

## Research Article

## Rapa whelk controls demersal community structure off Zmiinyi Island, Black Sea

Sergii Snigirov<sup>1\*</sup>, Volodymyr Medinets<sup>1</sup>, Volodymyr Chichkin<sup>1</sup> and Sergiy Sylantyev<sup>2\*</sup>

<sup>1</sup> Biological Department, Odesa National Mechnikov University, 7, Mayakovskogo lane, Odesa 65082, Ukraine

<sup>2</sup> DCEE, UCL Institute of Neurology, Queen Square House, Queen Square, London WC1N 3BG, UK

E-mail: [snigirev@te.net.ua](mailto:snigirev@te.net.ua) (SS), [medinets@te.net.ua](mailto:medinets@te.net.ua) (VM), [s.sylantyev@ucl.ac.uk](mailto:s.sylantyev@ucl.ac.uk) (SS)

\*Corresponding authors

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### Abstract

Between 2004 and 2012, populations of Mediterranean mussel (*Mytilus galloprovincialis*) and rapa whelk (*Rapana venosa*) from the coastal waters of Zmiinyi Island (Black Sea) were assessed for distribution, abundance, size, and age characteristics. Compared to 2004–2005, the mussel bed cover in 2012 decreased by 75.6%, the maximum depth of occurrence reduced from 22–25 m to 10–12 m, and total biomass declined by 44.6%. There was a concurrent decrease in abundance of demersal fishes dependent upon mussels as prey. We concluded that the invasive rapa whelk has had a detrimental impact on this demersal ecosystem. The possible influence of the introduced ctenophore *Mnemiopsis leidyi* on the two mollusc's populations has also been discussed.

**Key words:** *Rapana venosa*; *Mytilus galloprovincialis*; Black Sea; macrozoobenthos; community impacts

### Introduction

The veined or rapa whelk *Rapana venosa* (Valenciennes, 1846) is native to the East-Asian seas but has been unintentionally introduced into marine and brackish water areas world-wide (Ghisotti 1974; Harding and Man 1999; Kerckhof et al. 2006; Carranza et al. 2010). Due to its tolerance to a wide range of environmental conditions (temperature, salinity, and dissolved oxygen), it has become a successful invader, and it is a voracious predator of large bivalve molluscs (Zolotarev 1996; Savini et al. 2002).

First reported in the Black Sea in 1947 (Drapkin 1953), *R. venosa* colonized the whole sea within 25 years, including a well-established population in the north-western Black Sea (NWBS) (Chukhchin 1984). The main prey of *R. venosa* in the Black Sea is the Mediterranean mussel *Mytilus galloprovincialis* (Lamarck, 1819) (Seyhan et al. 2003); therefore, it has been blamed for major declines in abundance of this and other large-bodied species of bivalves in the Black Sea (Drapkin 1963; Chukhchin 1984; Zolotarev 1996). However, to the best of our knowledge, no

similar effects on populations of benthic bivalves are reported for localities of *R. venosa* introduction other than in the Black Sea. Nevertheless, *R. venosa* is considered to be a dangerous alien species and a high priority for study on its effect on the ecosystem (Mann et al. 2004).

Zmiinyi Island, located some 35 km seaward from the Danube Delta in the NWBS, is the only non-coastal island of the Black Sea. The mainly rocky substrate around the island, together with several sandy areas, is in striking contrast to the extensive sand and silt flats that are typical for the NWBS. Such a habitat provides an excellent opportunity for *in situ* comparative study of benthic communities that occupy the different types of substrate. The relative remoteness from human settlements, and the wildlife sanctuary status of adjacent waters, minimizes the anthropogenic pressures on the benthic community, which was one reason to choose Zmiinyi Island waters as our study area. The main goal of this study was to assess the current state of the *R. venosa* population around Zmiinyi Island and its effects on mussel-dominated benthic community in this area.

