at 32% of the sites, while the barnacle was recorded at 57% of the investigated sites. The mollusc *M. arenaria* was observed only once, at one site off the coast of Sevastopol. This alien species was characterised by spatial aggregation and not very high occurrence, which did not exceed 23% on the boundaries of the distribution sites.

It was only in 1999 that the blood-cockle *A. kagoshimensis* was recorded on the Crimean shelf for the first time (Revkov *et al*., 2002). The Harris crab and the Rapana sea snail have been recorded in the benthic communities of the Crimean shelf for more than 60 years. The results showed that some of the biological indicators of settlement of the mollusc *A. kagoshimensis* were not lower than those of Harris crab and the Rapana sea snail (Table. 2).

With very few exceptions, the biomass of the alien species *A. improvises, R. harrisii*, *R. venosa* and *A. kagoshimensis* was predominantly low. The adult molluscs with a high individual biomass, *R. venosa* and *A. kagoshimensis*, were recorded in some parts of the mountainous coast of the Crimea only. The *Rapana* sea snail was distributed at the small local site of the coastal shelf, not exceeding 500 m along the coast. The density and biomass of the alien mollusc *R. venosa* was 100 ind/m^2 and 6032 g/m^2only once, respectively, in the *Mytilus galloprovincialis* community on the Crimean shelf (Fig. 2). Therefore, its influence on the zoobenthos, as predator, is limited by its distribution area only.

In general, both the abundance and the occurrence of the molluscs *R. venosa* and *A. kagoshimensis* were low. Furthermore, an increasing trend was revealed for the abundance of alien species in the last five to seven years (Fig. 4 a-d). The trend did not affect the biological characteristics of all zoobenthos in the investigated areas of the Crimean shelf.

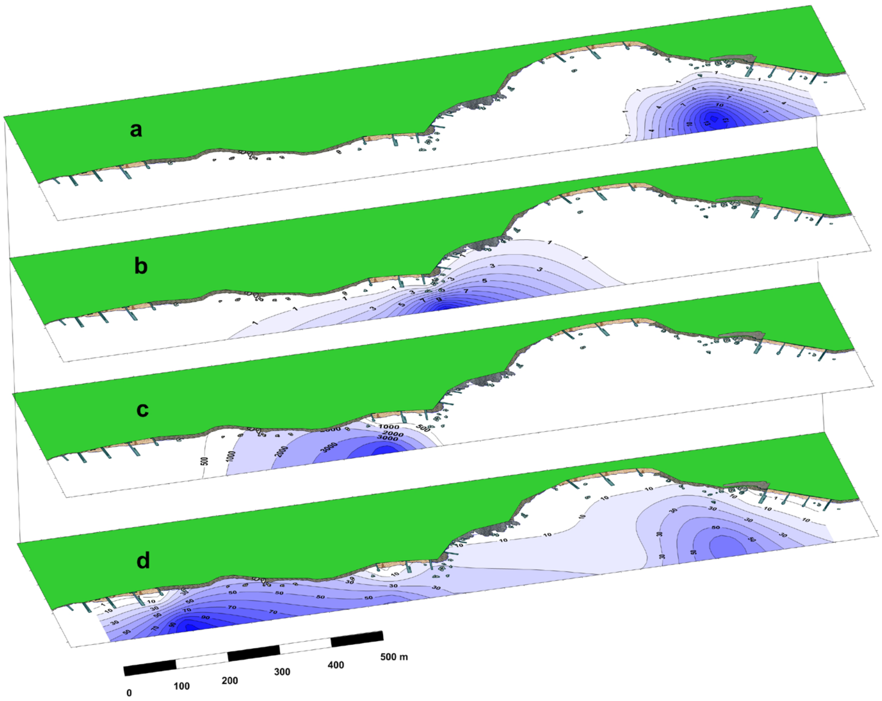

Fig. 2 a-d: Study area (60 sites, solid yellow line) and area of recording (dotted brown line) of the alien mollusc *A. kagoshimensis* along the CSpatial variability of the biomass distribution (g/m^2) of the alien molluscs, *A. kagoshimensis* (a) and *R.* v*enosa* (b), of the alien crab *R. harrisii* (c), and of the all macrozoobenthos (d) at one of the investigated sites ("2" on the map, Fig. 1).

