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Lodgers or tramps? *Aporrhais pespelecani* and *Turritella communis* on the north-western Black Sea shelf

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The present paper reports the first finding of two gastropod species, Aporrhais pespelecani *and* Turritella communis *in the north-western part of the Black Sea more than 500 km north from the edge of their native range (the Bosphorus Strait). The possible role of different hydrological factors in a spread of the species range, their perspective influence on the local demersal community and probable vectors of dissemination are discussed.*

Keywords: *Aporrhais pespelecani*, *Turritella communis*, north-western part of the Black Sea, global warming, mediterranization

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INTRODUCTION

Contemporary global warming has induced a rise of the global mean sea surface temperature (SST) by 0.67°C over the last hundred years (Trenberth *et al.*, 2007). However, more rapid changes were observed in semi-enclosed seas. The Black Sea is within this latter group, and with an SST increase of 0.96°C between 1982 and 2006, it experienced one of the strongest impacts (Belkin, 2009). Due to the peculiarities of its water column stratification and thin surface mixing layer, which is ~10 m in summer and ~80 m in winter (Ginzburg *et al.*, 2004), the Black Sea's SST readily responds to changes in global climate, suggesting quick and high-amplitude alterations in the near future.

There is a growing body of evidence that suggests SST elevation is correlated with the spread and success of alien marine species (Lambert & Lambert, 1998; Thresher *et al.*, 2003; Sorte *et al.*, 2010). Evidence of responses to the present warming in the shelf biota includes such indicators as shifts in the geographical range of species, and in the composition of benthic assemblages. Due to the relative simplicity of the intravital, as well as postmortal identification of the shell molluscs and their capability for rapid expansion by trochophore and veliger larvae, the molluscan benthic community provides a clear readout of both aforementioned indicators, allowing recognition of the global warming effects in a wide range of marine ecosystems (Sauriau, 1991; Cintra-Buenrostro *et al.*, 2002; Warwick & Turk, 2002). Therefore, the monitoring of the molluscan fauna can potentially give important empirical clues related to the assessment and prediction of ecosystem changes in the Black Sea caused by global warming.

The Black Sea basin was isolated from the world's oceans due to the lowering of global sea levels during the last glacial phase. As sea levels rose during the early Holocene period, the Black Sea was once again connected to the eastern Mediterranean and had become an area of colonization for Mediterranean species (Buynevich *et al.*, 2011). As a result, the most part of the modern Black Sea molluscan fauna was made up by the species of Atlantic–Mediterranean origin with several Thetis relics (Mordukhai-Boltovskoi, 1972). However, the arrival of new molluscan species still continues. These species can be divided into two major groups: Mediterranean and non-Mediterranean immigrants. Apparently the main factor for the appearance of the latter group in the Black Sea is the development of shipping; this is also in line with a rapid increase of the number of alien species discovered during the last several decades (Table 1). The arrival of new non-Mediterranean molluscs has had substantial ecological consequences; the most important changes in the Black Sea benthic biocenosis were induced by the introduction of two such species, *Rapana venosa* (Valenciennes, 1846) and *Mya arenaria* Linnaeus, 1758. In contrast, replenishment of the Black Sea molluscan fauna with Mediterranean species (Table 2) did not lead to the appreciable rearrangements in demersal communities.

The north-western part of the Black Sea (NWBS) receives a large volume of freshwater run-off, with approximately 80% of the total outflow into the Black Sea discharged there. The River Danube accounts for about 75% of this outflow, or approximately 230 km^3 per year, and the other large rivers, the Dnieper and the Dniester, discharging a further 53 km^3 and 9.5 km^3, respectively (Mee, 1992). This makes the NWBS the least salinized region of the Black Sea, and apparently establishes a barrier against the expansion of

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Table 1. Alien and cryptogenic molluscs in the Black Sea: species arrived due to human activity.

