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State of *Mnemiopsis leidyi* (Ctenophora: Lobata) and mesozooplankton in Iranian waters of the Caspian Sea during 2008 in comparison with previous surveys

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Abstract

Mnemiopsis leidyi which was accidentally introduced into the Caspian Sea in 1999 and since then has colonized extensively. The horizontal distribution of *M. leidyi* and dominant mesozooplankton species was investigated in the south western Caspian Sea during February, May, July and November 2008. The average number and biomass of *M. leidyi* were in the same range (ca 200 individuals·m^{-3} (2000 ind·m^{-2}) and 16 g wet weight·m^{-3} (180 g·m^{-2}) in comparison with previous surveys. As in previous years the population consisted mainly of individuals <1 cm. The decline in mesozooplankton species observed since 1996 continued in 2008. Only two species of the previously recorded 24 Cladocera species were found in 2008. Of five Copepoda species recorded in 1996, only one, *Acartia tonsa*, was found in 2008 and even here adult individuals have reduced 3-fold since 1996. Bivalve larvae have declined by one order of magnitude since 1996. Among the dominant species, only the numbers of Cirripedia larvae and in part the numbers of *Pleopis polyphemoides* (Cladocera) were in the same range as in 1996.

Keywords: *Mnemiopsis leidyi*, *Acartia tonsa*, Mesozooplankton, Long-term fluctuation, Caspian Sea

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Introduction

Mnemiopsis leidyi Agassiz, 1865 (Ctenophora: Lobata), endemic to the east coast of North and South America is classified as a very successful invader-species. It was transported, most possibly in ballast water, to European seas where it developed massive localized blooms. It was first discovered in the Black Sea during the mid 1980's (Mutlu, 2009; citations therein) and has to date established in the Caspian Sea (Esmaeili et al., 1999; Ivanov et al., 2000; Shiganova et al. 2001), the Mediterranean Sea (Boero, 2009; Fuentes, 2009; Galil et al., 2009), the North Sea and Baltic Sea (Faassel and Bayha, 2006; Oliveira, 2007; Hintikainen, 2009; Javidpour et al., 2009a).

The expansion of *M. leidyi* in the Caspian Sea since 1999 (Ivanov et al., 2000) is linked with striking changes in the biodiversity of phytoplankton, zooplankton, macrobenthos, and fishes (Kideys et al., 2008; Ganjian et al., 2010; Roohi et al., 2010). In this period there has been a marked decline in zooplankton species (Shiganova et al., 2004; Kideys et al., 2005) and fish catches (Daskalov and Mamedov, 2007). About half of the mesozooplankton species that existed in the southern Caspian Sea in 1996 were absent during the period 2001-2006 (Roohi et al., 2008). Furthermore, the annual mean zooplankton abundance was reduced two- to five-fold as compared to 1996.

In 2001, a long-term program was initiated by Iranian Fisheries Research Organization (IFRO) to monitor the spread of *M. leidyi*, mesozooplankton, phytoplankton, and the environmental parameters of the southern Iranian coast of Guilan and Mazandaran districts (Kideys et al., 2001). Within the framework of this program Roohi et al. (2008) and Bagheri et al. (2011a) documented seasonal fluctuations of *M. leidyi* and mesozooplankton species in the southern and south western Caspian Sea from 2001-2006. Roohi et al. (2008) concluded that the total number and biomass of *M. leidyi* decreased to a certain extent after 2003 although the impact of *M. leidyi* on zooplankton in terms of the latter species composition and abundance was still evident and may remain for years.

In order to investigate the situation in which was developed since 2006, a new survey was undertaken in 2008. In this survey, the state of *M. leidyi* and the composition of mesozooplankton communities of the south western Iranian coast of the Caspian Sea were investigated and compared with the findings of before 2006.

Materials and methods

The area under investigation is located at the south west of Caspian Sea (Figure 1) an area influenced by freshwater input from the Sefidrood Delta and Anzali wetlands, located at the west of the delta of the Sefidrood River, and to a lesser extent from the Lisar River (total discharge: 1.2 million m^3 $year^{-1}$; Iranian Force power Geography Organization, (IFGO, 2003; Bagheri et al., 2010). The catchment area of the Sefidrood River is 54,100 km^2 with an average discharge of 3,998.4 million m^3 $year^{-1}$. The Anzali wetlands with a catchment area of 3740 km^2 (Sharifi, 1990; Bagheri et al., 2011b, 2012) contribute about 2 million m^3 freshwater per year. The lowlands of the basin are intensively cultivated for rice, while the natural cover of the uplands is temperate-deciduous forest. Generally, the mean monthly rainfall exceeds the evapotranspiration (Shantia, 1989).

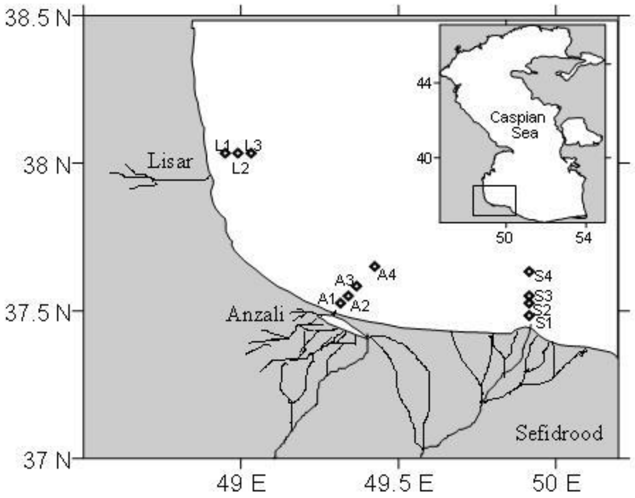

Figure 1: Area of investigation 2008: south-western Caspian Sea. All transects were sampled in February, May, July and November.

Large volumes of freshwater outflow causes marked variations of salinity in the area under investigation, especially during spring when the rivers carry winter melt water (Roohi et al., 2008; Bagheri et al., 2010, 2012). Salinity can drop locally to 5.6-8.3 PSU (Practical Salinity Unit). Generally, the surface average salinity is 11.9 ± 1.2 PSU, increasing with depth to values of 12.4 ± 1.6 (Roohi et al., 2008; Bagheri et al., 2010, 2012). The surface water temperature varies between 26–32°C in summer and between 8–12°C in winter (Roohi et al., 2008; Bagheri et al., 2011a, b).

Owing to the strong agricultural utilization, and deforestation of woodlands, the nutrient load of river flow has increased since the early 1980s (Salmanov, 1999; Sharifi, 1990; Caspian Sea Environment Programme, (CEP, 2006); Stolberg et al., 2006). During 2001–2006, the total dissolved inorganic nitrogen (DIN = NNO_2+ N-NO_3 + N-NH_4) concentrations varied between 2.10–2.15 $\mu M{\cdot}dm^{-3}$ in spring-summer and between 2.95–3.24 $\mu M{\cdot}dm^{-3}$ during autumn–winter; total dissolved inorganic phosphorus (DIP = P-PO_4) concentrations varied between 0.50 and 0.65 $\mu M{\cdot}dm^{-3}$, respectively (Roohi et al., 2008). The increased nutrient load of the south western Caspian Sea caused an increase in primary productivity reflected by high chlorophyll *a* levels (2.71–35.25 $\mu g{\cdot}dm^{-3}$) in 2006 as compared to 1994, when levels were 0.56–1.34 $\mu g{\cdot}dm^{-3}$ (CEP, 2006; Khodaparast, 2006; Kideys et al., 2008; Bagheri et al., 2012).