Another recent invader that caused a dramatic change in the Black Sea ecosystem is the American comb jelly *Mnemiopsis leidyi* A. Agassiz, 1865, which was introduced in the early 1980s (Vinogradov et al. 1989). Being a highly effective planktonivore (Colin et al. 2010), with mollusc veliger larvae constituting up to 40% of the overall prey consumption (Mutlu 1999), *M. leidyi* can remove up to 89% of bivalve veligers per day in a given area (McNamara et al. 2010). Thus it is not surprising that the population explosion of this ctenophore, which occurred soon after its introduction (Shiganova et al. 2001), was considered by several authors as the main factor causing the bivalves' population decline (Marinov 1990; Frolenko et al. 2000; Shiganova et al. 2003). Thus we also set out to compare the input of *M. leidyi* and *R. venosa* on the decline of the bivalve populations and to clarify the extent to which the presence of *M. leidyi* could mask the impact of *R. venosa* on the NWBS benthic community.

Lastly, it has long been accepted that demersal fishes represent the highest trophic level of most benthic communities in the Black Sea and can be used as a sensitive indicator of community change (Petersen and Curtis 1980; Möller et al. 1985; Methratta and Link 2006). Therefore, to characterize the complex impact of *R. venosa* on the associated food web, we documented the abundance of different demersal fish species potentially competing with rapa whelk for benthic-bivalve prey.

## Materials and methods

### Study area

Zmiinyi Island (45°15'18" N; 30°12'11" E) and adjacent waters are located in NWBS to the east from the Danube Delta in the territorial waters of the Ukraine (Figure 1). The shortest distance from the Ukrainian coast to the island is 34.5 km; from Romania it is 36.7 km. Since January 1998 (decree № 1341/98) parts of the island and its adjacent shelf (232 hectares) have been a protected area: the National Zoological Protected Area "Zmiinyi Island" (IBA code 088).

The area of Zmiinyi Island is ca. 20 ha. The maximum depth in the zone extending 500-m out from the shoreline is 37.0 m; the mean depth is 23.5 m. The bottom composition in the island's vicinity varies from bedrock, rock and boulder, shells and sand, to sand and silt.

### Field investigations

Temperature (accuracy 0.3°C), salinity (accuracy as 0.01 psu), and oxygen concentration (accuracy 0.01 mg/l) were measured at sampling sites with HQ40D digital multimeter kit (Hach Lange Ltd., Salford, UK) at midday on each day of sampling; water samples for salinity and oxygen concentration testing were taken using a twin bathometer.

Collections of *R. venosa* and *M. galloprovincialis* were done by divers at depths of 0.5 to 25 m. Sampling was performed at seven stations along each of six transects (Figure 1). The geographical coordinates of the sampling sites were controlled using a PK042 GPS navigator (Pharos Science & Applications Inc., Torrance, CA, USA). At each station, all molluscs of both species were collected manually in three 1 m<sup>2</sup> quadrat frames submerged before the beginning of sampling (three true replicates).

*R. venosa* shell height and *M. galloprovincialis* shell length were measured with a Facom electronic digital LCD vernier calliper (Stanley Black & Decker, New Britain, CT, USA; accuracy 0.02 mm). Wet weight of *R. venosa* and *M. galloprovincialis* was measured with electronic scales (Scout Pro SPU402, Ohaus Corporation, USA; accuracy 0.01 g). Age of molluscs was determined based on internal growth lines in the cross-sections of the shell (Chukchin 1970). Here we use the age rounded to the whole year (age groups 2–6). In addition, for *R. venosa*, we recorded the incidence and percentage of shell covered by the boring sponge *Piona vastifica* (Hancock, 1849). Final values of *M. galloprovincialis* characteristics for each sampling site were calculated as an average of those obtained for three sampling quadrats.

Fish sampling was performed with 20 mm mesh size gillnets as described in our previous work (Snigirev et al. 2012).

### Data analysis

Interannual tendencies in *R. venosa* individuals' characteristics (shell measurements and wet weight) were determined with the one-way Analysis of Variance (ANOVA) followed by Tukey's *a posteriori* test. To analyse the *M. galloprovincialis* abundance on different substrates over the period of research, we applied a two-way ANOVA followed by Tukey's *a posteriori* test for the main effects (the time×substrate interaction was not significant:  $F_{15,116} = 1.35$ ,  $P = 0.187$ ). Changes in catch-per-unit effort in time were described for demersal fishes (data from Snigirev et al. 2012) by