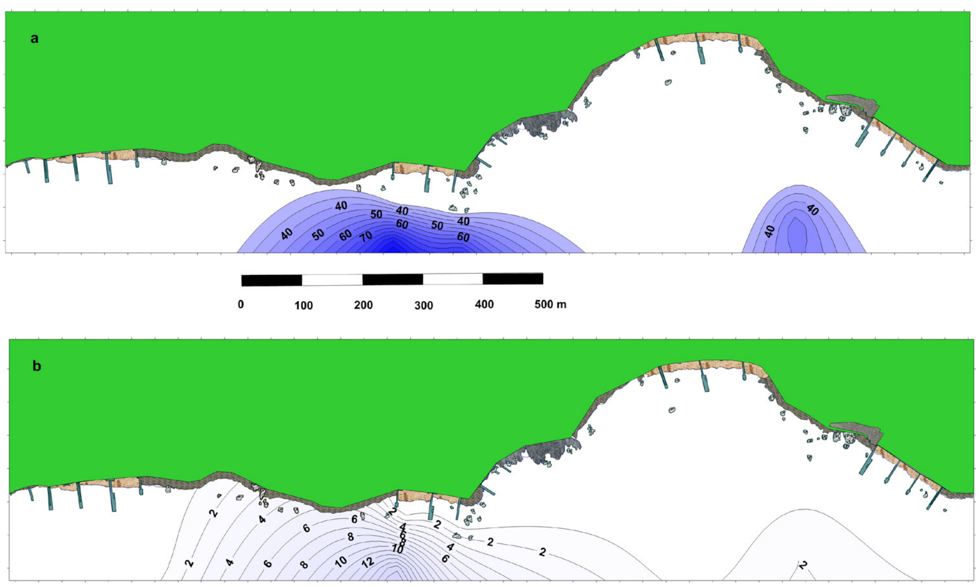

Fig. 3 a-b: Spatial heterogeneity of relative a) biomass (%) and b) abundance (%) of the alien species (*A. kagoshimensis, R.* v*enosa* and *R. harrisii*) at the investigated site ("2" on the map, Fig. 1).

Table 1. Average values of the biomass (**B**) and standard deviation (**SD_B**), of the abundance (**N**) and standard deviation (**SD_N**), and frequency of occurrence (**F**) for the benthic species at the local investigated site (Fig. 1) of the Crimean shelf.

Species	**B g/m²**	**SD_B**	**N ind/m²**	**SD_N**	**F %**
Polychaeta					
Genetyllis tuberculata (Bobretzky, 1868 г.)	0.001	0.003	0.313	1.25	6
Mysta picta (Quatrefages, 1866)	0.008	0.031	0.625	2.5	6
Pholoe inornata Johnston, 1839	0.001	0.003	1.563	5.073	13
Alitta succinea (Leuckart, 1847)	0.005	0.014	1.222	3.339	13
Platynereis dumerilii (Audouin & Milne Edwards, 1834)	0.115	0.357	4.063	10.201	25
Eunice vittata (Delle Chiaje, 1828)	0.006	0.019	3.75	10.878	13
Protodorvillea kefersteini (McIntosh, 1869)	0.015	0.023	58.125	93.325	44
Prionospio cirrifera Wirén, 1883	0.016	0.027	5.313	7.181	44
Ophelia bicornis Savigny in Lamarck, 1818	0.016	0.065	0.625	2.5	6
Vermiliopsis infundibulum (Philippi, 1844)	0.00006	0.0003	0.313	1.25	6
Crustacea					
Amphibalanus improvisus (Darwin, 1854)	0.007	0.027	0.313	1.250	6
Diogenes pugilator (Roux, 1829)	0.571	0.804	24.688	35.566	56
Xantho poressa (Olivi, 1792)	0.321	1.286	0.313	1.25	6
Rhithropanopeus harrisii (Gould, 1841)	0.01	0.036	1.222	3.845	13
Hippolyte leptocerus (Heller, 1863)	0.004	0.016	0.625	2.5	6
Pisidia longimana (Risso, 1816)	0.45	1.655	28.153	100.942	19
Echinogammarus olivii (Milne Edwards, 1830)	0.009	0.036	0.625	1.708	13
Dexamine spinosa (Montagu, 1813)	0.001	0.003	0.625	2.5	6
Tritaeta gibbosa (Bate, 1862)	0.0004	0.002	0.625	2.5	6
Microdeutopus versiculatus (Bate, 1856)	0.002	0.004	5.625	11.384	25
Microdeutopus gryllotalpa Costa, 1853	0.004	0.015	1.25	5	6
Gastropoda					
Lepidochitona caprearum (Scacchi, 1836)	0.019	0.078	0.313	1.25	6
Tricolia pullus (Linnaeus, 1758)	0.096	0.212	4.375	10.468	25
Gibbula divaricata (Linnaeus, 1758)	0.656	1.832	5	13.540	19
Rissoa splendida Eichwald, 1830	0.009	0.037	0.313	1.25	6
Tritia reticulata (Linnaeus, 1758)	0.702	2.473	0.625	1.708	13
Tritia neritea (Linnaeus, 1758)	1.576	3.371	5.625	9.811	38
Tritia pellucida (Risso, 1826)	0.539	1.965	4.063	12.003	13
Rapana venosa (Valenciennes, 1846)	391.026	1505.073	7.273	25.237	19
Bivalvia					
Anadara kagoshimensis (Tokunaga, 1906)	0.931	3.723	0.313	1.250	6
Mytilaster lineatus (Gmelin, 1791)	0	0.002	0.313	1.25	6
Mytilus galloprovincialis Lamarck, 1819	2.193	8.770	0.938	3.75	6
Lucinella divaricata (Linnaeus, 1758)	0.034	0.108	6.25	19.959	19
Parvicardium exiguum (Gmelin, 1791)	0.775	2.947	2.813	9.995	13
Gouldia minima (Montagu, 1803)	12.814	15.246	223.722	329.885	63
Pitar rudis (Poli, 1795)	1.817	3.657	13.722	39.483	44
Chamelea gallina (Linnaeus, 1758)	2.544	6.309	11.563	20.714	38
Donacilla cornea (Poli, 1791)	0.274	0.623	4.063	8.004	25
Chordata					
Branchiostoma lanceolatum (Pallas, 1774)	0.317	0.586	12.5	22.136	38