Species	Native region	Time of introduction	Distribution in the Black Sea	References
Class Bivalvia				
Arcuatula senhousia (Benson in Cantor, 1842)	North-eastern Atlantic Ocean, Mediterranean Sea	2004	Romanian coast, Danube delta	Micu & Micu, 2004
Anadara kagoshimensis (Tokunaga, 1906)*	Western Pacific Ocean	1987	Black Sea coast of Crimean Peninsula, Caucasian coast, near-Bosphorus area	Zolotarev, 1996; Albayrak, 2003; Kolyuchkina & Miljutin, 2013
Crassostrea gigas (Thunberg, 1793)**	South-eastern Asia	1900–1910	Coast of Crimean Peninsula, Gulf of Odesa, Caucasian coast	Zolotarev, 1996; Kovtun & Zolotarev, 2008
Crassostrea virginica (Gmelin, 1791)**	Northern Atlantic Ocean, Baltic Sea, Caribbean Sea, Gulf of Mexico	1974	Romanian coast	Skolka & Preda, 2010
Mya arenaria Linnaeus, 1758	Atlantic Ocean, Baltic Sea, Arctic Ocean	1966	Whole sea	Zolotarev, 1996
Mytilopsis leucophaeata (Conrad, 1831)	North-western Atlantic Ocean, Baltic Sea	2004	Dniester liman	Therriault *et al.*, 2004
Mytilus edulis Linnaeus, 1758***	Northern Atlantic Ocean, Arctic Ocean	2001	Gulf of Odesa	Alexandrov *et al.*, 2007
Mytilus trossulus Gould, 1850***	North-western Atlantic Ocean	2001	Gulf of Odesa	Alexandrov *et al.*, 2007
Perna viridis (Linnaeus, 1758)	Caribbean Sea, Gulf of Mexico	2000	Southern coast of Crimean Peninsula	Mironov *et al.*, 2002
Teredo navalis Linnaeus, 1758****	Northern Atlantic Ocean, Mediterranean Sea	750–500 BC	Whole sea	Alexandrov *et al.*, 2007
Class Gastropoda				
Corambe obscura (A.E. Verrill, 1870)	Northern Atlantic Ocean, Gulf of Mexico, North Sea	1989	Whole sea	Roginskaya & Grintsov, 1990
Neptunea arthritica (Valenciennes, 1858)	Sea of Japan	2000	Kamyshovaya Bay (Crimean Peninsula)	Shadrin *et al.*, 2002
Rapana venosa (Valenciennes, 1846)	Sea of Japan	1954	Whole sea	Zolotarev, 1996

*, previous attribution of the Black Sea population to *Anadara inaequivalvis* (Bruguière, 1789) was later disproved (Lutaenko, 2006); **, oyster species *Crassostrea gigas* (Thunberg, 1739) and *Crassostrea angulata* (Lamarck, 1819) of the same native region have been shown to be closely related and able to produce fertile F1s (Leitão *et al.*, 2007). Slight morphological differences are observed between these species as well as between them and *Crassostrea virginica*. The only reliable way to distinguish between the species is a DNA analysis (Huvet *et al.*, 2000). However, to the best of our knowledge, to date the detailed genetic analysis of the Black Sea *Crassostrea* population has not been performed; ***, the characteristic feature of *Mytilus edulis* species complex (*M. edulis*, *Mytilus trossulus* and *Mytilus galloprovincialis* native to the Black Sea) is a widely observed inter-species hybridization (Riginos & Cunningham, 2005). This suggests wariness when interpreting reports about findings of *M. edulis* and *M. trossulus* in the Black Sea; ****, cryptogenic species.

Mediterranean faunas. Nevertheless, fish of Mediterranean origin were repeatedly detected in the NWBS and their presence was shown to correlate primarily with temperature and salinity values (Snigirov *et al.*, 2012). Thus, the possible expansion of the molluscan species of Mediterranean origin into this water area should clarify the comparative importance of different hydrological factors for the stability of the Black Sea ecosystem.

Turritella communis Risso, 1826 is a Gastropoda mollusc that occurs in the eastern Atlantic from Norway to Morocco and in the Mediterranean Sea. It normally inhabits soft muddy bottoms (Fretter & Graham, 1981) but can also be found at rocks, gravel and sand (Van Straaten, 1960). The common bathymetric range for this species is 15–100 m (Fretter & Graham, 1981); however, sometimes the mollusc can be found at 0–10 m depths (Keegan & Mercer, 1986). It commonly forms large colonies (Sartenaer, 1959) and feeds predominantly by ciliary suspension collecting (Graham, 1938; Yonge, 1946). In *Turritella communis* sexes are separate. Some authors report sexual dimorphism with female individuals being slightly larger than males (Wright, 1956); however, others do not confirm this observation (Fretter & Graham, 1981). Breeding was reported for different periods from April to July (Lebour, 1933; Wright, 1956; Fretter & Manly, 1979). Egg masses are attached to substrate, larvae have relatively short planktonic life of 2–3 weeks (Lebour, 1933); protoconch is small, sharp, weakly sculptured and hardly distinguishable from teleoconch mainly by initiation of spiral relief at a latter one (Fretter & Manly, 1979).