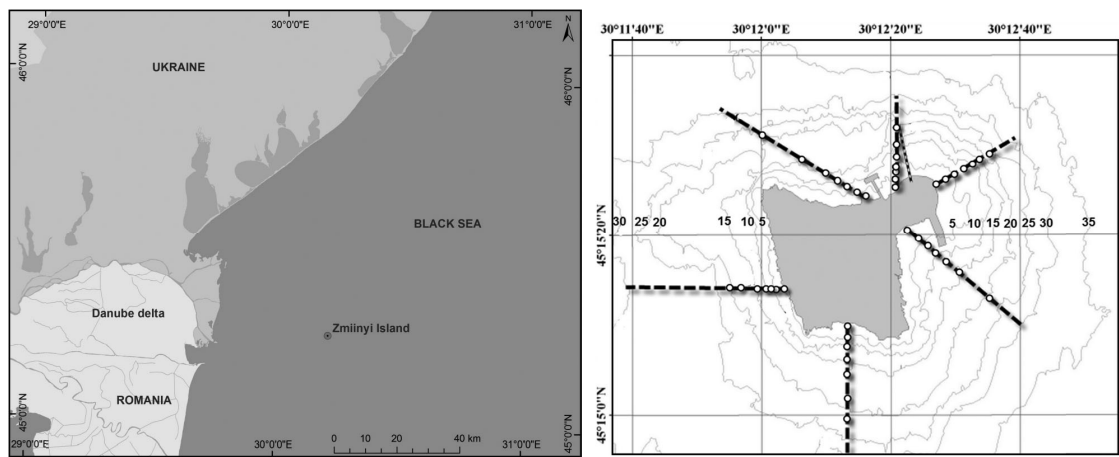


Figure 1. Left: geographical location of Zmiinyi Island in NWBS. Right: transects with sampling stations.

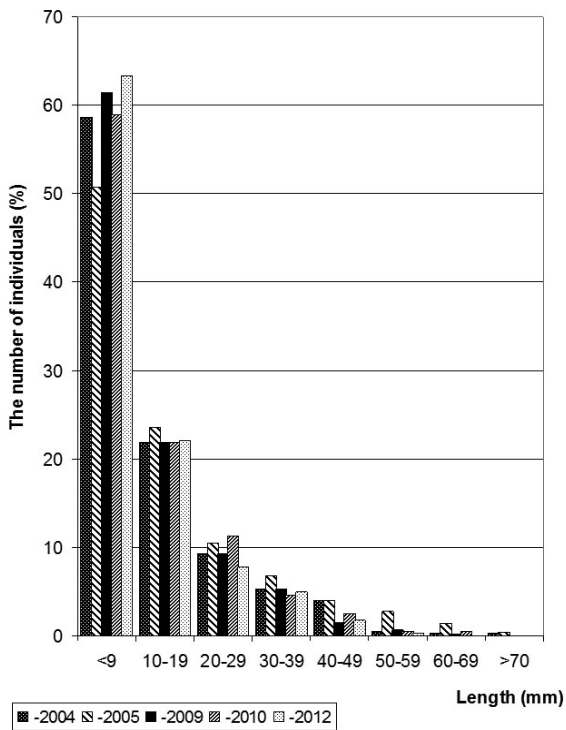


Figure 2. Size (shell length in mm) distribution of *Mytilus galloprovincialis* in Zmiinyi Island coastal waters, 2004 to 2012.

means of least-squares linear regression. Here we used a 100 m net per day as the unit of fishing effort. All data were represented graphically as mean  $\pm$  SE. Spearman's correlation coefficient  $r_s$  and

Student's unpaired t-test were used as indicated. Numerical calculations were performed with the Mathematica 10.0 software.