Table 2. Variability of the mean and maximal values of the biomass (**B** and **B_{max}**), abundance (**N** and **N_{max}**); mean and SD of the dominance indices (**D_B** and **D_N**) of invasive species in the benthos of the Crimean coast.

Species	**B g/m²**	**B_{max} g/m²**	**D_B %**	**N ind/m²**	**N_{max} ind/m²**	**D_N %**
Amphibalanus improvisus	0.001 – 44.924	361.25	2.029±0.502	1 - 762	2295	13.586±2.614
Rhithropanopeus harrisii	0.01 - 4.809	32.066	1.463±0.267	1 - 5	100	1.056±0.154
Rapana venosa	0.15 - 391.026	6032.942	33.621±4.530	1 - 7	101	0.427±0.055
Anadara kagoshimensis	0.001 - 9.482	100.850	4.590±0.944	1 - 6	60	0.508±0.069
Mya arenaria	0.278	3.336		1	5	

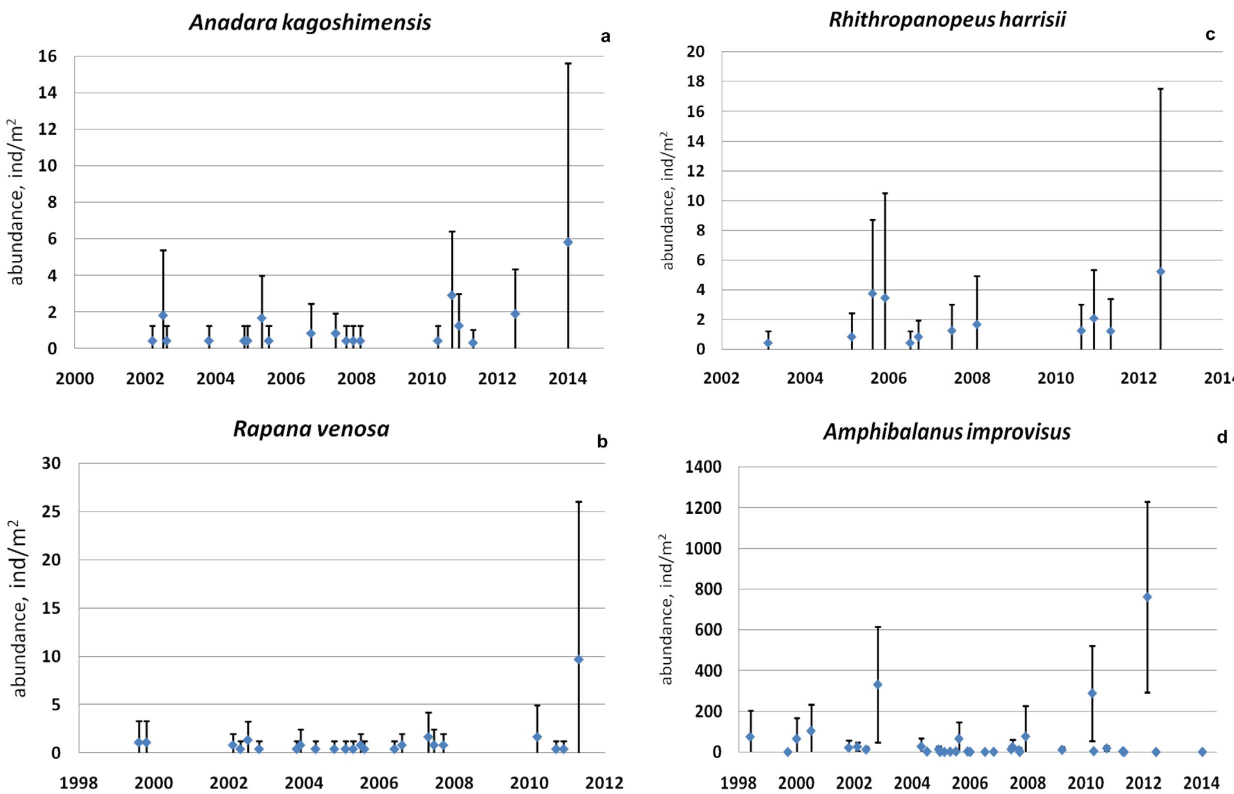

Fig. 4 a-b: Temporal variability of the abundance (average and confidence interval) of the alien species at the local sites of the Crimea shelf. *Mya arenaria* not shown because of limited distribution.

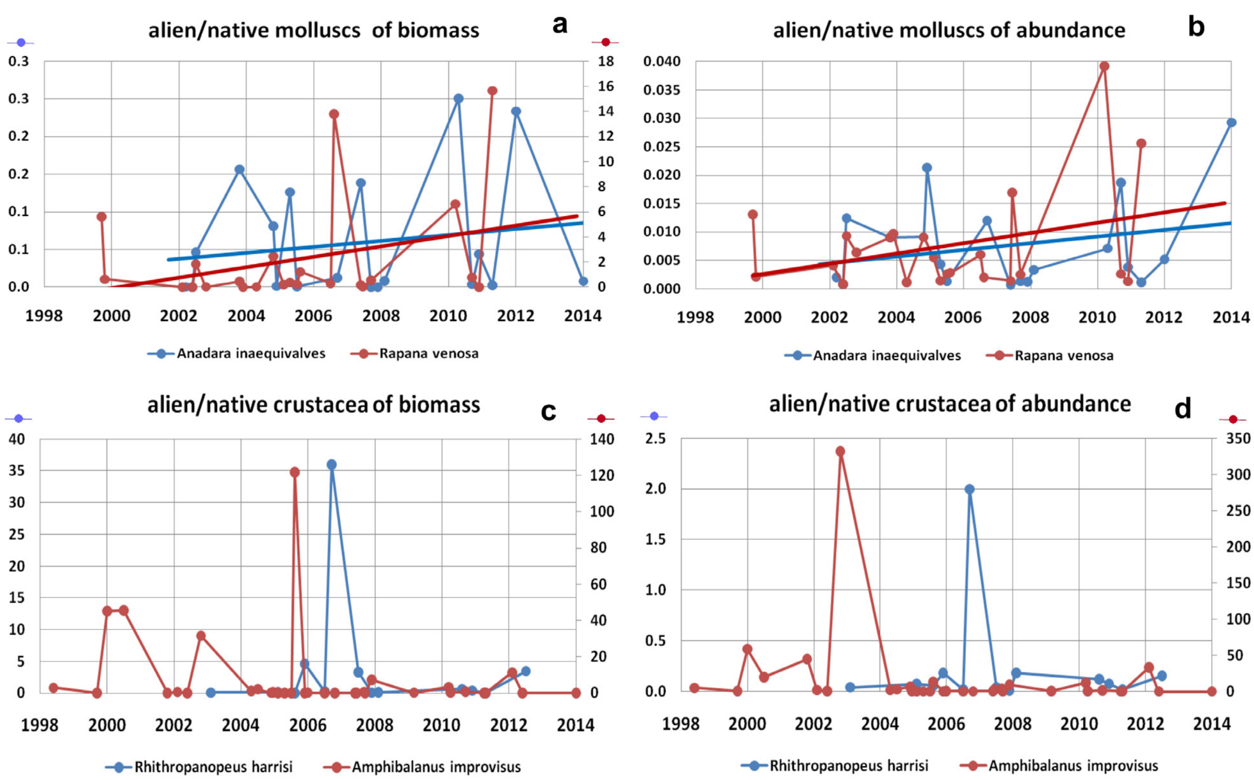

Fig. 5 a-b: Interannual variability and trend of the alien-to-native ratio of the molluscs and crustaceans in terms of biomass and abundance in the taxonomic groups on the coastal areas of the Crimea.