Aporrhais pespelecani (Linnaeus, 1758) is another Gastropoda species with a geographical range from the Mediterranean to Iceland, north Norway and the western Kola Peninsula. It is a mainly sublittoral mollusc inhabiting mud, muddy sand and sand bottoms to depths of ~180 m where it lives wholly or partially buried (Yonge, 1937). This species is a detritus feeder, feeding mostly on plant fragments (Barnes & Bagenal, 1952). The sexes are separate without significant sexual dimorphism in shell shape and size. Breeding is reported to occur at different periods from January to September in different parts of its range. Eggs are attached

Table 2. Newcomer molluscs in the Black Sea: species which have naturally spread from the Mediterranean Sea.

Species	Native region	Time of introduction	Distribution in the Black Sea	References
Class Bivalvia				
Acanthocardia tuberculata (Linnaeus, 1758)	Mediterranean Sea, eastern and north-eastern Atlantic Ocean	1990–1995	Turkish coast, Strait of Kerch area	Terentiev, 1998
Clausinella fasciata (da Costa, 1778)	Eastern Atlantic, Mediterranean Sea	1990	Near-Bosphorus area, coast of Crimean Peninsula	Revkov, 2003
Hiatella rugosa (Linnaeus, 1767)	Eastern Atlantic Ocean, Mediterranean Sea	2001	Turkish coast, south coast of Crimean Peninsula	Revkov, 2003
Class Gastropoda				
Aporrhais pespelecani (Linnaeus, 1758)	Eastern Atlantic Ocean, Mediterranean Sea	1987	Southern and eastern coasts, Crimean Peninsula, north-western part of the Black Sea (NWBS)	Anistratenko, 1998; Shadrin & Latushkin, 2002; our data
Ercolania viridis (A. Costa, 1866)	Caribbean Sea, Gulf of Mexico, Madeira, Cape Verde, eastern Atlantic coast, Mediterranean Sea	2001	Gulf of Odesa	Alexandrov *et al.*, 2007
Turritella communis Risso, 1826	Eastern Atlantic Ocean, Mediterranean Sea	2001	Near-Bosphorus area, NWBS	Demir, 2003; our data

to the substrate granules singly or in twos or threes (Lebour, 1933; Smidt, 1944), veliger larvae hatch out with a smooth shell of 1.5 whorls (Thiriot-Quiévreux, 1969) and occur in plankton during 8–9 months of the year (Thorson, 1950).

We hereby report for the first time the presence of these two species, *Aporrhais pespelecani* (Linnaeus, 1758) and *Turritella communis* Risso, 1826, in the NWBS and more than 500 km north from the edge of their native range.

MATERIALS AND METHODS

Molluscs were collected in March 2013, at two different localities during a series of fish samplings on the marine side of the sandbar separating the Tuzly group of limans (lagoons) from the Black Sea, ~300 m off the coastline (Figure 1). Sampling was performed using a 30 m long, 5 mm mesh dragnet pulled for 200 m parallel to the coastline at a depth of 5–7 m. Molluscan species' identifications were made in accordance with widely used species guides (Poppe & Goto, 1991; Appeltans *et al.*, 2013). Shell measurements were completed to the nearest 0.01 mm with a Vernier digital caliper. After identification and measurement, specimens were lodged in a malacological collection in Odesa National Mechnikov University's Zoological Museum: Catalogue Numbers 360/3 for *Aporrhais pespelecani* (Linnaeus, 1758) and 331/3 for *Turitella communis* Risso, 1826.

To characterize long-term changes of aquatic environment in the NWBS we used hydrological data (water temperature, oxygen concentration and salinity) collected during the period 2006–2012 at Zmiinyi Island's marine research station (45°15′18″N 30°12′15″E), which was the closest observational point to the catchment site. Environmental data have been represented as a mean ± SEM. To elucidate the interannual dynamics of hydrological parameters we used regression coefficients obtained when the field-collected datasets were fitted with the linear regression method using the least squares approach. Numerical calculations were performed with Mathematica 9.0 software.