Distribution of *M. leidyi* and mesozooplankton populations were studied along three transects: Lisar, Anzali and Sefidrood in the south western Iranian coast of the Caspian Sea in four different seasons: February (16–18), May (26–28),

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July (26–28), and November (3–5) 2008 (Figure 1, Table 1). All transects consist of three stations located at 5 m (L1, A1, S1), 10 m (L2, A2, S2), and 20 m (L3, A3, S3) depth contours. At the Anzali and Sefidrood transects, an additional station at 50 m water depth was included (A4, S4). The sampling of the whole station grid was performed in three days; each transect was sampled by using a speedboat in one day during 10 am – 2 pm.

Table 1: Positions and depth of the stations investigated in the south-western Caspian Sea in February, May, July and November in 2008

Region	Station	Depth (m)	Latitude	Longitude	Distance from shore (km)
Lisar	L1	5	48° 51' 42"	38° 02' 21"	2
	L2	10	48° 58' 30"	38° 04' 51"	9
	L3	20	49° 04' 21"	38° 03' 40"	16
Anzali	A1	5	49° 29' 31"	37° 29' 00"	1
	A2	10	49° 28' 59"	37° 29' 20"	3
	A3	20	49° 29' 43"	37° 30' 30"	6
	A4	50	49° 28' 37"	37° 35' 07"	15
Sefidrood	S1	5	49° 56' 00"	37° 28' 08"	2
	S2	10	49° 55' 20"	37° 29' 42"	4
	S3	20	49° 54' 59"	37° 30' 31"	6
	S4	50	49° 55' 16"	37° 31' 29"	10

Temperature and salinity of the seawater at 5, 10, 20 and 50 m were measured *in situ* using an inverted thermometer and a digital salinometer, respectively. Dissolved oxygen (DO) was measured by the Winkler method. Water samples for analyses of nutrients such as phosphates, nitrates, nitrites, silicate, total dissolved nitrogen, and phosphorus were deep frozen and determined in the laboratory using standard methods (Clesceri et al., 2005).

Individuals of *M. leidyi* were sampled using a METU Plankton net (500 µm mesh size; opening diameter: 50 cm; net bucket volume: 1000 ml (Kideys et al., 2001). Mesozooplankton was collected at the same stations and same depth as *M. leidyi* using a Juday net (opening diameter: 36 cm, mesh size: 100 µm; Vinogradov et al., 1989). The towing speed of both nets was approximately 1 m per second. The volume of sea water filtered was calculated by formula V = (towing speed) x (haul duration) x (net opening), assuming 100 % filtering efficiency. At each station (except the 50 m deep stations A4, S4) two vertical hauls, one with METU plankton net and one with the Juday net were carried out from bottom to surface using a handle pulley for heaving the net.

Mnemiopsis leidyi samples were investigated immediately after the haul. The net bucket content was emptied into a dish and the ctenophores counted by eye. The total length (lobate length) of 5,593 individuals was measured and the individuals <1 cm were sorted in length groups of 5 mm, and individuals >1 cm into 10 mm length groups. The biomass of each of the measured individuals was

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calculated using the equation Wet Weight (g) = 0.0013 x Length$^{2.33}$ (mm); r^2 = 0.96, *n* = 269 obtained (Bagheri and Kideys, 2003).

Mesozooplankton samples were preserved in neutral 4 % formaldehyde and analyzed in the laboratory. Samples were divided into sub-samples using a 1-ml Hensen–Stempel pipette and transferred to a Bogorov tray for counting. At least 100 individuals were counted per sample and identified to species level, life-cycle stages, or taxonomic groups using an inverted microscope (Harris et al., 2000).

Statistical comparisons were undertaken using SPSS vers.13. Spatial and seasonal differences in the distribution of *M. leidyi*, mesozooplankton and chemical parameters were verified by one-way analyses of variance (ANOVA). Spearman's rank correlation was used to measure the degree of the relationship between abundance of *M. leidyi*, mesozooplankton, and the temperature and salinity parameters.

Results

Hydrophysical characteristics

The salinity in the south western Caspian Sea (measured in 5 m depths) varied between 10.0 and 12.5 PSU in 2008 (Figure 2A). High spatial variation occurred particularly in November and February. Variations could be related to increased fresh water input by rivers during these months owing to a weak halocline at about 5–10 m depth at the deep stations (50 m) in November and February. In May and July no major stratification of salinity was detected. The surface water temperature (measured in 5 m depth) displayed a pronounced seasonal fluctuation with values between 6.8°C in February and 29.8°C in July (Figure 2B). In contrast to the halocline which occurred in February and May, a thermocline was formed in summer and autumn, occurring in about 20 m depth. The stratification started to disperse in November. In February, the temperature of the water column was almost uniform, varying between 8°C at the surface and 6°C at the bottom. The dissolved oxygen profiles indicated a well ventilated water column during winter and summer with values between 7.9–9.4 $mg \cdot dm^{-3}$. Nutrient concentrations were generally high in the area under investigation and displayed a wide seasonal variation (Table 2). Generally, the concentrations of $N\text{-}NO_3$ and $P\text{-}PO_4$ were higher during November–February than in May–July. Silicate concentrations reached 13.39 $\mu M \cdot dm^{-3}$ in May, and varied between 9.83–13.13 $\mu M \cdot dm^{-3}$ in February and November.

Zooplankton

No differences were noted in the spatial distribution of *Mnemiopsis leidyi* the mesozooplankton, and nutrients between the three transects of Lisar, Anzali and Sefidrood in 2008 (one-way analyses of variance, ANOVA: *M. leidyi* (number) : n = 42, df = 2, *P* = 0.352; *M. leidyi* (biomass); n = 42, df = 2, *P* = 0.412; Mesozooplankton: n = 42 , df = 2, *P* = 0.433; nutrients: n = 76, df = 2, *P* = 0.195). Therefore, the data for the three transects were combined per season and arranged in Table 3.

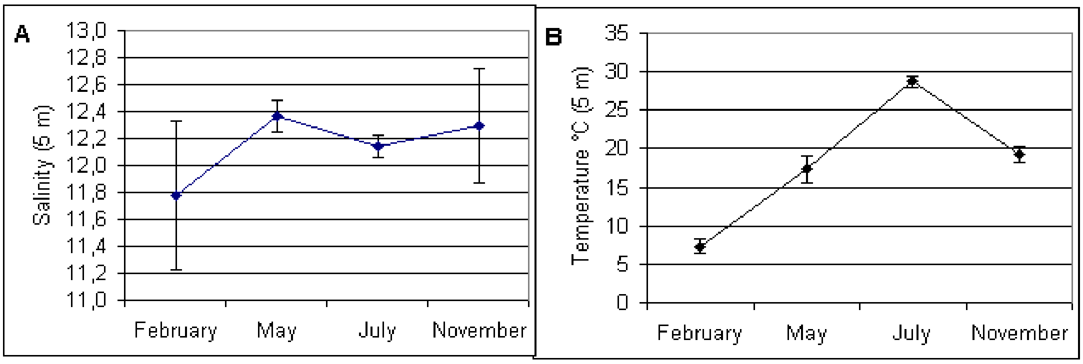

Figure 2: Seasonal changes in salinity (PSU) and temperature (°C) in 5 m depth in the south-western Caspian Sea in 2008. The averages and standard deviations of all 11 stations sampled in each month are shown.

