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Possible effect of *Balanus improvisus* on *Cerastoderma glaucum* distribution in the south-western Caspian Sea

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We studied the communities of the invasive Balanus improvisus *and native* Cerastoderma glaucum *populations in the south-western Caspian Sea. The massive movement of live Bivalvia attached to Cirripedia colonies along the studied coastline strengthens the hypotheses asserting the possible negative effects of exotic species on endemic species. Different live stages of both animals including meroplankton and macro-invertebrates were considered in the analysis. Bivalvia larvae showed a downward trend in population, in contrast with an upward trend of Cirripedia larvae from 1996 to 2013. The abundance of* C. glaucum *decreased west to east along the sea shore in contrast with increasing biomass of* B. improvisus. *Both Bivalvia and Cirripedia larvae did not show any overlapping temporal abundance. The Cirripedia larvae showed its highest abundance in winter while the bloom of Bivalvia larvae occurred in April and May during 2004–2013. The biomass of* B. improvisus *reported in this study was higher than those reported for the northern parts and for the middle parts. Distribution patterns of both species were described based on temperature, salinity gradient and local nutrient content. A non-linear growth model of Bivalvia showed the short-term effects of Cirripedia on Bivalvia growth. The controversy between the effects of Cirripedia on the movement of two different Cardiidae (*C. glaucum*, which is affected by the presence of* B. improvisus*, and* Adacna vitrea *with no attached Cirripedia) highlights the contributing role of several other factors including ecosystem degradation.*

Keywords: *Cerastoderma glaucum*, *Balanus improvisus*, *Adacna vitrea*, abundance, Caspian Sea

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INTRODUCTION

The Caspian Sea is the largest inland water on the earth (Dumont, 2000). It has a drainage basin covering almost 3.5 million km^2 compared with 2.4 million km^2 for the Black Sea (Stolberg *et al.*, 2006; Mertens *et al.*, 2012). The water inputs of this lake contain river discharges, including the Volga (contributing up to 80–85% of the total), Emba, Ural, Terek and Sefidrud rivers (67,000 km^2 catchment area and discharge of 4037 million m^3; Rodionov, 1994; Bagheri *et al.*, 2011).

The exchange of species between the Caspian and Black seas has existed since the Pliocene and Quaternary periods. One of the remarkable features of its fauna is the high level of endemism (Dumont, 2000). Numerous groups of the crustaceans (e.g. Mysidacea, Cumacea, Amphipoda and Onychopoda) and molluscs (e.g. Cardiidae and Pyrgulidae) have formed its species groups (Grigorovich *et al.*, 2003). At least 159 species have sorts that include obviously isolated habitats in the Caspian Sea (Grigorovich *et al.*, 2003). However, the accidental transfer of species by shipping has intensified since the construction of the Volga–Don canal in 1952 (Grigorovich *et al.*, 2002). Furthermore, the severe environmental destruction which occurred at the beginning of the 1990s (Dumont, 1995; Kideys *et al.*, 2008; Bagheri *et al.*, 2014) and previous introductions of alien species such as *Balanus eburneus* (1954), *Acartia tonsa* (1981), *Mnemiopsis leidyi* (1865) and *Hediste diversicolor* (1939–1940) would have had an impact on the endemic population (Grigorovich *et al.*, 2003).

There are eight mollusc species in the Caspian Sea with Mediterranean origin, of which three are Bivalvia (Kasymov, 1994). Cirrpedia *Balanus improvisus* (Darwin, 1854) was also accidentally introduced from the Black Sea in 1954 (Grigorovich *et al.*, 2003) and is now extensively distributed in the Caspian Sea.

Balanus improvisus is distributed in mesohaline low intertidal zones to subtidal regions of estuaries worldwide (Newman & Abbott, 1980; Dineen & Hines, 1992) and presently found throughout the Caspian Sea, except in areas with fresh water prevailing.

These species attach themselves to all available surfaces, including other aquatic organisms, and with their osmoregulatory characteristics can spend as much as 10 months of the year in fresh water (Newman & Abbott, 1980). Laboratory studies have indicated the highest larval survival rate (Nasrolahi *et al.*, 2006) and enhanced reproductive success, through year-round breeding and shorter embryonic development time, in Caspian Sea water (Rahmani & Sari, 2009).

Riedel *et al.* (2006) reported the infestation of endemic Bivalvia *Didacna* by invasive *Balanus improvisus* and the

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cheilostomate bryozoans *Conopeum seurati* in the north-western Caspian Sea. Also, Olszewska (1999) reported the existence of *B. improvisus* on *C. glaucum*. Taxonomic identity of *C. glaucum* complex has been studied over time. Members of the complex live in isolated communities and there is limited genetic exchange between them (Hummel *et al.*, 1994). They have a continuous distribution along European shores in the Mediterranean and Black Seas (Nikula & Väinölä, 2003). It is considered a native species in the Caspian Sea because the date of its introduction to the Caspian, Black and Aegean Seas remains controversial (Nikula & Väinölä, 2003).