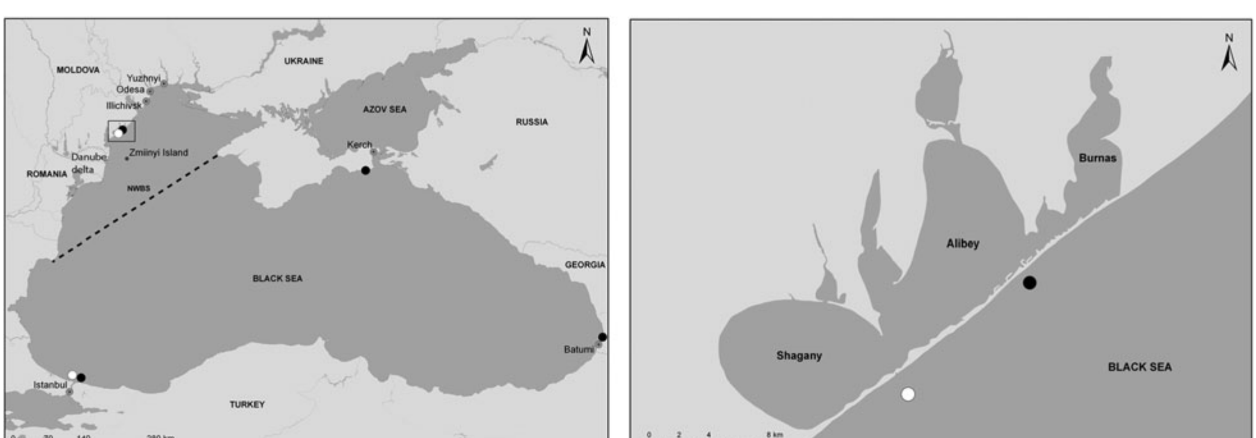

Fig. 1. Left: Black Sea map with finding locations of *Aporrhais pespelecani* (black circles) and *Turritella communis* (open circles) in 20th and 21st Centuries. Right: catchment area with our findings of *A. pespelecani* and *T. communis* (similar symbols).

RESULTS

One live isolated specimen of *Aporrhais pespelecani* (Linnaeus, 1758) (found at 45°46′1.62″N 30°3′58.84″E) and one dead specimen (fresh dead with animal tissue clearly visible attached inside the shell) of *Turritella communis* Risso, 1826 (found at 45°41′57.13″N 29°57′5.77″E) had the following morphological characteristics:

Aporrhais pespelecani (Linnaeus, 1758) measurements (mm): height, 36.41; breadth to tip of outer lip, 31.59; aperture from tip of lobe 1 (closest to the spire) to tip of lobe 4 (runs basally to the columella), 32.31; tip of the lobe 4 bent at 45–55° towards the aperture (Figure 2).

Turritella communis Risso, 1826 measurements (mm): height, 28.98; width, 6.48; aperture opening, 3.65 × 4.21; apical angle 12.8° (Figure 3).

Both measurement sets are in a range of characteristics reported for mature shells of these species (Gude, 1981a, b).

To clarify what environmental changes could facilitate the arrival and occurrence of new molluscan species in the extrinsic waters of the NWBS we analysed the dynamics of water temperature, salinity and oxygen concentration in this area over the period 2006–2012 (Figure 4). The linear regression analysis revealed positive regression coefficients (i.e. augmenting interannual dynamics) of water temperature and salinity. In turn, dissolved oxygen data fitting generated the regression coefficients of much smaller values and opposite signs in summer and in winter (Table 3).

Fig. 3. Apertural and abapertural views of *Turritella communis* shell from the north-western part of the Black Sea. Scale bar: 1 cm.

DISCUSSION

The discovery of two Mediterranean molluscan species raises questions about their current status and perspectives in the NWBS ecosystem.

Firstly, it is not clear whether the species we have found can be considered as an integral component of the local benthic community that have joined it due to the effects of global warming. Both species were registered for the Black Sea based on rare findings of solitary shells, mainly in the near-Bosphorus area (Dumont, 1999; Demir, 2003), thus making doubtful a hypothesis about their existence as stable populations in other parts of the sea in previous decades. Indeed, it was repeatedly shown that SST warming as observed for the periods 1982–2006 (Belkin, 2009) and 2006–2012 (our data) can lead to a sufficient extension of the aquatic molluscs' habitat. However, the water temperature rise in the Norwegian and Barents Seas, being considerably smaller than that observed in the Black Sea (Belkin, 2009), has already ensured a substantial expansion of *Aporrhais pespelecani* (Linnaeus, 1758) areal in the Arctic, and the establishment of its new sustainable populations (Kantor *et al.*, 2008). Further to the three-decadal SST rise, the spacious sand and silt flats of the NWBS sea-floor are the typical habitat of both species (Yonge, 1946; Gude, 1981a). Nevertheless, to the best of our knowledge we are the first to report the presence of *Aporrhais pespelecani* (Linnaeus, 1758) in the NWBS and *Turritella communis* Risso, 1826 in the Black Sea region other than the near-Bosphorus area. Thus, the molluscs are more likely to be recent colonizers rather than members of the long-established populations. If so, there are probably factors other than temperature (such as the recent increase of salinity values) that are facilitating the infiltration of these species into the NWBS.