Table 2: Nutrient concentrations in the south western Caspian Sea in 2008 (measured in February, May, July and November) in comparison to the average nutrient concentration during 2001–2006 (Roohi et al., 2008).

Season	N-NO3				P-PO4				Si-SiO2				DIN			
	2001-2006		2008		2001-2006		2008		2001-2006		2008		2001-2006		2008	
	µM	Std	µM	std	µM	std	µM	std	µM	std	µM	std	µM	std	µM	Std
Winter	1,7	*0,8*	6,64	*2,16*	0,6	*0,2*	1,3	*0,3*	8,8	*2,1*	9,8	*1,9*	2,9	-	7,6	*2,40*
Spring	1,4	*0,2*	1,64	*0,31*	0,5	*0,1*	0,9	*0,2*	8,2	*2,6*	13,4	*3,5*	2,1	-	2,4	*0,75*
Summer	1,0	*0,4*	1,96	*0,46*	0,5	*0,1*	0,9	*0,1*	8,6	*2,7*	nd	*nd*	2,1	-	2,8	*0,54*
Autumn	1,5	*1,4*	4,15	*1,70*	0,7	*0,5*	1,2	*0,2*	9,5	*3,3*	13,1	*6,1*	3,2	-	5,1	*1,80*

Mnemiopsis leidyi

The distribution of *M. leidyi* was very patchy, indicated by strong variations of abundance at single stations, especially in July and November (Figure 3A, B). Owing to wide variation, no general difference in abundance of *M. leidyi* could be verified between coastal and deep water stations (abundance: P = 0.698, df = 3, n = 42) and biomass (P = 0.395, df = 3, n = 42). The seasonal fluctuation of the numbers and biomass of *M. leidyi* was independent from salinity but positively correlated with the fluctuation of the surface water temperature in 5 m depth (Spearman's rank correlation: n = 42; for salinity: abundance: r = 0.164, P = 0.293; biomass: r = 0.199, P = 0.200; for temperature: abundance: r = 0.650, P = 0.000; biomass: r = 0.794, P = 0.000).

In February 2008, *M. leidyi* was very rare; it did not occur at coastal stations (L1, A1, S1; with 5 m total depth; Figure 1). Few individuals were found only at stations with a total depth of at least 20 m (Figure 3A, B). The stock of *M. leidyi* increased during the year. Starting with 7 ind$\cdot$m^{-3} (135 ind$\cdot$m^{-2}) and a biomass of 0.06 g$\cdot$m^{-3} (1.0 g$\cdot$m^{-2}) in February it became very abundant in July, and reached a maximum average number of more than 504 ind$\cdot$m^{-3} (5600 ind$\cdot$m^{-2}) in November, including one patch of more than 1430 ind$\cdot$m^{-3} (7015 ind$\cdot$m^{-2}) at the 5 m station S1 (Figure 3A). Unlike the abundance, the average biomass was the highest in July (37 g$\cdot$m^{-3}; 439 g$\cdot$m^{-2}) and decreased in November to the similar levels as were found in May, about 13 g$\cdot$m^{-3} (120 g$\cdot$m^{-2}) (Figure 3B).

Table 3: Average abundances of mesozooplankton taxa (number m^{-3}) per month collected in the south-western Caspian Sea in 2008. h: holoplankton, m: meroplankton

			Fresh water species	February		May		July		November		Annual average		
No		Group	Taxa	average	std	average	std	average	std	average	std	total no	average	std
1	m	Arachnida	Arachnida larvae	0.05		0.10		0.00		0.00		2.00	0.03	*0.35*
2	h	Ciliata	*Tintinnopsis tubulosa* Levander, 1900	17.09	*54.10*	0.00		0.00		19.38	*30.58*	401.00	9.00	*31.00*
3	m	Cirripedia	*Balanus* sp. *Cypris* Costa, 1778	78.36	*145.0*	150.83	*121.00*	18.50	*20.50*	64.23	*178.50*	3280.00	75.00	*133.00*
4	m	Cirripedia	*Balanus* sp. *Nauplius* Costa, 1778	1961.20	*1324.0*	413.17	*172.00*	90.44	*122.00*	683.06	*622.30*	34213.00	778.00	*1017.00*
5	h	Cladocera	*Pleroxus trigenellus* Müller, 1785	0.00		0.00		0.00		0.05		1.00	0.01	
6	h	Cladocera	*Chydorus* sp. Leach, 1843	0.91	*1.90*	0.00		0.00		0.00		10.00	0.23	*0.99*
7	h	Cladocera	*Moina* sp. Baird, 1850	0.00		0.00		0.00		0.05		1.00	0.01	*0.08*
8	h	Cladocera	*Podonevadne* sp. Gibitz, 1922	0.00		0.32		0.00		0.00		3.00	0.07	*0.48*
9	h	Cladocera	*Pleopis polyphemoides* Leuckart, 1859	0.00		386.42	*284.00*	0.27	*0.65*	0.05		3868.00	88.00	*209.00*
10	h	Copepoda	*Acartia tonsa nauplii* Dana, 1849	717.17	*334.0*	932.43	*308.00*	2354.90	*1901.00*	9268.20	*7870.00*	145067.00	3297.00	*5282.00*
11	h	Copepoda	*Acartia tonsa adult* Dana, 1849	490.09	*234.0*	761.80	*534.00*	2946.70	*1446.00*	3743.80	*3440.00*	86604.00	1968.00	*2313.00*
12	h	Copepoda	*Cyclops* sp.adult Risso, 1826	0.64	*1.40*	1.40		0.00		0.00		21.00	0.48	*2.00*
13	h	Copepoda	*Cyclops* sp. nauplii Risso, 1826	0.64	*1.60*	0.00		0.00		0.00		7.00	0.16	*1.00*
14	h	Copepoda	*Ectinosoma concinnum* Akatova, 1935	0.82	*2.14*	0.23	*0.42*	0.97		0.00		22.00	1.00	*2.00*
15	m	Bivalvia	Bivalvia larvae Linnaeus, 1758	8.73		380	*464.00*	0.64	*1.12*	0.00		3903.00	89.00	*266.00*
16	m	Nematoda	Nematoda larvae	0.27		1.70	*2.17*	0.00		0.00		20.00	0.45	*1.49*
17		Pisces	Pisces larvae	0.24	*0.62*	0.07		0.00		0.00		3.00	0.08	*0.33*
18		Pisces	Pisces ovae	0.12		0.23	*0.42*	0.34	*1.47*	0.00		14.00	0.32	*0.85*
19	m	Polychaeta	*Hypania* larvae Ostroumouw, 1897	0.00		0.00		17.70	*31.80*	0.03		195.00	4.00	*17.00*
20	m	Polychaeta	*Nereis* sp. larvae Linnaeus, 1758	0.35	*0.78*	5.3	*10.40*	70.09	*97.60*	357.38	*625.90*	4759	108.00	*340.00*
21	h	Rotifera	*Brachionus plicatilis* Müller, 1786	0.73	*1.42*	4.1	*8.60*	0.00		0.09		50.00	1.00	*4.00*
22	h	Rotifera	*Keratella cochlearis* Gosse, 1851	0.55	*1.29*	0.00		0.00		0.00		6.00	0.14	*0.67*
23	h	Rotifera	*Synchaeta krogne krogne* Kasimov, 1997	1735.10	*2926*	54.50	*76.10*	3.70	*9.66*	0.00		19667.00	447.00	*1600.00*
			Total (average)	5013.00	*3175*	3092.00	*582.00*	5505.00	*3251.00*	14136.00	*12168.00*	302116.00		
			Total (number)	55144.00		30922.00		60552.00		155499.00		302117.00		