Results

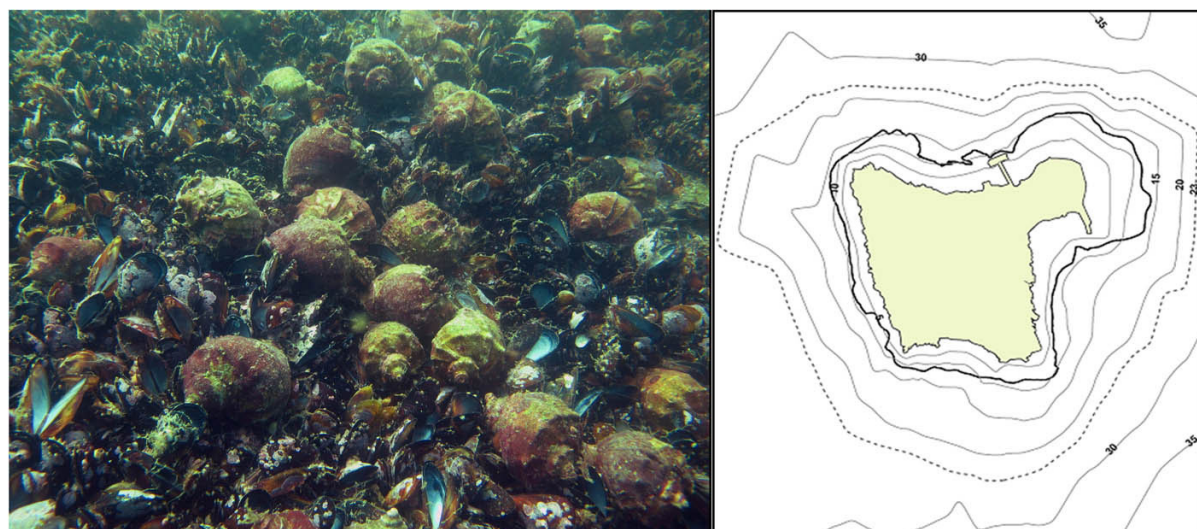
General characteristics of macrobenthos and influence of hydrological factors

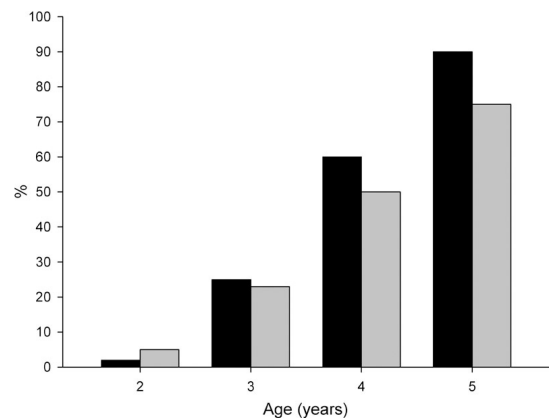
While 78 invertebrate benthic species were detected during the 2004–2012 period, *M. galloprovincialis* accounted for more than 50% of the total number and 90–98% of total biomass, demonstrating its pivotal role in structure and functioning of the benthic community. Individuals < 20 mm long were most common for this bivalve; in contrast, individuals of commercial size (>50 mm) never exceeded 4.5% of the total number of mussels (Figure 2). The number of *R. venosa* in the study area was up to 120 individuals/m<sup>2</sup> with a biomass of up to 8.1 kg/m<sup>2</sup>.

Oceanographic characteristics of Zmiinyi Island waters in the summer-autumn period did not display substantial variation from 2004 to 2012 (Table 1). In 2005, 2010 and 2011 water column mixing was reduced, and thermoclines and haloclines developed between 10 and 15 m depths. While variable, mean oxygen concentration was never < 6.8 mg/l. There were, however, no significant correlations ( $r_s < 0.6$ ;  $P > 0.2$  for all cases) between variation in water-mass characteristics (water temperature, salinity and oxygen concentration measured at 2–10 m, 10–20 m, and > 20 m depths) and biomass estimates of *R. venosa* and *M. galloprovincialis*.

**Table 1.** Water temperature (T), salinity (S) and oxygen concentration (O<sub>2</sub>) in the Zmiinyi Island coastal waters at depths of 0.5, 8, 15 and 20 m, 2004 to 2012.