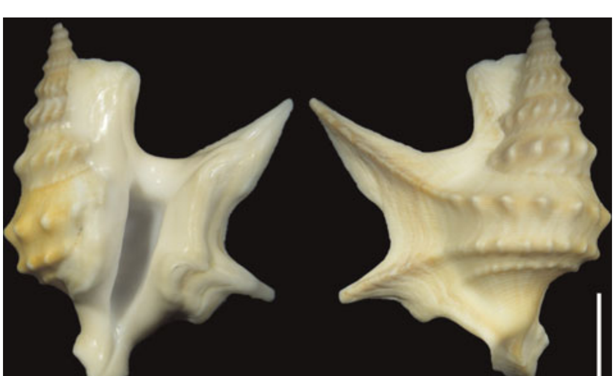

Fig. 2. Apertural and abapertural views of *Aporrhais pespelecani* shell from the north-western part of the Black Sea. Scale bar: 1 cm.

Secondly, an important question is how the molluscs we have found arrived at the NWBS. There are several possible intrusion vectors into this water area: as planktonic larvae from outside of the Black Sea with a Mediterranean current travelling north and then north-west from the Bosporus Strait (Yüce, 1996); as spillover specimens as a result of net cleaning performed by fishing boats arrived from remote operational areas (Goud, 1997) and/or with ship ballast waters; alternatively, collected animals could indicate the enlargement of the area of these species distribution in the Black Sea itself.