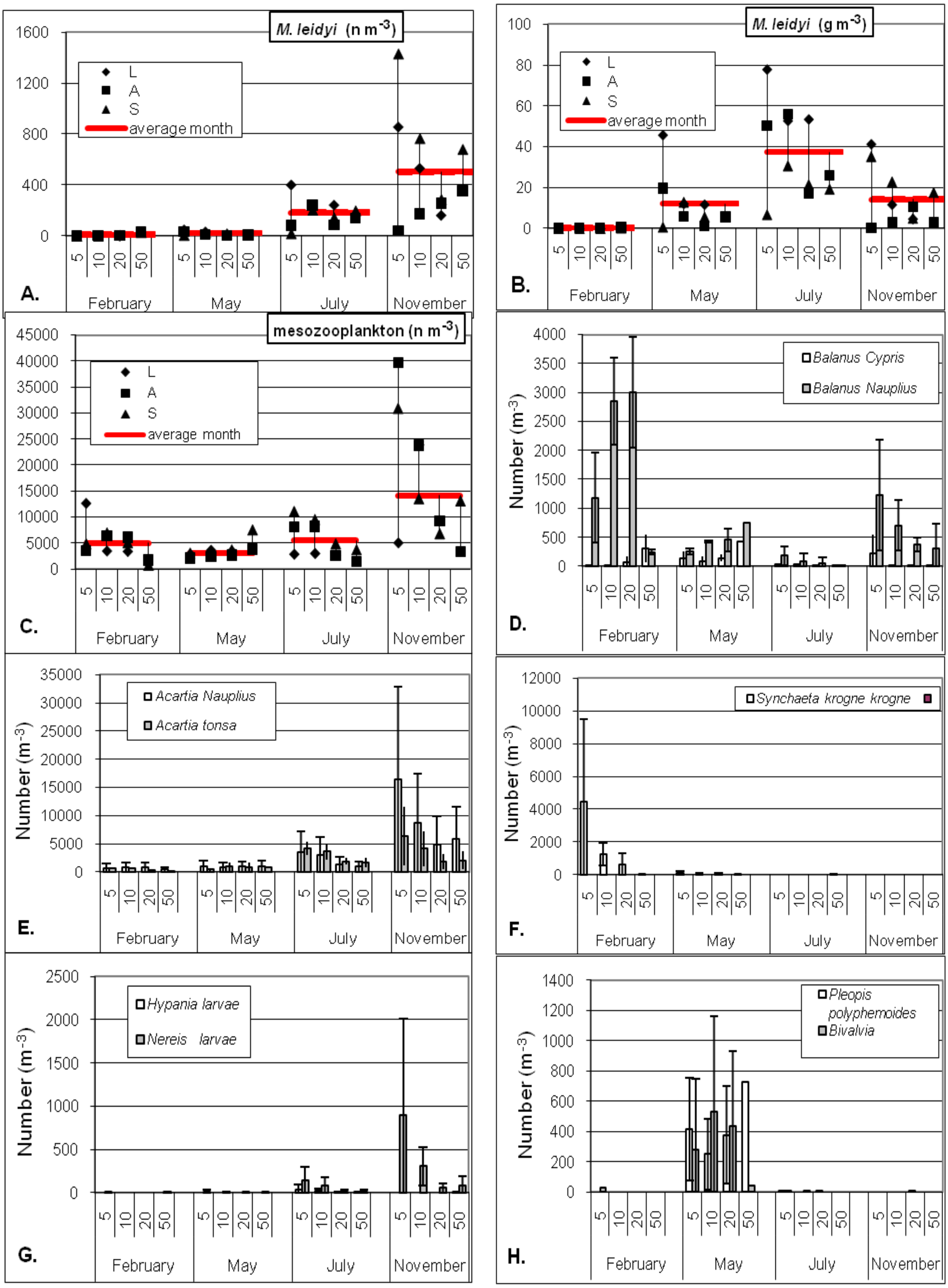

Figure 3: Seasonal fluctuations of *Mnemiopsis leidyi* (number m^{-3}, biomass g wet weight m^{-3}; original data) and dominant mesozooplankton taxa (average number m^{-3}) in the water column (bottom – surface) of stations with different total depth (5, 10, 20, 50 m) at transects off Lisar L, Anzali A and Sefidrood S during 2008.

Size of Mnemiopsis leidyi

The mean size of adult individuals of *M. leidyi* population varied between 20 and 30 mm; larger individuals were exceptional. The largest individual was 65 mm caught at station L2 in July 2008. Small individuals up to 5 mm dominated the population in all seasons during 2008 (Figure 4). This size group made up 100 % of all individuals in February and 98 % in November. Larger individuals occurred in higher proportions only in May and July. In May, the percentage of medium-sized (6–20 mm) and large individuals (≥ 20 mm) were the highest of the year (35 % and 10 % respectively). In July, the proportion of these size groups decreased to 12 % and 2 % respectively. In November, only 2 % of the individuals belonged to the medium-sized (6–20 mm) group, while large individuals (≥ 20 mm) contributed less than 1 % to the total abundance.

Mesozooplankton

A total of 23 mesozooplankton items, belonging to 18 taxa (mero– and holozooplankton) were found in the area under investigation (Table 3). Five of them, *Pleroxus trigenellus, Chydorus* sp., *Moina* sp., (all Cladocera), the Copepod *Cyclops* sp., and the Rotifera *Keratella cochlearis* were freshwater species which occurred in coastal areas (<10 m depth). Fish eggs and larvae were not identified to species level. The six meroplankton taxa consist of individuals of water spiders (Arachnida) and larvae of Bivalvia, Nematoda, Polychaeta (*Nereis* sp., *Hypania* sp.) and the multitudinous Cirripedia *Balanus* sp., represented by nauplius and cypris larvae (Table 3). The seven holoplankton taxa belong to Ciliata (*Tintinnopsis tubulosa*), Rotifera (*Brachionus plicatilis, Synchaeta krogne krogne*), Cladocera (*Podonevadne* sp., *Pleopis polyphemoides*) and Copepoda (*Ectinosoma concinnum* (Harpacticoida), *Acartia tonsa*). The most three abundant groups were Rotifera, Cirripedia, and the frequent Copepoda which made up 62% of all sampled individuals. In each group, only one species was very abundant: The Rotifera *Synchaeta krogne krogne* and the Cirripedia *Balanus* sp. dominated the mesozooplankton community in February (Table 3). The Copepod *Acartia tonsa* was the most dominant species of the whole plankton community of the study area (averaged over all seasons).