In this regard, the interannual changes of the alien-to-native ratio of the molluscs and crustaceans to biomass and abundance in their taxonomic groups is an important indicator for assessing the state of zoobenthos. Relative abundance of the alien molluscs was not high and amounted to no more than 0.04. This ratio was considerable for the crustaceans; it was 0.2 for the Harris crab and 350 for the barnacle (Fig. 5 a-d). At the same time, the biomass of the Rapana sea snail and the Harris crab periodically exceeded, several times, the total biomass of native benthic species in the taxonomic groups (5 a-d). The interannual variability of the alien-to-native ratio of molluscs had the tendency to increase during the investigated period. Statistical analysis of interannual variability of the biomass ratio of the alien molluscs *A. kagoshimensis* and *R. venosa* to the native molluscs was detected by autocorrelation in the time series. Autocorrelation coefficients were not high: 0.41 (SE = 0.19) and 0.35 (SE = 0.17) for *A. kagoshimensis* and *R. Venosa*, respectively. These results suggest that the time series of changes in the relationship of biomass had cyclical fluctuations. Time periodicity (the time-lag) in the changes of the relationships of the biomass was 2 years for the blood-cockle *A. kagoshimensis* and 3 years for the sea snail *R. venosa*. Thus, interannual variability of the biomass ratio of alien to native molluscs is characterized by an increasing trend and periodic fluctuations.

Similar patterns have been observed in the interannual variability of the biomass and abundance ratio of aliens to all native zoobenthic taxonomic groups, i.e. the dominance index of alien species. The interannual variability of these ratios had the same upward trend in conjunction with fluctuations (Figs 6 a-d, 7 a-d). For the molluscs *A. kagoshimensis* and *R. venosa*, the autocorrelation coefficients of the interannual variability of the dominance index were not high (0.31 and 0.24, respectively), i.e. the statistical relationship almost lacks reliability. Besides, the values of the autocorrelation coefficients for the crustacean *A. improvises* were higher - 0.38 (SE = 0.15) and the time-lag - 3 years.

The frequency of occurrence of the blood-cockle *A. kagoshimensis* on the shelf was obviously associated with the natural zoning (steppe and mountain) of the Crimean coast. Thus, the frequency of occurrence of the mollusc fluctuated around 20% on the shelf of the mountainous coast. On the shelf of the steppe and foothill zones of the coast, the indicator did not exceed 10% for this mollusc (Fig. 8). The blood-cockle *A. kagoshimensis* has settled at many sites of the Black Sea shelf, for forty years after the first detection along the Caucasian coast. The mollusc began to be recorded during our regular benthic community research projects on the Crimean shelf in 2002. The first detection (1999) along the Crimean coast and temporal variability of biological indicators of the mollusc population coincided with the variability of water temperature