Populations of Bivalvia and the bulk of benthos biomass have been mainly found in shorelines (<20 m depth) of the Caspian Sea (Mirzajani & Ghaninezhad, 2005; Roohi *et al.*, 2010) and constitute the main diet of the important commercial fish *Rutilus frisii kutum* (Zarinkamar, 1996; Afraei Bandepei *et al.*, 2009). This fish provides more than 60% of the income of local fishermen (Abdolmaleki & Ghaninezhad, 2007). Therefore, population variations of kutum will have a major impact on fisheries activities along the coastlines in the Caspian Sea.

There are several studies on the state of Bivalvia and Cirripedia distribution reported by Tadjali-Pour (1977, 1980), Hosseini *et al.* (1996), Laloei (2001) and Mirzajani & Vonk (2006) in the southern Caspian Sea. In 2001, a long-term programme was initiated by the Iranian Fisheries Research Organization (IFRO) to investigate the abundance of mesozooplankton species and the impact of alien species (*Mnemiopsis leidyi*) on endemic fauna in the southern Iranian coast of Guilan and Mazandaran provinces (Bagheri, 2012). Within the framework of this programme Roohi *et al.* (2008), Nasrollahzadeh *et al.* (2008a) and Bagheri *et al.* (2012b, 2013, 2014) documented variations of *M. leidyi* and mesozooplankton species in the southern Caspian Sea from 2001–2010. Roohi *et al.* (2008) and Nasrollahzadeh *et al.* (2008a) concluded that the impact of alien species on composition and abundance of plankton community was evident and may remain for years. Bagheri *et al.* (2011, 2012b, 2013, 2014) discussed that the main cause of the reduction in endemic species is the Caspian Sea ecosystem destruction, which facilitated the existence of alien species such as *Acartia tonsa* and *M. leidyi*. These species in their turn have had their own negative effects on the distribution and abundance of the endemic species.

Recently a huge abundance of Bivalvia was observed at the seashore which was mostly found along with *B. improvisus* colonies. This strengthens the hypothesis of possible negative effects of exotic species. In this paper, the possible effect of exotic species *B. improvisus* on the abundance of Bivalvia *C. glaucum* in the Caspian region was studied.

MATERIALS AND METHODS

Meroplankton (Bivalvia and Cirripedia larvae)

Samplings were performed at 5, 10 and 20 m water depth due to the high abundance of Bivalvia and Cirripedia in the coastal areas with less than 20 m depth (Bagheri *et al.*, 2012b), along five transects: Astara, Lisar, Anzali, Sefidroud and Chaboksar in the south-western Caspian Sea (Figure 1, Table 1).

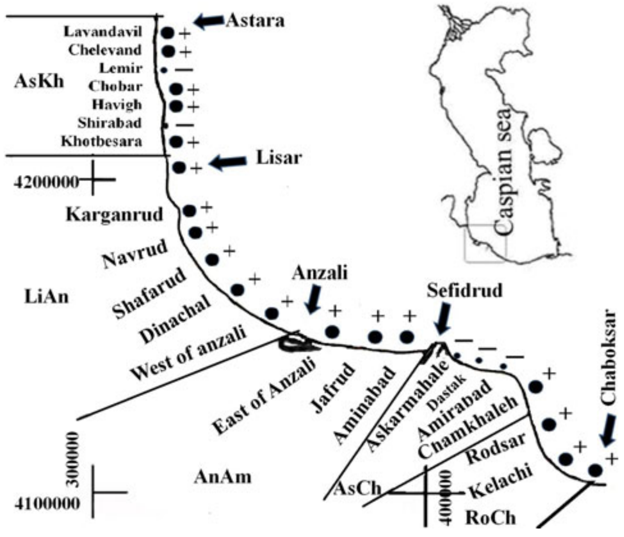

Fig. 1. Sampling regions in the south-western Caspian Sea (−: no alive Bivalvia; +: with alive Bivalvia; ⁄: transect).

Meroplankton was sampled using a Juday net (opening diameter: 36 cm, mesh size: 100 μm) during April–May and in September 2013 (Table 1). At each station (three different depths) a vertical haul with a Juday net was carried out from bottom to surface using a handle pulley. All samples were preserved in neutral 4% formaldehyde and were taken to the laboratory for analysis. Samples were divided into subsamples using a 1 mL Hensen–Stempel pipette and transferred to a Bogorov chamber for identification of meroplankton. At least 100 individuals were counted per sample and identified to the species level using an inverted microscope (Birshtain *et al.*, 1968; Harris *et al.*, 2000).

Furthermore, the Cirripedia and Bivalvia larvae data were adopted from the archives of the Inland Water Aquaculture Research Center (IWARC); including data of 1996 (12 samples) from Hosseini *et al.* (1996); data of 1999–2000 (24 samples) from Laloei (2001), and data of 2001–2010 (225 samples) from Bagheri *et al.* (2014) (Table 1).

Benthic

Benthic Bivalvia were collected at the same stations and at the same depths as meroplankton. Simultaneously, Bivalvia were sampled using a bottom sampler (Van-Veen grab; opening mouth: 400 cm^2; Table 1). The collected samples were washed and sieved (mesh size: 500 μm) by seawater and transferred to the laboratory.