Year	Depth (m)	Variables			Number of measurements
		T (°C)	S (psu)	O <sub>2</sub> (mg/L)	
2004	0.5 m	22.0±1.3	11.6±2.2	7.5±1.0	63
	8.0 m	20.6±0.6	15.2±1.5	7.1±1.9	63
	15.0 m	-	-	-	-
	20.0 m	-	-	-	-
2005	0.5 m	25.7±2.2	14.2±3.5	8.4±0.4	63
	8.0 m	25.6±2.5	16.6±2.0	6.8±1.4	63
	15.0 m	17.4±0.3	16.8±0.2	8.4±0.5	7
	20.0 m	17.5±0.2	16.8±0.3	8.9±0.8	5
2008	0.5 m	23.5±1.7	15.9±1.4	7.7±0.9	34
	8.0 m	22.0±1.5	16.0±1.0	7.9±1.6	34
	15.0 m	-	-	-	-
	20.0 m	-	-	-	-
2009	0.5 m	24.8±2.5	11.4±0.9	7.7±1.0	38
	8.0 m	24.8±1.7	16.8±1.1	7.8±0.5	38
	15.0 m	17.7±0.9	17.0±0.4	8.5±0.5	5
	20.0 m	17.8±0.1	17.1±1.2	8.7±0.4	4
2010	0.5 m	25.8±1.6	12.8±1.3	7.4±1.8	38
	8.0 m	24.3±1.8	16.2±1.3	7.5±0.9	38
	15.0 m	16.9±0.2	16.3±0.5	10.7±1.1	5
	20.0 m	17.0±0.5	16.8±1.7	10.5±2.1	5
2011	0.5 m	23.7±2.4	12.5±1.8	7.7±0.4	37
	8.0 m	23.5±2.0	14.4±0.7	7.8±0.3	37
	15.0 m	17.7±0.1	15.6±0.3	8.9±0.5	5
	20.0 m	17.5±1.5	15.9±0.1	8.7±1.8	5
2012	0.5 m	22.1±2.2	14.9±0.5	9.3±1.2	38
	8.0 m	21.7±1.4	15.4±0.9	8.4±0.3	38
	15.0 m	21.5±0.5	15.7±0.7	8.2±0.1	4
	20.0 m	-	-	-	-

**Figure 3.** Left: *Rapana venosa* destroying a mussel colony: ~50 whelks at 1 m<sup>2</sup> (photograph by S. Snigirov). Right: boundary of *Mytilus galloprovincialis* distribution with depth in 2004–2005 (dashed line) and 2010–2012 (solid line).



**Figure 4.** Top left: shell of 5-years-old *Rapana venosa* infested by shell boring sponge *Piona vastifica*. Top right: part of the shell surface at a higher magnification. Bottom: fraction of *R. venosa* population infested by *P. vastifica* (black columns) and fraction of shell surface covered with the sponge (grey columns) in different *R. venosa* age groups.

### *Rapa whelk* population

Overall, 1012 specimens of *R. venosa* in five age groups were collected from 2005 to 2012. The population density varied with depth: from less than 3 individuals/m<sup>2</sup> for the >20 m depths, 20–40 individuals at a 10–20 m depths, and up to 120 individuals/m<sup>2</sup> at 2–10 m depths. Some rapa whelks were found at a depth <0.2 m and in the splash zone in areas densely covered with mussels (Figure 3).

The characteristic feature of *R. venosa* population in Zmiinyi Island waters was its infection with the boring sponge *P. vastifica*. Both incidence and severity of the infection increased with the age: from 2.2% of infected individuals in age group 2 with an average shell surface covered with sponge of ~5% to 91% of whelks infected and ~75% of shell surface covered in age groups 5 and 6 (Figure 4).

Mean values of the morphological parameters (shell height and wet weight) of male and female individuals of the same age group did not differ significantly ( $P > 0.4$  for all cases, Student's t-

test), hence the size-at-age data were combined. The sex ratio (female/male whelks) of individuals collected in different years was not significantly different from unity ( $0.96 \pm 0.14$ ,  $n=4$ ,  $P > 0.8$ , Student's t-test).

The analysis of interannual variation in morphological characteristics of *R. venosa* was restricted to age groups 2–5 (Figure 5, Table 2) due to the small numbers of age 6 animals collected in some years. In all but one case (shell height in the group 5), the ANOVA revealed significant interannual differences in morphology: *R. venosa* became larger and heavier with time for ages 2 and 4; however, the pattern was not as clear for age 3 animals.

### *Mussels' population*

The population of *M. galloprovincialis* in the study area decreased substantially during the period of research. In 2004, bivalve colonies occurred to depths down to about 23 m whereas in 2009–2012 the number and biomass of live mussels within 12–23 m depth zone had decreased over 80-fold compared to 2004 and did not exceed five individuals per m<sup>2</sup> (35–65 g/m<sup>2</sup>). No living mussels were found in samples taken from sand/shell substrates at a depths of 15 m and deeper in 2010–2012. In recent years, the dense mussel colonies were restricted to the interval from splash zone to depths of about 12 m, which is where stone substrates end (Figure 3). The overall area supporting dense colonies of *M. galloprovincialis* thus decreased from 78 ha in 2004–2006 with a biomass ~8300 tons to 19 ha in 2010–2012 with a biomass ~3700 tons of mussels.