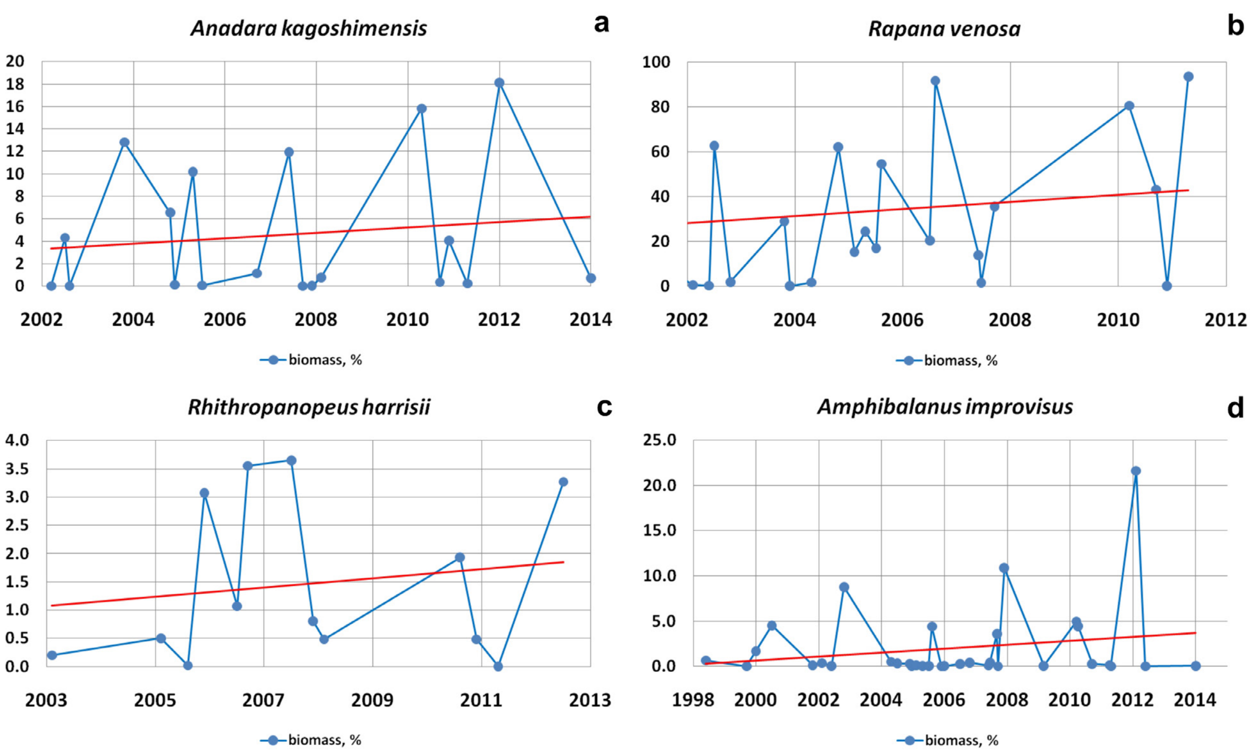

Fig. 6 a-b: Interannual variability (blue) and trend (red) of the alien-to-native ratio of the molluscs and the crustaceans in terms of biomass of all zoobenthos in the coastal areas of the Crimea.

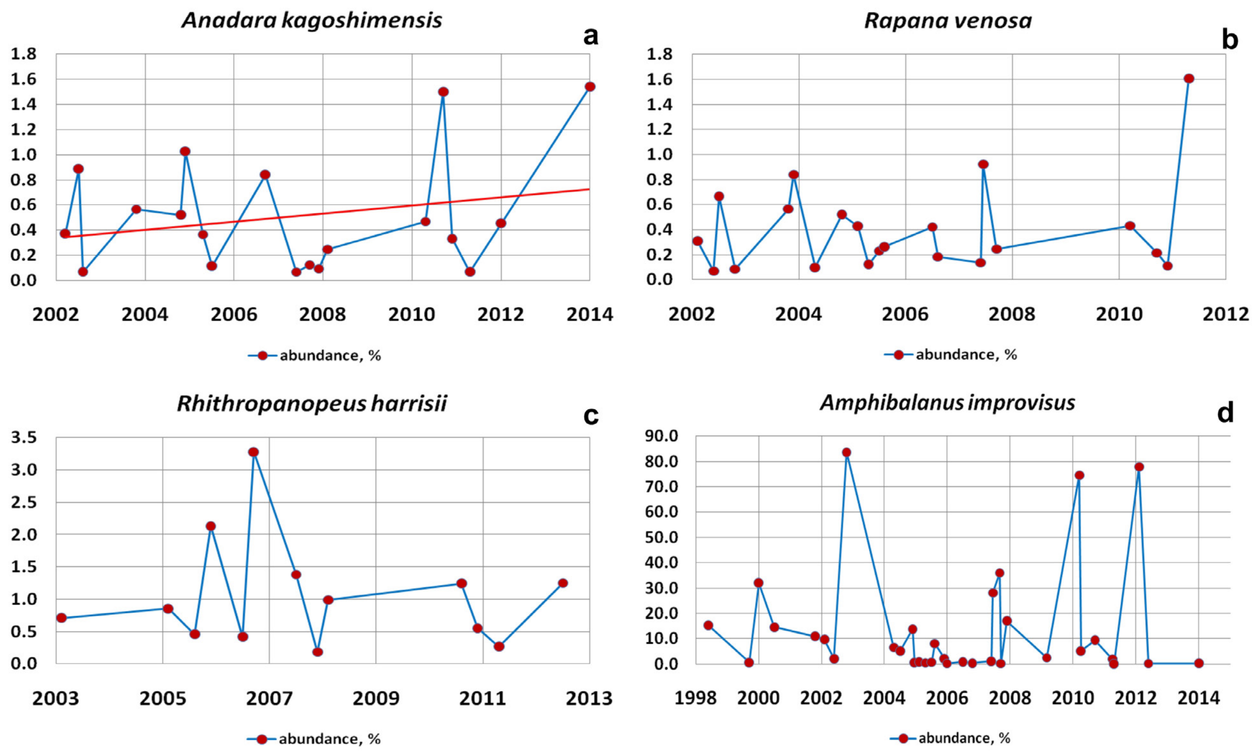

Fig. 7 a-b: Interannual variability (blue) and trend (red) of the alien-to-native ratio of the molluscs and the crustaceans in terms of abundance of all zoobenthos in the coastal areas of the Crimea.