In addition, data of different years were obtained from the archives of the Inland Water Aquaculture Research Center (IWARC) from the following resources to compare Bivalvia abundance data: (a) Hosseini *et al.* (1996) for data of 1995–1996 (38 samples); (b) Laloei (2001) for data of 1999–2000 (40 samples); (c) Khodaparast (2006) for data of 2006 (six samples); and (d) Mirzajani (2010) for data of 2009 (45 samples) (Table 1).

Species composition of the Bivalvia was determined in 23 localities along the 300 km coastline (Figure 1). Live Bivalvia and Cirripedia colonies in their shells were collected by hand along the beach at each locality after a sea-storm when there was a rise in Bivalvia abundance on the coastline,

Table 1. Sampling procedures at different regions and depths in the south-western Caspian Sea during 1995–2013 (+ meroplankton, • benthos); adopted from the archives of the Inland Water Aquaculture Research Center (IWARC).

Year	Month	Astara				Lisar				Anzali				Sefidroud				Chaboksar			
		Day	5 m	10 m	20 m	Day	5 m	10 m	20 m	Day	5 m	10 m	20 m	Day	5 m	10 m	20 m	Day	5 m	10 m	20 m
1995	Oct	22		•	•	24		•	•	26		•	•	28				29		•	•
1996	May	24		•	•	26		+•	+•	28		+•	+•	30		•	•	31		•	•
	Sep	1		•	•	3		+•	+•	5		+•	+•	7		•	•	8		•	•
	Nov	4		•	•	6		+•	+•	8		+•	+•	10		•	•	11		•	•
1999	Aug	24	•	•		22	+•	+•		18	+•	+•		16	+•	+•		12	•	•	
	Nov	4	•	•		6	+•	+•		16	+•	+•		19	+•	+•		22	•	•	
2000	Mar	3	•	•		5	+•	+•		7	+•	+•		9	+•	+•		12	•	•	
	May	31	•	•		29	+•	+•		17	+•	+•		14	+•	+•		10	•	•	
2001	Jul					27	+	+	+	19	+	+	+	21	+	+	+				
	Aug					21	+	+	+	20	+	+	+	22	+	+	+				
	Sep					6	+	+	+	24	+	+	+	29	+	+	+				
	Oct					22	+	+		8	+	+	+	20	+	+	+				
	Nov					26	+	+	+	24	+	+	+	25	+	+	+				
	Dec									30	+	+	+								
2002	Jan					22	+	+	+	19	+	+	+	20	+	+	+				
	Apr									30	+	+	+								
	May					2	+	+	+	28	+	+	+	1	+	+	+				
	Jun					12	+	+	+					11	+	+	+				
	Jul					13	+	+	+	4	+	+	+	3	+	+	+				
	Aug					5	+	+	+	15	+	+	+	3	+	+	+				
	Sep					17	+	+	+	11	+	+	+	12	+	+	+				
2003	Jun									1	+	+	+								
	Oct									20	+	+	+								
	Nov									23	+	+	+								
	Dec									21	+	+	+								
2004	Apr									13	+	+	+								
	May									26	+	+	+								
	Jul									28	+		+								
	Sep									22	+	+	+								
	Oct									27	+	+	+								
	Nov									30	+	+	+								
2005	Feb									26	+	+	+								
	May					31	+	+	+												
	Jul									26	+	+	+								
	Sep									22	+	+	+								
	Nov									3	+	+	+								
	Dec					19	+	+	+												
2006	Feb									28	+	+	+								
	May					16	+	+	+	23	+	+	+	17	+	+	+				
	Jul					24	+	+													
	Aug									12		+	+								
	Sep	10			•	22			+												
	Oct	25			•	8			+•	2			+•	1			+•				

Continued

Table 1. Continued

Year	Month	Astara				Lisar				Anzali				Sefidroud				Chaboksar			
		Day	5 m	10 m	20 m	Day	5 m	10 m	20 m	Day	5 m	10 m	20 m	Day	5 m	10 m	20 m	Day	5 m	10 m	20 m
	Dec	24			•	5			+												
2008	Feb					18	+	+	+	16	+	+	+	17	+	+	+				
	May					27	+	+	+	26	+	+	+	28	+	+	+				
	Jul					28	+	+	+	26	+	+	+	27	+	+	+				
	Nov					5	+	+	+	3	+	+	+	4	+	+	+				
2009	Feb	10	•	•	•	12	•	•	•	15	•	•	•	17	•	•	•	22	•	•	•
	May	15	•	•	•	17	•	•	•	20	•	•	•	22	•	•	•	26	•	•	•
	Jul	20	•	•	•	23	•	•	•	25	+•	+•	+•	27	•	•	•	30	•	•	•
	Nov									14	+	+	+								
2010	Jan													31	+	+	+				
	Mar					6	+	+	+	3	+	+	+								
	Oct					26	+	+	+	13	+	+	+								
2013	Jan									14	+•	+•	+•								
	Apr	20	+•	+•	+•									9	+•	+•	+•	27	+•	+•	+•
	May					11	+•	+•	+•	4	+•	+•	+•								
	Sep	8	+•	+•	+•	10	+•	+•	+•	4	+•	+•	+•	17	+•	+•	+•	13	+•	+•	+•

twice: during January–February, and during April–May 2013.