The biomass of *M. galloprovincialis* differed significantly with both time ( $F_{5,116}=12.22$ ,  $P=1.602 \times 10^{-9}$ ) and substrate type ( $F_{3,116}=73.98$ ,  $P=8.19 \times 10^{-27}$ ) with the lowest values for all substrate types occurring between 2010 and 2012 and biomasses on mussel shell or shell and sand substrate consistently lower than on rock-boulder or mixed substrates (Figure 6).

### *Populations of demersal fishes*

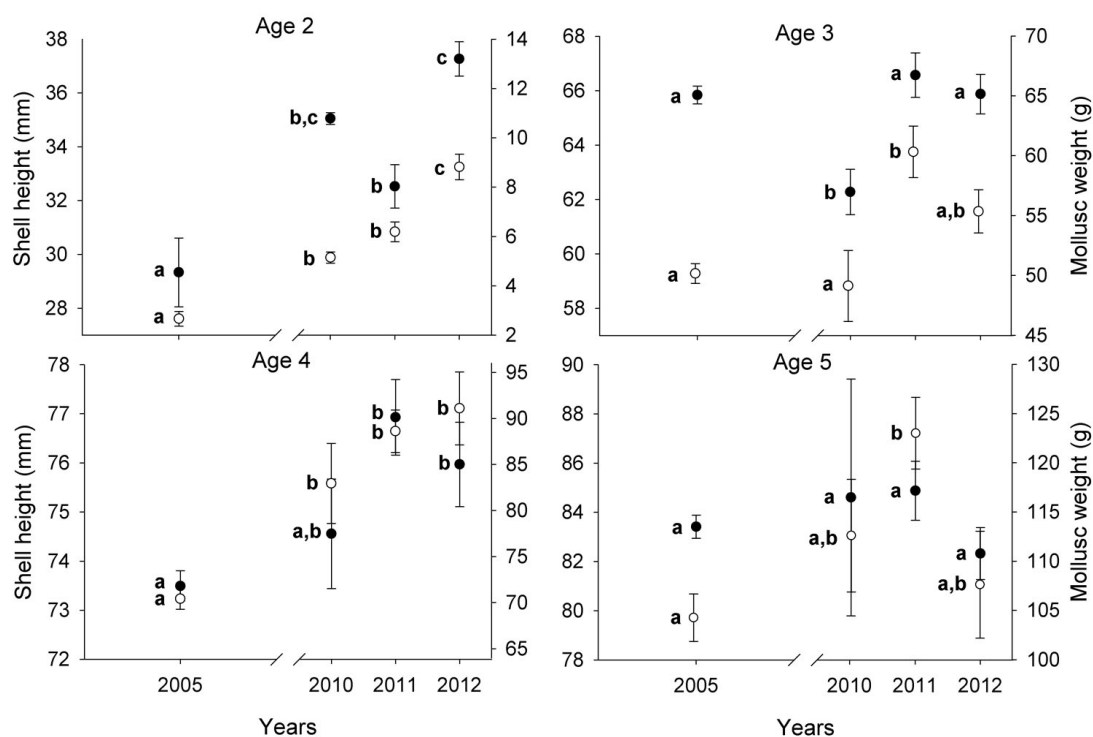
The catch-per-unit-effort of two species of demersal fishes, *Neogobius melanostomus* (Pallas, 1814) and *Symphodus cinereus* (Bonnaterre, 1788) decreased significantly with time (Figure 7, Table 3), consistent with the observed decrease in abundance of their prey, *M. galloprovincialis*.

**Table 2.** Results of the one-way ANOVA of *R. venosa* morphological characters over the 2005–2012 time interval for different age groups.