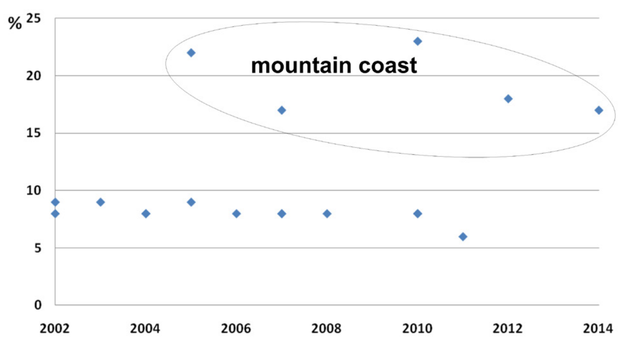

Fig. 8: Peculiarities in the frequency of occurrence of the mollusc *A. kagoshimensis* on the shelf of the Crimean coast.

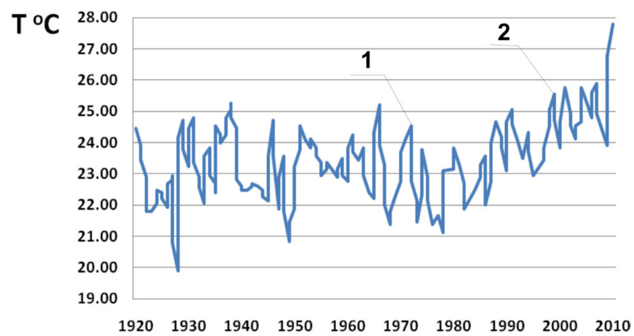

Fig. 9: Interannual variability of water temperature on the surface of the Black Sea in August, monthly average data from three meteorological stations of the Crimea (Belokopytov, 2014); first record of the blood-cockle *A. kagoshimensis* in the Black Sea (1), and on the Crimean shelf (2).

over the last 10-15 years. Those years were characterized by climate change and a temperature rise in the surface layer of coastal waters (Fig. 9). The spatial distribution of the mollusc population was also connected with the natural zoning of the Crimean coast. Larger populations were recorded at the sites of the mountainous coast, where a higher level of rainfall was observed during reproduction of the shellfish.

The low level of the dominance index of the crustacea *R. harrisii* and the molluscs *M. arenaria* and *A. kagoshimensis* indicated absence of their significant influence on the structure of the benthic communities of the Crimean shelf, i.e. at metacommunity scale (Table 2). The crustacea *A. improvisus* and the mollusc *R. venosa* are the successful invaders, which have relative higher dominance indices in the benthic communities of the Crimean shelf.

Discussion

The crustacea *A. improvisus* is recorded to a depth of 50 meters in the benthic communities of the Black Sea (Băcescu *et al*., 1965; Kiseleva, 1981). As a rule, barnacles constitute a small part of the biomass and abundance of zoobenthos in soft bottoms . Sometimes, the dominance index for the crustacean *A. improvisus* can be high in zoobenthos, as noted in previous research. This situation was recorded when the biomass and abundance of other benthic species was low after the influence of short-time hypoxic conditions.

With the exception of the mollusc *R. venosa*, the successful invaders have higher biomass and abundance in the populations of the Black Sea shelf compared to the shelf of the Crimean coast. Thus, high population parameters for the mollusc *A. kagoshimensis* have being recorded on the coastal shelf of the Caucasus and also in the Danube estuary in the last ten years. In these areas, the biomass of the molluscs reached 450 and 2700 g/m^2, the abundance of the molluscs - 220 and 1160 ind/m^2 (Chikina & Kucheruk., 2005; Abaza *et al*., 2006; Shurova & Zolotarev, 2007; Chikina, 2009). The biomass of clam populations decreased considerably on the shelf of the Bulgarian coast and in the north-west region of the Black Sea. In the 1980s, the biomass of *A. kagoshimensis* varied from 1000 to 4000 g/m2 for the Bulgarian coast, while clam biomass was already less than 200 g/m^2 at the beginning of the 21st century (Todorova & Konsulova, 2008).