Biometry and statistical analysis

We used a Vernier caliper to measure length, height and inflation of Bivalvia shells (Leal & Matthews, 2013) (Figure 2). Dimensions of attachment location of Cirripeds on posterior dorsal portion of shells (called settlement surface, SS), which are darker in colour, were measured to estimate Cirripedia biomass.

Spatial differences of biomass and length of Bivalvia and Cirripedia were verified by one-way analyses of variance (ANOVA), followed by a Tukey's test. Pearson's rank correlation was used to determine the degree of relationship between Cirripedia biomass and Bivalvia abundance.

RESULTS

The substrate in the study area is composed of small sand, mud and shell debris offering an appropriate habitat for *Cerastoderma glaucum*, which can then be a proper surface for the settlement of *Balanus improvisus*. *Cerastoderma glaucum* shells constituted 68–100% of Bivalvia shell composition in 23 regions, whereas *Didacna trigonoides* shells were more abundant in the AsKh region (average 11.9%; Table 2). *Adacna vitrea* was dominant in the LiAn region particularly in the west of Anzali (Figure 1) with a maximum of 15.3% of bivalve shell composition. No live *C. glaucum* was observed in the east of Sefidroud (Figure 1; AsCh) region. All *C. glaucum* (100%) samples collected from the eastern

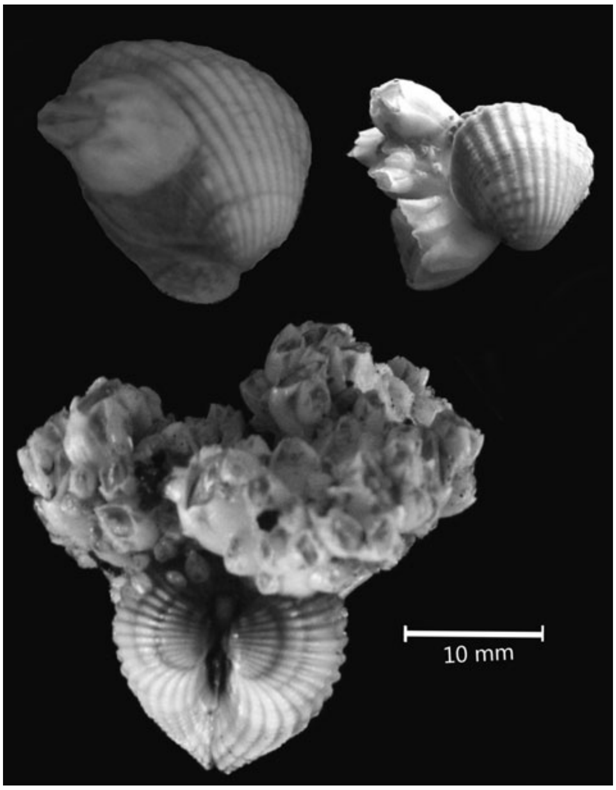

Fig. 2. *Cerastoderma glaucum* with *Balanus improvisus* in the south-western Caspian Sea in 2013.

Table 2. The composition of Bivalvia species (number, %) in the south-western Caspian Sea in 2013.

Region	Number	Species composition percentage				
		Cardiidae				Others
		Cerastoderma glaucum	*Didacna trigonoides*	*Adacna vitrea*	*Monodacna caspia*	Scrobiculariidae & Dreissenidae
AsKh	1566	82.7 ± 7.5	11.9 ± 7.6	1.0 ± 1.9	2.7 ± 2.1	1.7 ± 2.3
LiAn	3174	92.3 ± 5.2	2.9 ± 3.2	3.6 ± 5.9	0.1 ± 0.3	1.2 ± 1.9
AnAm	1010	92.6 ± 4.3	1.4 ± 0.7	0.3 ± 0.5	0.1 ± 0.1	5.6 ± 3.4
AsCh	692	98.9 ± 1.6	0.7 ± 1.4		0.1 ± 0.2	0.3 ± 0.4
RoCh	690	98.7 ± 2.3				1.3 ± 2.3

region were attached by *B. improvisus* (AsCh), while in the western regions this was 68–82% (AsKh and LiAn) (Figure 3).

Descriptive statistics on Cirripedia biomass in different regions are depicted in Figure 4. Density in different regions is significantly different ($F = 22.6$; $P < 0.05$). Although a peak density was observed in the Anzali region (3.6 g cm^{-2}), the highest average density was observed in RoCh (1.21 g cm^{-2}) compared with AsKh where the lowest average density (0.46 g cm^{-2}) was observed. The statistical test showed there were significant differences between Bivalvia sizes in different regions ($F = 16.9$; $P < 0.05$).

Bivalvia lengths in western regions (AsKh-LiAn) were shorter than those of eastern regions (AsCh-RoCh), belonging to different homogeny groups. In this study we observed a significant positive correlation between Cirripedia biomass and SS (Pearson rank correlation, $r = 0.83$; $P < 0.01$) and a significant negative correlation between Cirripedia biomass and Bivalvia abundance ($r = -0.71$; $P < 0.01$). Bivalvia samples with no attached Cirripedia showed a higher non-linear growth curve (mean annual growth rate of 1.8 mm year^{-1}) compared with those that were attached to Cirripedia (mean annual growth rate of 1.6 mm year^{-1}) (Figure 5). However, the difference in their growth was not statistically significant ($F = 0.06$; $P > 0.05$).