Age group	Degrees of freedom	Shell height		Wet weight	
		F ratio	P value	F ratio	P value
2	3,62	15.66	$1.09 \times 10^{-7}$	36.21	$1.2 \times 10^{-13}$
3	3,536	6.65	$2.04 \times 10^{-4}$	6.98	$1.3 \times 10^{-4}$
4	3,308	7.29	$9.7 \times 10^{-5}$	22.37	$3.94 \times 10^{-13}$
5	3,78	0.73	0.54	2.86	$4.2 \times 10^{-2}$

**Table 3.** Results of the linear regression analysis of *N. melanostomus* and *S. cinereus* catches over the 2003–2012 time interval.

Species	Regression coefficient estimate	Standard error	t-Statistic	P value
<i>N. melanostomus</i>	-2.67	0.63	7.9	$3.96 \times 10^{-12}$
<i>S. cinereus</i>	-0.61	0.21	2.79	$7.15 \times 10^{-3}$

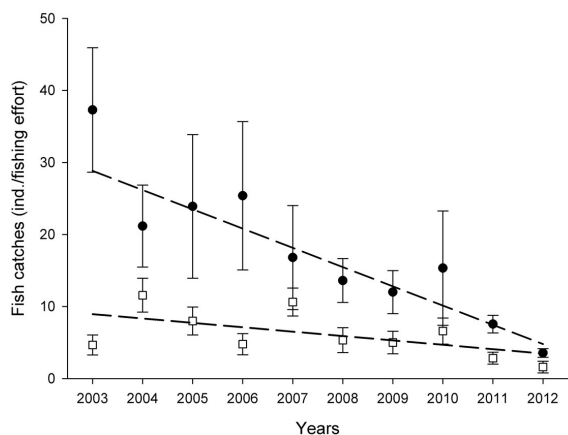
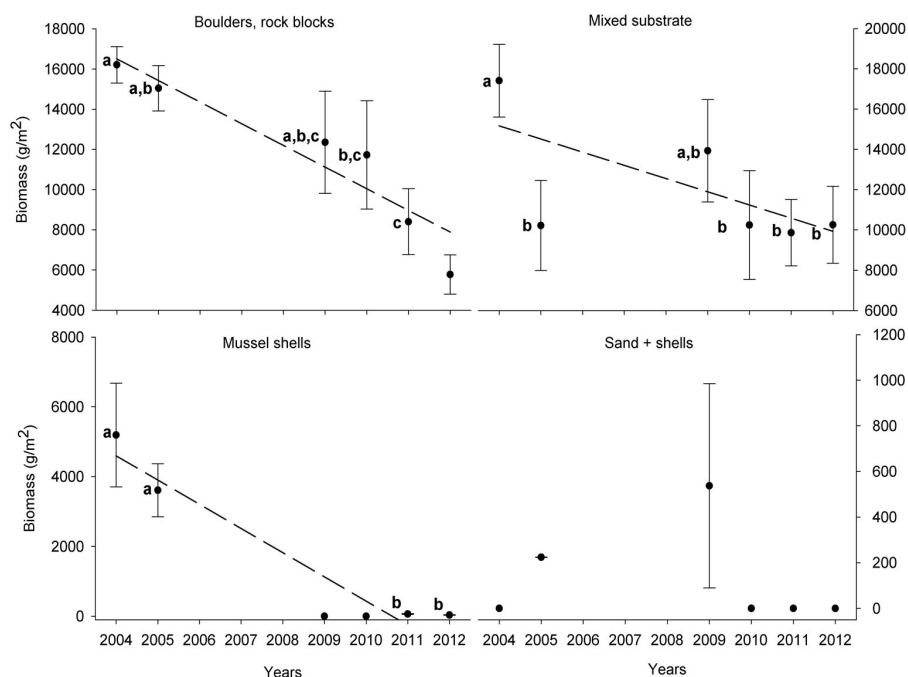
**Figure 5.** Morphological changes in different age groups of *Rapana venosa* over the study period. Black circles: shell height. Open circles: mollusc wet weight. Similar letters indicate absence of significant difference between annual means (Tukey's post-hoc test,  $P > 0.05$ ).

## Discussion

Sex ratio of 1:1 in the *R. venosa* population in Zmiinyi Island waters is consistent with that observed in other areas of successful invasion (Mann et al. 2006); however, it is different from the value reported for Turkish Black Sea waters

(~1:1.6) where *R. venosa* is commercially harvested (Sağlam et al. 2009). On top of that, our data reveal an increase of both shell size and molluscan body weight over the study period. Taken together, these facts indicate favourable environmental conditions were found by *R. venosa* upon its expansion to the Zmiinyi Island area, and that food is not limiting at present.