Seasonal fluctuation of mesozooplankton

The highest abundance of mesozooplankton species, with an average of more than 14,000 individuals per m^3, occurred in November; and the lowest in May (Figure 3C). In May, the total abundance accounted only for 1/5th of the average for November, while in February and July the total abundance was about 1/3rd of the November values. Owing to the high level standard deviations of the total monthly abundances (February: 63%; May: 19%; July: 59%; November: 86%), no detailed statements should be made according to the seasonal fluctuation (Table 3).

The total numbers of zooplankton per month depends strongly on blooming period of the nine following taxa: *Synchaeta krogne krogne* and *Balanus* sp. (nauplii and cypris larvae) bloomed in February (Figure 3D, F). Bivalvia species

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and *Pleopis polyphemoides* (Cladocera) bloomed in May (Figure 3H). The number of *Acartia tonsa* (including nauplii) and those of the polychaets *Hypania* sp. and *Nereis* sp. increased in July and peaked in November together with second peak of balanid nauplii (Figure 3D,E,G). The dominant species in November were *A. tonsa* and *Balanus* sp.. The seasonal fluctuation of *Acartia tonsa*, both adults and nauplii, displayed the same pattern as the number of *M. leidyi*, while the number of *Balanus* nauplii was negatively correlated with the number of *M. leidyi* (both correlations significant at 0.01 level; Spearman rang (2–tailed); Figure 3A,B,D,E). During their blooming period occurred the larvae of meroplankton (such as Bivalvia, Polychaeta, and *Balanus* sp.) in higher abundance at the near shore stations (5–20 m depth) as compared to those at the deep stations offshore (Figure 3D,G,H). The same observation applies for the nauplii of the holoplanktonic species *Acartia tonsa* which was more frequent at near shore stations (total depth: 5; 10 m) than at deep water stations (total depth 20; 50 m) in July and November (Figure 3E).

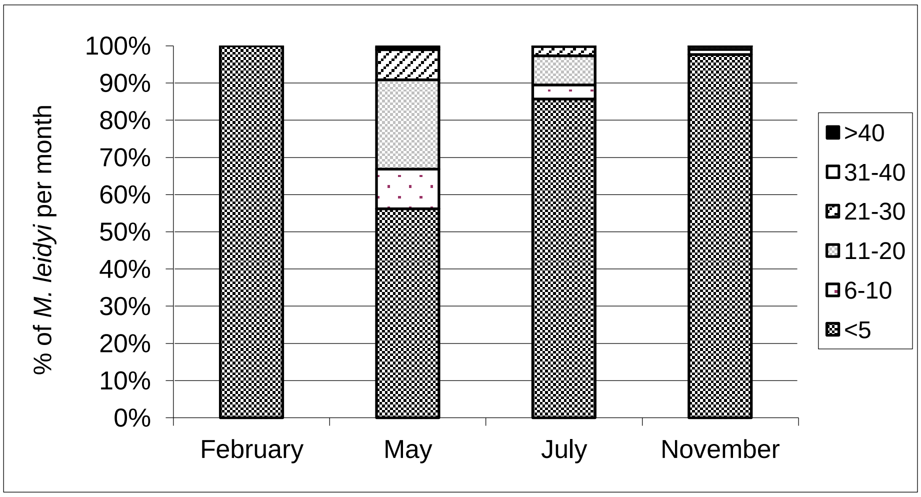

Figure 4: Size structure (total length) of *Mnemiopsis leidyi* population in the south-western Caspian Sea in different months of 2008 (Percentage of all measured individuals per month). The legend box indicates the length groups [mm].

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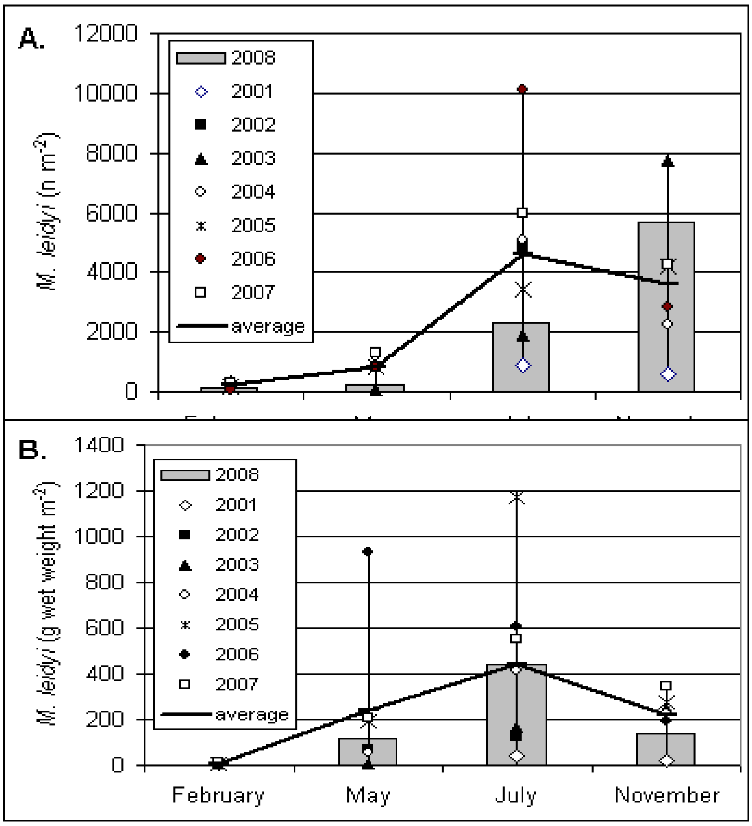

Figure 5: Seasonal fluctuation of the number and biomass of *Mnemiopsis leidyi* in the south- western Caspian Sea during 2001–2008 (averages per month). Column: values of 2008. Line: average per month (calculated from all monthly averages of all the years).

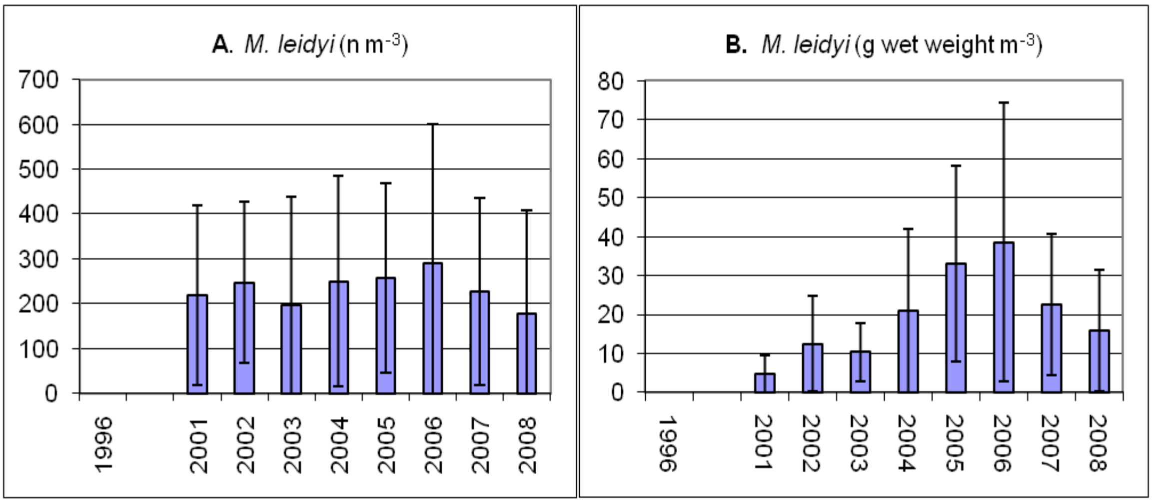

Figure 6: Fluctuation of the number and biomass of *Mnemiopsis leidyi* in the south-western Caspian Sea during 2001–2008 (Averages per year were calculated from the averages per month). Data of 2001–2007 from Bagheri et al. (2011).