The findings showed that abundance of Bivalvia and Cirripedia larvae declined drastically during 2001–2002 (Figure 6). The abundance of Bivalvia larvae remained very low between 2008 and 2010 (average 157 n m^{-3} in 2010) as compared with previous years (average: 35,025 n m^{-3}; during 1996–2000). However, a maximum abundance (10,642 n m^{-3}; Figure 6) was observed in May 2006. The Cirripedia larvae showed a gradual increase after 2002 (average 6785 n m^{-3} in 2010; Figure 6) as compared with 1996–2000 (average 2981 n m^{-3}; Figure 6).

In 2013, mean abundance of Bivalvia and Cirripedia larvae were 4180 and 1675 n m^{-3}, respectively (Figure 6). The meroplankton abundances were high in Astara and Lisar compared with the Anzali and Sefidroud transects.

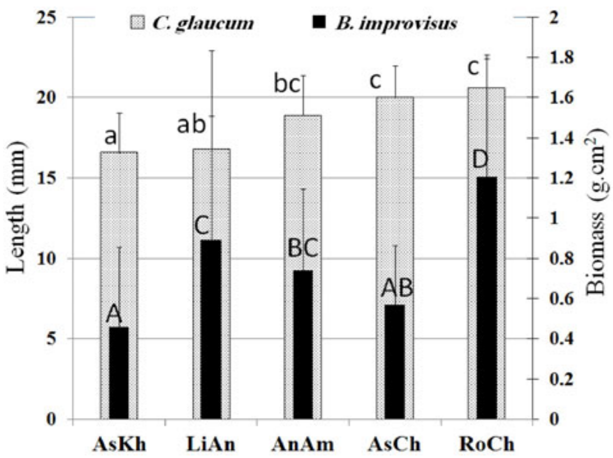

Fig. 4. Length of Bivalvia and biomass of Cirripedia in the south-western Caspian Sea in 2013 (letters indicate the homogeneous groups).

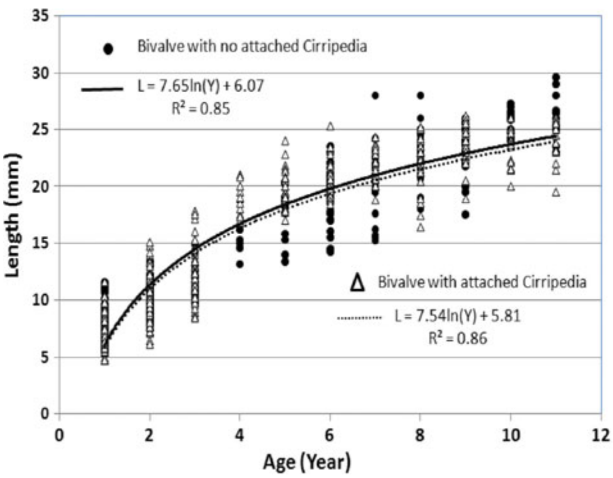

Fig. 5. The equations and growth curve of Bivalvia *C. glaucum* in presence and absence of Cirripedia *B. improvisus* in the south-western Caspian Sea in 2013.

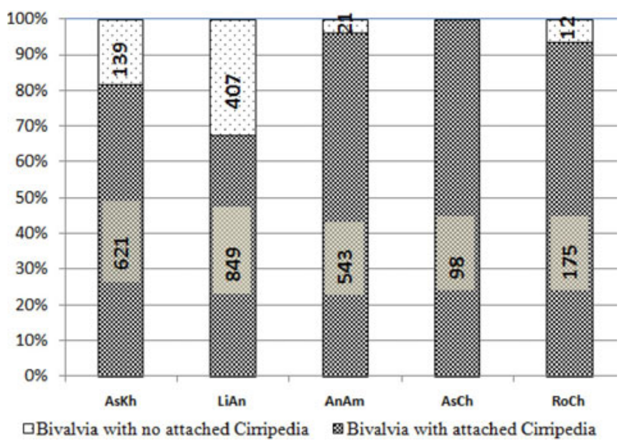

Fig. 3. Percentage of Bivalvia individuals with and without attached Cirripedia in different regions in the south-western Caspian Sea in 2013 (numbers indicate the counted specimens).