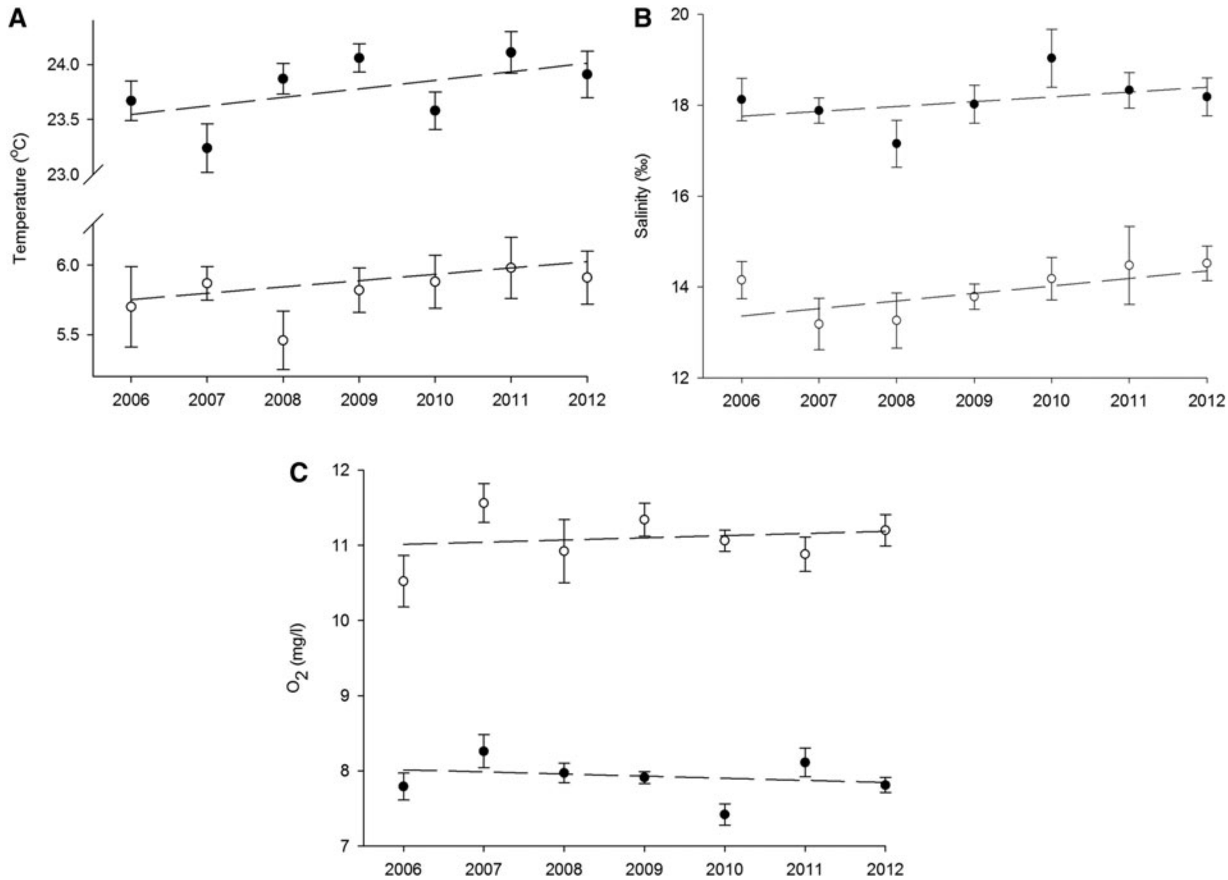

Fig. 4. Hydrological parameters of the north-western part of the Black Sea in the period 2006–2012 during winter (December–February, open circles) and summer (June–August, black circles): (A) temperature; (B) salinity; (C) oxygen concentration.

The surface rim water current circulates counter-clockwise in the western Black Sea basin, i.e. roughly from north-east to south-west along the coast in a catchment area (Shapiro, 2009) opposite to the tentative flow from the Bosphorus Strait. Since these water masses pass by a group of large commercial harbours (Odesa, Illichivsk and Yuzhnyi) located to north-east from the catchment area, this seems to support a hypothesis regarding larvae introduction with ballast waters. This also resonates with the fact that previous findings of both species occurred in close proximity to the ports of Istanbul (Demir, 2003), Batumi (Dumont, 1999) and Kerch (Shadrin & Latushkin, 2002) (Figure 1). However, if true, this hypothesis implies that the collected species should have invaded water areas other than NWBS, but to the best of our knowledge they are not among the common aquatic intruders. Short larval life of *Turritella communis* Risso, 1826 also prejudices such a hypothesis.

Table 3. Results of the linear regression analysis of interannual dynamics of hydrological parameters in the collection area.

Parameter, season	Regression coefficient estimate	Standard error	*t*-statistic	*P* value
Temperature, summer	0.0775	0.0119	4.86	4.02×10^{-4}
Temperature, winter	0.0454	0.0087	4.93	4.12×10^{-4}
Salinity, summer	0.1057	0.0161	3.29	7.86×10^{-4}
Salinity, winter	0.1646	0.0153	5.07	5.22×10^{-6}
Oxygen, summer	−0.0282	0.0092	2.37	1.8×10^{-2}
Oxygen, winter	0.0293	0.01	2.31	2.16×10^{-2}

Since there are no fishing or commercial harbours at a sea coast between Illichivsk and the Danube delta the hypothesis about introduction as a result of net cleaning performed by remotely operated fishing trawlers also seems to be doubtful.

Therefore, it appears that to date our findings most probably indicate the natural expansion of the Black Sea areas of *Aporrhais pespelecani* (Linnaeus, 1758) and *Turritella communis* Risso, 1826 to the NWBS. Substantial water temperature augmentation due to the global warming and interannual increase of salinity are probably the factors facilitating their establishment in this water area. In turn, values of regression coefficients obtained for the oxygen concentration data set are sufficiently smaller than that generated by the temperature and salinity data fitting, and have different signs depending on the year season (Table 3). This dissuades us from considering the dissolved oxygen concentration as a factor promoting establishment of new species in NWBS.

The pivotal role of water temperature and salinity changes in (possible) colonization of NWBS by *Aporrhais pespelecani* (Linnaeus, 1758) and *Turritella communis* Risso, 1826 is in line with the earlier conclusion about these factors as main barriers to the mediterranization of the Black Sea fauna (Oğuz & Öztürk, 2011). This places the found molluscan species into the general context of Mediterranean species infiltration into the Black Sea. Therefore, similar to the other Mediterranean newcomers, these species are unlikely to induce abrupt changes in demersal communities. However, due to the low level of competition characteristic of the Black Sea ecosystems the local populations of the molluscan newcomers, once established, are likely to sustain and develop in the NWBS.

Therefore, ongoing sampling and future monitoring of the presence of more live individuals or established colonies should be undertaken to verify if these two species can be considered as successful colonizers in the NWBS and, in case if they spread rapidly their range beyond the area of initial introduction, can be qualified as 'invasive'. Otherwise they might represent isolated events as a result of fishing activity, larval settlement, range expansion due to global warming and salinization, etc.

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