**Figure 6.** Dynamics of *Mytilus galloprovincialis* biomass at different underwater substrates in Zmiinyi Island waters. Similar letters indicate absence of significant difference between annual means (Tukey's post-hoc test,  $P > 0.05$ ).



**Figure 7.** Variation in catches of *Neogobius melanostomus* (black circles) and *Symphodus cinereus* (open squares) over the period 2003–2012 with linear regression trendlines (dashed).

Catches of *N. melanostomus* and *S. cinereus* displayed a clear decrease over the period of 2003–2012; however, with substantially different slopes (regression coefficients - 2.67 and - 0.61,

respectively). The simplest explanation for such a divergence is the different importance of bivalves in the fish diet: 75–90% of prey biomass for *N. melanostomus* (Porumb 1961; Kvach and Zamorov 2001) and ~15% for *S. cinereus* (Pirrotti et al. 1999). The uninterrupted decrease in the fish catches between 2003 and 2012 confirmed indirectly a continuous decline in mussels' biomass during the years for which we do not have data (2006–2008). In general, data on fish catches support the hypothesis that *R. venosa* has a major role in structuring the demersal community in Zmiinyi Island waters.

Establishment of new *R. venosa* populations in the Black Sea had been facilitated by the general lack of competition for the food source and a lack of direct predation of rapa whelk by resident predators (Marinov 1990; Zolotarev 1996). Nevertheless, until the mid-1990s, *R. venosa* was scarce in the NWBS (Zolotarev 1996). This suggests an alternate factor was the driver of *M. galloprovincialis* biomass decline observed in this area before the beginning of 1980s (Daskalov 2003).

The most likely cause of the earlier declines in bivalve abundance is the ctenophore *M. leidyi*, which was introduced accidentally to the Black



Sea in early 1980s, rapidly spread over the whole Sea (Vinogradov et al. 1989). There were major population outbursts of *M. leidy* during 1988–1989 and 1994–1995 that caused dramatic decreases in zooplankton biomass (Shiganova et al. 2001). However, after arrival (in 1997) of another alien ctenophore *Beroe ovata* Bruguière, 1789 the situation has changed radically. *B. ovata* is a specialized predator of *M. leidy* and caused a rapid decrease in its abundance and, as a consequence, gradual regeneration of the zooplankton community (Shiganova et al. 2003). Since *B. ovata* breeds rapidly and is highly responsive to the abundance of *M. leidy*, after 1997 *B. ovata* became an efficient controller of *M. leidy*'s population. The presence of *B. ovata* has, therefore, drastically reduced the abundance of *M. leidy* and smoothed out its population fluctuations (Shiganova et al. 2004).

The later arrival of *M. leidy* to the Black Sea established a classical three-species intra-guild predation system (Holt and Polis 1997) where *R. venosa* and *M. leidy* functioned as intermediate and top predator, respectively, and *M. galloprovincialis* was their common food source. Rapid and short increases of *M. galloprovincialis* biomass in the NWBS observed in the middle of 1980s and 1990s (Langmead et al. 2009) just before the *M. leidy* population outbursts, probably represent two cycles of oscillations characteristic for the intra-guild predation systems. In marine ecosystems, oscillations of this type lead to the overall stabilization of biomasses of interacting species or extinction of one of predators (Leung et al. 2011). However, the arrival of *B. ovata* in 1997 caused a removal of the top predator (*M. leidy*) from the system without a direct effect on other two species due to the new predator's high feeding specialization. Therefore, the "predator-prey" system was switched back to the two-species mode and started stabilization processes from the new initial point. Thus the large increase in rapa whelk abundance observed during the last ten years suggests the *R. venosa* population in NWBS has yet to reach a stable equilibrium under new conditions. Apart from the possible depopulation of the main food objects (*M. galloprovincialis* and other large bivalves), other potential equilibrating factors are infestation by *P. vastifica* (as observed in our study) and perhaps effects of the shell boring polychaete *Polydora ciliate* (Johnston, 1838) (Gutu and Marinescu 1979). Continued monitoring of the Ziminyi Island area is needed to track the continuing evolution of the demersal community.

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