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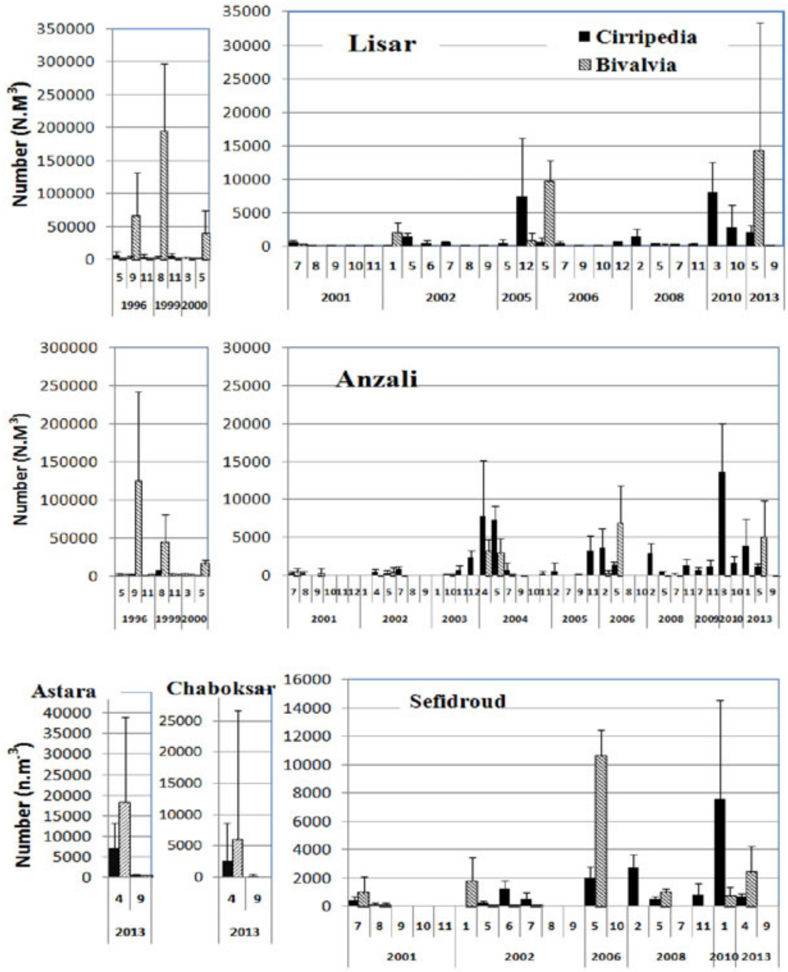

Fig. 6. Fluctuation of abundance (n m^{-3}) of Cirripedia and Bivalvia larvae in different regions in the south-western Caspian Sea during 1996–2013.

A spatial difference of meroplankton abundance was also found in a long time comparison (Figure 6), where Lisar had higher abundances of meroplankton than Anzali. In 2008, Sefidroud transect showed a higher mean abundance of meroplankton than Anzali and Lisar transects.

Neither Bivalvia or Cirripedia larvae showed an overlapping temporal abundance. The Cirripedia larvae showed a high abundance throughout the year with a peak abundance in winter. During 1996–2013, the abundance of Cirripedia larvae varied between 584 and 3255 n m^{-3} in summer and winter, respectively (Figure 6). The bloom of Bivalvia larvae occurred in April and May during 2004–2013 (average 4704 n m^{-3}), while the highest Bivalvia larvae abundance (average 2135 n m^{-3}; Figure 6) occurred in August and September during 1996–1999.

The benthic *C. glaucum* showed decreased abundance from west to east along the seashore. The highest abundance of *C. glaucum* was observed in the Astara and Lisar regions, while its lowest abundance was observed in the Sefidroud (AsCh) region (Figures 1 & 7). In 2009, the abundance of *C. glaucum* for these regions was more than 200 and about 12 n m^{-2}, respectively (Figure 7). In 2013, the highest abundance of *C. glaucum* (163 n m^{-2}) was observed in the Lisar region, while there was 100 n m^{-2} in other regions (Figure 7).

DISCUSSION

A drastic decrease in abundance of Bivalvia larvae and a gradual increase in Cirripeda larvae after 2000 (Figure 6) coincided with decrease of diversity and abundance of native zooplankton (Dumont *et al.*, 2004; Shiganova *et al.*, 2005; Roohi *et al.*, 2008, 2010; Bagheri, 2012) after the appearance of

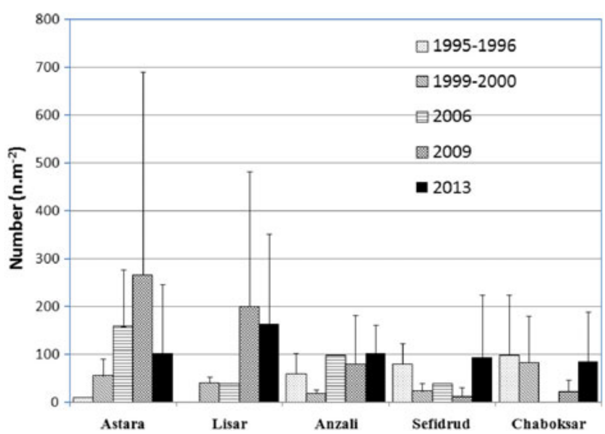

Fig. 7. *Cerastoderma glaucum* abundance in different regions in the south-western Caspian Sea during 1995–2013.

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Mnemiposis leidyi at the end of 1990s (Ivanov *et al.*, 2000). The abundance of Bivalvia and Cirripedia larvae declined drastically due to drought years and strong stratification of the Caspian Sea during 2001–2002 (Bagheri *et al.*, 2012b, 2014). Our findings showed that the abundance of *B. improvisus* increased after 2002 while abundance of Bivalvia larvae stabilized at about one-tenth of their abundance levels before 2000 (Figure 6). Maximum abundances of Bivalvia larvae have been changed from August–September (1996 and1999) to April–May (2004–2013) (Figure 6). It might be related to changes in weather or habitat conditions.