Table 4: Average abundance of mesozooplankton taxa (number m^{-3}) per month collected in the south-western Caspian Sea during 2001–2008. Data 1996: Hossieni et al. (1996); data for *Lymnocalanus grimaldii* 2001: Shiganova et al. (2004); data 2001-2006: Roohi et al. (2008). h: holoplankton, m: meroplankton, nq: not quoted

			Hossieni *et al.* 1996	Roohi *et al.* 2008							present survey	
			1996	2001	2002	2003	2004	2005	2006	2007	2008	Std
h	Cladocera	*Polyphemus exiguus* Sars, 1897	83									
h	Copepoda	*Limnocalanus grimaldii* Guerne, 1886	5	few								
h	Copepoda	*Eurytemora minor* Sars, 1897	few									
h	Copepoda	*Calanipeda aquaedulcis* Kritchagin, 1873	85	1		1						
h	Copepoda	*Eurytemora grimmi* Sars, 1897	2172						5			
h	Ostracoda	Ostracoda larvae	nq	5	32	2	58					
m	Arachnida	Arachnida larvae	nq	14	170	3	8		0.3		0.03	*0.35*
h	Copepoda	*Ectinosoma concinnum (Harpacticoida)* Akatova, 1935	nq		3		1	11	0.4		1	*2*
m	Nematoda	Nematoda larvae	nq		13	133	208	150	75		0.45	*1.49*
m	Polychaeta	*Nereis* sp. Larvae Linnaeus, 1758	nq	573	435	12	13	38	9		108	*340*
m	Cirripedia	*Balanus* sp. Costa, 1778	439	86	661	387	723	328	277		852	*1027*
h	Cladocera	*Pleopis polyphemoides* Leuckart, 1859	237		450	1205	228	328	367		88	*209*
h	Copepoda	*Acartia tonsa including nauplii*	8502	6999	10360	6176	5370	8144	3975		5265	*7324*
h	Copepoda	*Acartia tonsa adult* Dana, 1849	5766								1968	*2313*
h	Copepoda	*Acartia tonsa nauplii*	2736								3297	*5282*
m	Bivalvia	Bivalvia larvae Linnaeus, 1758	5459		282	33	365	55	430		89	*266*
h	Cyclopidae	*Halicyclops sarsi* (Cyclopoida) Akatova, 1935	170	5	2	120	5	22	1			
m	Nematidae	Nematidae	nq		214	163	0	2	0,5			
m	Chironomidae	Chironomidae larvae	nq			5			4			
h	Mysidaceae	Mysidaceae larvae	nq						2			
h	Ciliata	*Tintinnopsis tubulosa* Levander, 1900	nq								9	*31*
m	Polychaeta	*Hypania* larvae (Terebellidae) Ostroumouw, 1897	nq								1	*2*
h	Rotifera	*Brachionus plicatilis* Müller, 1786	nq								1	*4*
h	Rotifera	*Synchaeta krogne krogne* Kasimov, 1997	nq								447	*1600*
h	Cladocera	*Podonevadne* sp. Gibitz, 1922	nq								0,07	*0,48*

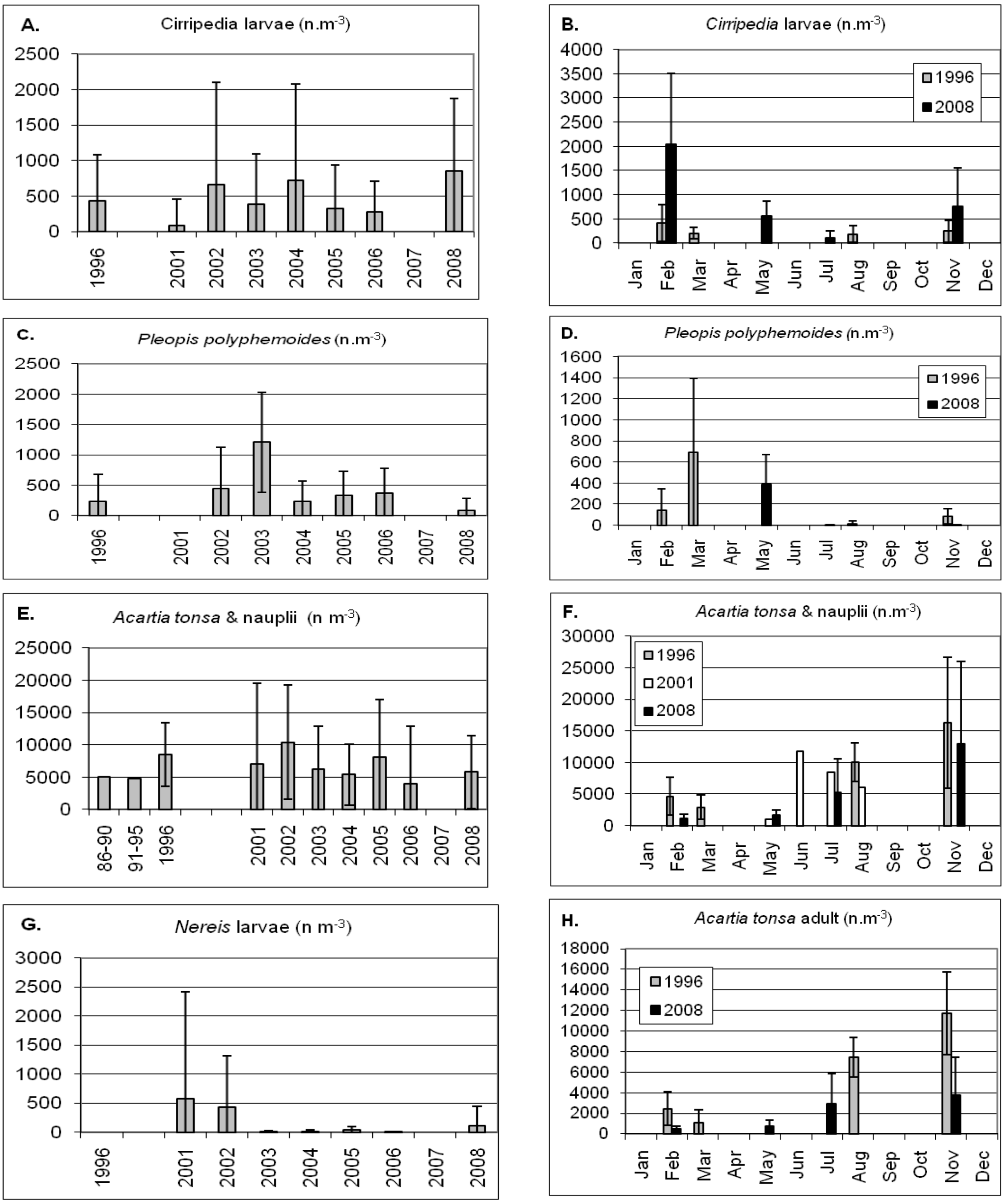

Figure 7: Annual and seasonal fluctuations of dominant mesozooplankton species in the southern Caspian Sea in comparison to other surveys. Data 1986–1995: Kurashova (2009); data 1996: Hossieni et al.(1996) listed in Roohi et al. (2008); data 2001 in Fig 7f: Shiganova et al. (2004).