The Harris crab and the Rapana sea snail, as predators, may have a negative impact on native benthic communities. The average biomass and abundance values for the crab *R. harrisii* were low on the Crimean shelf. The same low values of the biological indicators are characteristic at other sites of the Black Sea shelf as well, with the exception of the salty lakes of Varna and Beloslav, where the maximum values recorded for the biomass and density of the local population of *R. Harrisii* reached 640 g/m^2 and 260 ind/m^2, respectively.

The Rapana sea snail had colonized the seabed of the shallow water coastal area, practically all around the Black Sea. Usually, the maximum density of the mollusc-predator was 10-12 specimens per m^2 in the benthic communities (Gomoiu & Skolka, 2005; Todorova & Konsulova, 2008; Chikina, 2009; Alymov & Tikhonova, 2012; Zolotarev & Terentev, 2012; Snigerev, 2012). As noted above, in this study only once was the high density and biomass of the alien mollusc *R. venosa* marked in the *Mytilus galloprovincialis* community on the Crimean shelf. Subsequently, no live mussels were found at this site. The long-term negative impact of the sea snail caused considerable changes not only in the benthic communities in some areas of the Black Sea Shelf but also in the habitats (Chukhchin, 1984; Todorova *et al*., 2008; Chikina & Kucheruk, 2005; Chikina, 2009).

The alien mollusc *Mya arenaria* (Linne, 1758), has not been able to create a sustainable population on the shelf of the Crimean coast for 60 years after capturing the benthic communities in the Black Sea. The soft-shell clam *Mya* was recorded on the Crimean shelf (Karadag area) for the first time in 1981 (Kiseleva, 1992). Here, the abundance of shellfish was 5 ind/m^2 and biomass - 0,002 g/m^2. In our studies, the clam was recorded only once in the Sevastopol area (Karantinnaja Bay) in 2008. The average abundance of the mollusc was 1 ind/m^2 and the average biomass - 0.278 g/m^2.

The high biomass and abundance of the shellfish *M. arenaria* were recorded on the north-west shelf only, although it has settled in most parts of the Black Sea. The average biomass of the soft-clam *M. arenaria* varied from 300 to 900 g/m^2 in the 1980s, but now clam biomass is not more than 100 g/m^2 in the Black Sea. Many of the benthic species degraded in the upper circalittoral zone, in conditions of hypoxia, because of high eutrophication, which was recorded in these parts of the Black Sea shelf in the 1980s. The molluscs, despite their large sizes, can burrow relatively deep into the soft muddy sand. This helps them to overcome short-term hypoxia after intensive sedimentation of dead phytoplankton.

The polychaete worms *Ficopomatus enigmaticus* (Fauvel, 1923), *Polydora cornuta* (Bosk, 1802) and *Dipolydora quadrilobata* (Jacobi, 1883) were not recorded on the Crimean shelf during our long-term study. These invasive species were very seldom observed by researchers in zoobenthic communities, meroplankton or fouling communities of artificial substrates along the Crimean coast (Boltacheva *et al*., 2002; Boltacheva & Lisitskaya, 2007, 2014; Lisitskaya *et al*., 2010). The Chinese mitten crab, *Eriocheir sinensis* (Milne-Edwards, 1853), observed in 2005 (Lozovskij, 2005) was not found during our study either.

Conclusion

Five invasive species, the crustaceans *A. improvisus* and *R. harrisii*, and the molluscs *R. venosa, M. arenaria* and *A. kagoshimensis*, were recorded in the benthos during the study period. An increasing trend in the abundance of *A. improvises, R. harrisii*, *R. venosa* and *A. kagoshimensis* on the Crimean shelf in the last five to seven years was revealed. However, the biomass of these alien species was predominantly low.

At the metacommunity scale, the interannual variability of the biomass ratio of alien to native molluscs is characterized by an increasing trend and periodic fluctuations. Similar patterns were observed in the interannual variability of the biomass and abundance ratio of aliens to native for all zoobenthic taxonomic groups, i.e. the dominance index of alien species.

Furthermore, the low dominance index of the crustacean *R. harrisii* and the molluscs *M. arenaria* and *A.*

kagoshimensis indicates the absence of their significant influence on the structure of the benthic communities on the Crimean shelf, i.e. at metacommunity scale (Table 2). The crustacean *A. improvisus* and the mollusc *R. venosa* are the successful invaders that have relatively higher dominance indices in the benthic communities of the Crimean shelf.

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