High larval survival rate (Nasrolahi *et al.*, 2006), reproductive success (Rahmani & Sari, 2009) and high biomass of *B. improvisus* in this study showed its successful adaptation in the Caspian Sea. Malinovskaja *et al.* (1998) and Kasimov (2001) reported higher Cirripedia biomass for south-western areas compared with middle and northern areas in the Caspian Sea. The biomass of *B. improvisus* in the northern Caspian Sea increased from 1960s to 1980s, while the biomass of *Cerastoderma glaucum* decreased during the same period (Malinovskaja *et al.*, 1998). Perhaps this is due to improved trophic conditions and a drop in water salinity.

Salinity of the Caspian Sea markedly varied from 0.1 PSU in the northern parts up to 11 and 13.5 in the middle and southern parts, respectively (Mamaev *et al.*, 2002). The biomass of *B. improvisus* reported in this study was 8.2 kg m^{-2}, which is higher than those reported by Malinovskaja *et al.* (1998) for the northern parts (mean 3.5 g m^{-2}) and Kasimov (2001) for the middle parts (ranged from 8.1 to 64.0 g m^{-2} in middle Caspian Sea to 4.7 kg m^{-2} at off-shore oil installations). Thus it is suggested that as salinity decreases from the southern Caspian Sea toward central and northern areas, the spatial distribution pattern of Cirripedia shows a downward trend from south to north.

Salinity is a main factor in Cirripedia (larvae and adult) distribution with adults occurring at a salinity of 0–13 PSU while the *B. improvisus* cyprids were most numerous in higher salinities. A salinity decline because of river discharge caused mortality after prolonged exposure (Bousfield, 1955). Bousfield (1955) and Dineen & Hines (1992) noted the best salinity range for peak settlement was 10–15 PSU, and according to O'Connor & Richardson (1994) the settlement of *B. improvisus* cyprids declined in 30 PSU. The mean salinity in our study area ranged between 11.6 and 12.0 PSU with lower salinities of 5.8 and 8.3 PSU in the Anzali and Sefidroud regions, respectively (Bagheri *et al.*, 2012b). According to Bagheri *et al.* (2012a, 2014), the high volume of freshwater discharge by the Anzali wetland and Sefidroud River were reasons for salinity variations in the south-western Caspian Sea.

Distribution of Bivalvia shell coincides with distribution pattern of these organisms. As Moiseiev & Filatova (1985) noted, higher abundances of *Cerastoderma* was observed in the southern regions of the Caspian Sea compared with northern and middle parts, whereas *Adacna* sp. and *Didacna* sp. showed an opposite trend. Slugina (2006) reported the ranges of salinities for each species while *Cerastoderma* was found in the highest salinities (11–12 PSU), which nearly resembles our distribution results (Table 2).

Our findings showed that the highest abundance of *C. glaucum* was observed up to 700 n m^{-2} (Figure 7; in 2009) in the south-western Caspian Sea (Astara region), comparable to the study of Moiseiev & Filatova (1985), who reported a high frequency (about 800 n m^{-2}) in the same area.

High Bivalvia and Cirripedia abundance could be related to rise of salinity, trophic index and nutrient levels in Astara and Lisar regions. According to Kosarev *et al.* (1994) and Nasrollahzadeh *et al.* (2008b) nutrient concentrations, chlorophyll *a* and trophic index increased during 1946–2005 in the Caspian Sea. Furthermore, Nasrollahzadeh *et al.* (2008a) and Bagheri *et al.* (2014) reported that the nutrient concentrations (DIP & DIN) increased 2–3 times during 2001–2010 as compared with previous years. Spatially, the highest values of chlorophyll *a* (Kideys *et al.*, 2008; Jamalomidi, 2013) and the nutrient levels (Nasrollahzadeh *et al.*, 2008a, 2008b) were observed in Anzali and Sefidroud areas. According to Laloei (2001) and Bagheri *et al.* (2012a, b), the highest concentrations of DIN were observed in the Anzali and Sefidroud regions (average 0.08 and 0.06 mg L^{-1}, respectively). Furthermore the concentrations of DIP were higher in those regions (average 0.04 and 0.03 mg L^{-1}, respectively) than in the Astara, Lisar and Chaboksar regions (reported by Laloei (2001) and Bagheri *et al.* (2012a)). The Anzali and Sefidroud regions are under the influence of their extremely large catchment areas that might be a reason for their high nutrient levels. On the other hand, the runoff pollution from coastal cities such as Astara, Anzali, Rodsar and Chaboksar regions, that discharge their sewage directly into the sea, may be more than other regions. Eutrophication levels will increase in the Caspian region by anthropogenic activities such as fish cage culture which was launched in the Jaf region in 2012, where we observed high abundance of Cirripedia and their full settlement (Figure 3). Based on Malinovskaja *et al.* (1998) and our findings, full settlement of Cirripedia (Figures 1 & 3 in AnAm-AsCh regions) and absence of *C. glaucum* in many parts of this region might be related to trophic conditions needed for distribution of both organisms. It might be suggested that the increases in nitrogen and phosphorus concentrations result in the increase and decrease in the biomass of *B. improvisus* and *C. glaucum*, respectively.