Discussion

Hydrophysical characteristics

The surface water temperature was exceptionally low in February 2008 (average: 6.8°C); Figure 2B) as compared to long–term observations. (Roohi et al., 2008; Bagheri et al., 2011b, 2012: average > 10°C). This could be related to the harsh winter 2007/2008 with average high snow coverage of about 2.30 m for Guilan district (Anzali and Sefidrood regions). The exceptionally cold water temperature and the high salinity variation in February 2008 could be related to melt water input by rivers during this season. The high variation of salinity during November 2008 could be related to the high river inflow due to the high precipitation occurring during autumn (GWRO, 2010; Bagheri et al., 2010, 2011a). Depth and formation of the halocline and thermocline were not exceptional in 2008 (Roohi et al., 2008; Bagheri et al., 2011a). The oxygen supply in all water depths was more than sufficient in 2008. Since early 1980 the south western area of the Caspian Sea has become increasingly eutrophic (Salmanov, 1999; Sharifi, 1990; CEP, 2006; Stolberg et al., 2006; Bagheri, 2012). This trend was also visible in 2008; the nutrient load, e.g. N-NO_3 and P-PO_4, was in all months above the long term average of 2001–2006 (Table 2).

Mnemiopsis leidyi

The predominance of small individuals of < 10 mm (Figure 4) during all months is a characteristic for the *M. leidyi* population in the Caspian Sea, particularly in the southern part (Shiganova et al., 2004; Finenko et al., 2006; Roohi et al., 2008). According to Reusch et al. (2010) the population of the whole of the Caspian Sea is a genetically depleted version of the Black Sea population. The total average length of *M. leidyi* populations in other seas varies between 40–60 mm with a maximum length of > 150 mm (Purcell et al. 2001).In general *M. leidyi* displays pronounced seasonal fluctuations with low abundance in late winter until early spring and maximum values in summer to late autumn (Costello et al., 2006; Roohi et al., 2008; Javidpour et al., 2009b). However the start of the bloom and the spatial distribution are highly variable. For instance the bloom of *M. leidyi* started later in 2008 as compared to the long–term average of 2001–2007 (Figure 5). This might be attributed to the extreme cold winter 2007/2008 (Guilan Water Resource Organization, (GWRO, 2010; Bagheri, 2012). Thus, no *M. leidyi* was found at shallow coastal stations during February 2008. The bulk was concentrated in depth > 20 m (Figure 3A). This behaviour is typical for temperate habitats with a cold winter, and is likely a response to low surface temperature (Esser et al., 2004; Costello et al., 2006). Low temperatures during winter 2007/2008 could have delayed the reproduction of *M. leidyi*. Despite of that increased the biomass already to the 2001-2008 average in July, while the population number was below the long-term average until November 2008 when it reached maximum number (Figure 5). The average abundance and biomass of *M. leidyi* of about 182 ± 289 $ind^{.}m^{-3}$ (corresponding to 2079 ± 2978 $ind^{.}m^{-2}$) and 16 ± 20 $g^{.}m^{-3}$ (corresponding to 180 ± 289 $g^{.}m^{-2}$) wet weight were as

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well in the same range as estimated by Roohi et al. (2008) for the southern Caspian Sea during 2003–2006.

Mesozooplankton

As compared to earlier surveys of Hossieni et al. (1996) and Roohi et al. (2008) carried out in the southern Caspian Sea, major changes in mesozooplankton community became obvious after 2000. The comparison of our findings with those of both earlier surveys was not easy since the area of monitoring and the composition of the species lists were different by all contributing authors. Hossieni et al. (1996)'s sampling area was the largest. Roohi et al. (2008) and we sampled within Hossieni's sampling area. Hossieni et al. (1996) sampled 18 transects in the whole southern Caspian Sea during 1996. Roohi et al. (2008) investigated during 2001-2006 the same area as we did and additional transects in the area which Hossieni sampled. In years 2001–2002 Roohi' area under investigation was smaller than our investigated area. Roohi et al. (2008) calculated the annual averages of abundance and biomass of the mesozooplankton and presented them together with the data of Hossieni et al. (1996) in tables (their tables 4a – 4d). The comparison of our findings with those of both earlier surveys was a bit problematic since the species list of Hossieni et al. (1996) and Roohi et al. (2008) was not uniform (Table 4). Hossieni et al. (1996) did not list the following species, which were sampled in subsequent years: Ostracoda larvae, Arachnida larvae, Harpacticoida *(Ectinosoma concinnum),* Nematoda larvae, *Nereis* larvae, Nematidae and Chironomidae. During our 2008 survey, *Tinntinopsis tubulosa* Levander, 1900 (Cilliata), *Brachionus plicatilis* (Rotifera), *Synchaeta krogne krogne* (Rotifera), *Podonevadne* sp. (Cladocera) and *Hypania* larvae (Terebellidae, Polychaeta) were documented, but these taxa were not listed by Hossieni et al. (1996) and Roohi et al. (2008). Further on Roohi et al. (2008) presented the total number of *Acartia tonsa* including their larval stages while Hossieni et al. (1996) and we split up *Acartia tonsa* into nauplii and adult stages (Table 4). Therefore, it was difficult to state how the total number of the species changed in detail. Furthermore no statements could be made for species which were collected in small numbers or which were marked by high and irregularly annual fluctuations as Arachnida larvae, *Halicyclops sarsi* Akatova, 1935 (Cyclopoida), Harpacticoida, Nematidae and Oligochaeta larvae (in the present paper "Nematoda larvae"). Overall, the situation may be described as follows.

The number of Cladocera species was drastically reduced in 2008 as compared to the findings of Hossieni et al. (1996): He listed 24 Cladocera species which were known in the southern Caspian Sea, including the dominant species *Polyphemus exiguous* Sars, 1897. Only two of them (*Pleopis polyphemoides*, *Podonevadne* sp.) could be found in 2008. Five Copepoda species were present in 1996, of them four were not or hardly found during 2001–2008: *Limnocalanus grimaldii* Guerne, 1886, *Eurytemora minor* Behning, 1938, *Calanipeda aquaedulcis* Kritchagin, 1873, and *Eurytemora grimmi* Sars, 1897 (Table 4).