The findings revealed that there is negative correlation between *B. improvisus* biomass and *C. glaucum* abundance. The increase of *B. improvisus* biomass from western to eastern regions can be related to rising water temperatures as reported by Nasrollahzadeh *et al.* (2008a). Although the negative effects of *B. improvisus* on *C. glaucum* such as competition on feeding of suspended organic micro-particles and consuming oxygen were reported by Riedel *et al.* (2006), we could not detect any significant difference in the growth rate of the two species (Figure 5). This might be because Cirripedia settlement and development on Bivalvia occurs in relatively short periods.

Although no data on growth rate and age determination of Cirripedia are available, according to several authors (Bertness *et al.*, 1991; Sanford & Menge, 2001; Phillips, 2005), a complex set of oceanographic conditions such as water temperature, high nutrient inputs, abundance of planktonic food and wave-exposure might affect the growth rate of Ciiripedia. Based on our findings, the Cirripedia growth rate ranged between 0.03 and 0.12 mm d^{-1}, which suggest their short-term influence on Bivalvia. The presence of *B. improvisus* causes *C. glaucum* to be unstable and unsteady; therefore it is transported to the coastline with wave circulation in stormy situations.

Despite hydro-chemical and pollutant influences, the dominant small size of *C. glaucum* in the AsKh region is hypothesized to be the result of the high abundance of *B. improvisus* larvae (Figures 4 & 6). This leads to high Bivalvia transportation to coastline areas without having a chance for further growth. It is predicted that due to high abundance of *B. improvisus*, Bivalvia size will decrease in other regions too.

In areas not especially invaded by *B. improvisus*, widespread transportation of live Bivalvia indicated the contribution of other factors strengthened by abundance of *Adacna vitrea* which constituted 15.3% of Bivalvia individuals to the west of Anzali. The form and length of siphons is largely dependent on clam lifestyle and living depth. Schneider (1998) used the siphons' position to review the taxonomy of Cardiid. In his cladistic phylogeny tree, three genera of *Cerastoderma, Didacna* and *Hypanis* were very close to each other in terms of morphology. Vidal (2001) has described siphons of *C. glaucum* to be relatively long with few additional larger tentacles on the outside. No specific data are available on *A. vitrea*; however, our observations on live specimens showed siphon lengths up to 30 mm compared with 5 mm in *C. glaucum*.

A longer siphon allows *A. vitrea* to live a few centimetres below the surface where it is not invaded by *B. improvisus* but rather by *C. glaucum* which lives on the sea floor. Foliage and litter (resulting from overgrowth of aquatic plants in wetlands and deforestation in catchment basins) are transported into and settle in the Caspian Sea, and have a strong influence on movements of *C. glaucum* individuals in stormy situations. We observed that woody particles and other terrestrial plant detritus can expunge small-sized Bivalvia even with low settlement of Cirripedia. Although there is no information on the rate of litter discharge into the Caspian Sea, it seems to be very high.

Olszewska (1999) reported the sporadic colonization of *C. glaucum* by *B. improvisus* in the southern Baltic. This Bivalvia was known as a very unstable substrate for barnacle. This is because of its spherical shape that can readily roll along the bed by water currents (Olszewska, 1999). In spite of this morphological characteristic we think that *C. glaucum* is almost the only target for the settlement of *B. improvisus* in the southern Caspian Sea; where the bed at 10–20 m depths is composed of small sand and mud.

Although we report possibly negative effects of Cirripedia on Bivalvia survival, Roohi *et al.* (2010) reported a positive influence of the exotic species *Mnemiopsis leidyi* on Bivalvia abundance after its introduction to the Caspian Sea. The positive influence was observed to be in the form of increased Bivalvia abundance, because of increased food availability due to the decomposition of dead ctenophores. This controversy could be due to differences in sampling sites and statistical analysis. For example, Roohi *et al.* (2010) collected samples from the locations which are not considered as Bivalvia habitats. Furthermore, we used depths shallower than 20 m (as the main distribution areas of Bivalvia) in this study (Hosseini *et al.*, 1996; Mirzajani & Ghaninezhad, 2005; Mirzajani & Vonk, 2006), which is deemed to contribute to data reliability. Further studies on niche overlap and the possible feeding competition between *M. leidyi*, *B. improvisus* and *C. glaucum*, as primary consumers, by new techniques such as isotope measurements are needed.

CONCLUSION

The high volume of live Bivalvia transportation to southern Caspian coastlines, instead of entering into the food chain, is caused by massive settlement of exotic species (*B. improvisus*) and influences of anthropogenic activities such as erosion and discharge of solid suspended matters by rivers. This movement of molluscs will be intensified in the future due to higher urban nutrient loading, deforestation and many other anthropogenic influences such as cage fish culture, which is under consideration to be carried out in the Caspian Sea. Habitats of the native Caspian species will be restricted by these human activities especially in the coastal areas. Therefore, there is a great need for synecological monitoring of native fauna with special emphasis on evaluation of pollution impacts.

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