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A marked decrease of *Eurytemora grimmi* was striking. It was present in 1996 with the number of 2172 m^{-3} and has not been found since 2001, except five individuals in 2006. Ostracoda larvae listed by Roohi et al. (2008) during 2001–2004 did not occur during 2005–2006, and were also not found in our 2008 survey. A marked decline was also observed for Bivalvia larvae, which decreased by one order of magnitude after 1996. Only three dominate taxa which were numerous in 1996 (Hossieni et al., 1996) were more or less in the same range during 2001–2008: *Balanus* sp. larvae (Cirripedia), *Pleopis polyphemoides* (Cladocera), and *Acartia tonsa* (Copepoda) (Table 4). For these three species, the annual and seasonal fluctuation should be compared. The total annual average number of larval Cirripedia was higher in 2008 as compared to the previous years (Figure 7A). The high number in 2008 was achieved due to the high abundance in February and November (Figure 7B). *Pleopis polyphemoides* was found in almost constant numbers during 1996–2006 but with high standard variations (Figure 7C). In 2008, it was present in low numbers (annual average number) as compared to previous years. The reason was that this species occurred in moderate numbers only in May 2008 (386 $ind^{.}m^{-3}$). In February 2008, it was not found; however in July and November it was only present with 2 and 1 $ind^{.}m^{-3}$ respectively (Figure 7D). *Acartia tonsa* invaded Caspian Sea in the beginning of 1980s and spread over the whole of the Caspian Sea during 1980s (Kurashova, 2009). It occurred with the number of 4971 and 4722 $ind^{.}m^{-3}$ in the southern Caspian Sea during 1986–1990 and 1991–1995 (Tinenkova et al., 2000). According to Kurashova (2009), the invasion of *A. tonsa* had a positive effect on the enhancement of fish food. On the other hand, it took over the ecological niche of *Calanipeda aquaedulcis*, which led to a decline in its population.

During 1996, 2001 and 2008 *Acartia tonsa* displayed similar seasonal pattern (Figure 7F,H): Low number (below 5000 $ind^{.}m^{-3}$) in February and May, an increase in number until summer, with a further increase in November (12000–14000 $ind^{.}m^{-3}$ including nauplii and copepodites). By comparing the seasonal fluctuation of the *A. tonsa* stock with and without nauplii it became obvious that the number of nauplii masked the real situation of the *A. tonsa* stock (Figure 7F, H). These larvae, produced in high numbers in certain periods of the year, displayed a high mortality and distributional patchiness. Therefore, the compilation of these volatile larvae assemblages is not very meaningful in order to assess the long-term development of the population. This became obvious by comparing the annual means of the abundance of *A. tonsa* (including nauplii and copepodites) from 1986–2008 (Figure 7E): the annual average number of *A. tonsa* displayed no drastic changes in the southern Caspian Sea (data from Kurashova (2009); Hossieni et al. (1996); Roohi et al. (2008), and present survey). The total number was in the same range in 2008 as in the preceding period. But the differences between 1996 and 2008 became obvious when only the adults of *A. tonsa* in were considered. The number was significantly

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smaller in all seasons of 2008 as compared to 1996. In 2008, the number was reduced 3 fold in summer and November, and 5 fold in February as compared to 1996 (Figure 7H). The decrease in species diversity and individual number of mesozooplankton species in the southern Caspian Sea could be attributed to voracious feeding of *Mnemiopsis leidyi* (Roohi et al., 2008), and to environmental degradation (Dumont, 1995). The ability of *M. leidyi* to control zooplankton abundance is well recorded (Burrell and van Engel, 1976; Kremer, 1994; Finenko et al., 2006; Costello et al., 2006).

Limited low temporal resolution of sampling regime (once in a season) reduced the ability to draw conclusions regarding the impact of *M. leidyi* on mesozooplankton populations during 2008. Despite of our limited findings in 2008, the large number and biomass of *M. leidyi* during summer and autumn recorded since 2001 undoubtedly has had an impact on the abundance of mesozooplankton species (Shiganova et al., 2004; Kideys et al., 2005; Finenko et al., 2006; Roohi et al., 2010). It was striking that many species which were abundant in the Caspian Sea before 2000 were not found after the invasion of *M. leidyi* (Table 4). However, a similar drastic decline in species numbers was not observed in other invaded seas (Purcell et al., 2001). Possible reasons could be that the endemic Caspian Sea fauna is very sensitive to disruptions of invader species such as *Acartia tonsa* or *M. leidyi* (Kideys et al., 2005; Shiganova et al., 2005), or to that serious environmental degradation which started since the beginning of the 1990s (Dumont, 1995).

The decline of mesozooplankton diversity in relation to environmental parameters (e g. eutrophication and chemical pollution) was not extensively investigated up to now (Kideys et al., 2008; Bagheri et al., 2011a; Bagheri, 2012). Because the southern Caspian Sea is influenced to a great extent by fresh water inflow bringing a heavy load of artificial nutrients, an estimate to what extent the increased eutrophication affects the phyto– and zooplankton community, is required. Further on it is well known that jellyfish and ctenophore blooms coincide with human proliferations and environmental perturbations (Purcell, 2012).

Environmental impacts including pollution by herbicides and pesticides should be assessed in combination with the impact of *Mnemiopsis leidyi* on pelagic communities. It may be assumed that the increasing nutrient input into the south western Caspian Sea enhanced the phytoplankton production (Salmanov, 1999; Bagheri et al., 2012) leading to an increased food supply for zooplankton. Consequently, zooplankton stocks, such as *A. tonsa*, should enhance their production. This production may be supported along with the marked decline of small pelagic fish species, which are the primary consumer of mesozooplankton (Daskalov and Mamedov, 2007; Roohi et al., 2010). However, an increase in abundance of *A. tonsa* and other mesozooplankton species was not observed. Thus it could be assumed that *M. leidyi* may have

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consumed the surplus production of *A. tonsa* and other species.

The influence of atmospheric teleconnection patterns (climate changes) on the Pontocaspian region, and hence on the ecosystem of Caspian Sea cannot be disregarded (Rodionov, 1994; Polonsky et al., 2004; Niermann, 2004). Recent observations in other seas indicate that altering abundance of jellyfish and copepods, such as *Acartia tonsa*, can be related to climatic variability (Sullivan et al., 2007).

The survey documented the spatial and seasonal distribution of the zooplankton in the south western Caspian Sea in 2008. In comparison with previous publications the long-term fluctuation of dominant mesozooplankton species were accessed for the first time.

An attempt to access the development of the whole zooplankton community of the southern Caspian Sea since 1996 was dissatisfying because the data of the previous surveys were too heterogeneous. We request that the outcome of future surveys should be more standardized. Uniform species lists should be created and the annual and seasonal fluctuation, especially the blooming period of each species should be verified. A comparison of annual averages of the total mesozooplankton should be avoided. A central database should be established, in order that a long-term comparison of exactly the same areas and species could be extracted. Considering the huge environmental changes during the past 20 years, it is not sufficient to relate the changes of the mesozooplankton community only to the impact of *M. leidyi*. In future studies, the effects of eutrophication, environmental degradation, and changes to hydrology and teleconnections should be taken into consideration as well.

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