

Size structure of zooplankton ingested by four commercially important bivalves

Daria EZGETA-BALIĆ^{1*}, Melita PEHARDA¹, John DAVENPORT²,
Olja VIDJAK¹ and Josip BOBAN¹

¹*Institute of Oceanography and Fisheries, P.O. Box 500, 21000 Split, Croatia*

²*School of Biological, Earth and Environmental Sciences, University College Cork, Cork, Ireland*

*Corresponding author, e-mail: ezgeta@izor.hr

*Some bivalve molluscs are capable of zooplankton ingestion; however that aspect of their ecology is still relatively poorly studied. The objective of this investigation was to contribute to the understanding of size structure of zooplankters ingested by four commercially important bivalve species co-occurring in the same area. The study was performed in Mali Ston Bay – the most important bivalve aquaculture area in the eastern Adriatic Sea – from May 2009 to April 2010. We analyzed sizes of zooplankton ingested by cultured blue mussel *Mytilus galloprovincialis* and European flat oyster *Ostrea edulis*, and naturally-occurring bearded mussel *Modiolus barbatus* and Noah's Ark shell *Arca noae*. Ingested zooplankton ranged in maximum linear dimension from 60.1 to 1398.5 μm . Zooplankton found in stomach contents of *M. galloprovincialis* and *O. edulis* suspended in the water column showed a wider size range than zooplankton found in stomachs of bottom living *M. barbatus* and *A. noae*. Sizes of ingested zooplankton significantly differed between *O. edulis* and the other three species.*

Key words: bivalvia, Adriatic Sea, bivalve aquaculture, bivalve feeding, zooplankton

INTRODUCTION

During the last few years several studies have pointed out that zooplankton can be an important food source for bivalve molluscs (e.g. DAVENPORT *et al.*, 2000; LEHANE & DAVENPORT, 2002, 2004; ZELDIS *et al.*, 2004; ALFARO, 2006; LEHANE & DAVENPORT, 2006; DAVENPORT *et al.*, 2011; PEHARDA *et al.*, 2012) especially during periods of the year when phytoplankton biomass is low (CRANFORD & GRANT, 1990; LANGDON & NEWELL, 1990; EZGETA-BALIĆ *et al.*, 2012). Bivalves ingest a broad range of zooplankton taxonomic groups including tintinnids,

naupliar and post-naupliar stages of copepods, cladocerans, hydromedusa, gastropod larvae, bivalve larvae, and juvenile stages of decapod crustaceans (e.g. KRŠINIĆ & MUŠIN 1981; LEHANE & DAVENPORT, 2002; ZELDIS *et al.*, 2004; TROOST *et al.* 2008; PEHARDA *et al.*, 2012). Ingested zooplankton usually reflect the zooplankton composition of the surrounding water, however some differences are known to occur in respect to bivalve species and size (e.g. ALFARO, 2006; DAVENPORT *et al.*, 2011; PEHARDA *et al.*, 2012).

Numerous studies showed that bivalves are capable of selective particle feeding, but the reasons why some particles are ingested and

other rejected is still unknown, though it has been suggested that selection could be based on shape, size, nutritive value or presence of chemical components on the organisms' surfaces (e.g. SHUMWAY *et al.*, 1985; PRINS *et al.*, 1991; MACDONALD & WARD, 1994; BOUGRIER *et al.*, 1997; YAHEL *et al.*, 2009). In the case of zooplankton as bivalve prey, zooplankton size has been suggested as a major selection factor (LEHANE & DAVENPORT, 2006; MAAR *et al.*, 2008), but few studies have analyzed zooplankton size structure in the stomach contents of bivalves.

In a recent study PEHARDA *et al.* (2012) confirmed ingestion of zooplankton by adult bivalves in the Mali Ston Bay and gave a detailed qualitative and quantitative composition of zooplankton in bivalve stomach contents but didn't investigate size of the ingested zooplankton. Present research is a continuation of that study, with the objective to investigate size range of zooplankton ingested by commercially important bivalve species that co-exist in same area and are therefore potential competitors for food. Further on, in a present study size range of zooplankters in the surrounding water column was investigated to determine whether size selection was taking place.

MATERIAL AND METHODS

Research took place from May 2009 to April 2010 in Mali Ston Bay, south Adriatic (Fig. 1). Specimens of *Mytilus galloprovincialis* Lamarck, 1819 and *Ostrea edulis* Linnaeus, 1758 were collected from an aquaculture farm (CP - Cultured Population - 42°51'45 N, 17°40'59 E) at depths of 2 m and 5 m, respectively, while *Modiolus barbatus* (Linnaeus, 1758) and *Arca noae* Linnaeus, 1758 were collected using SCUBA from the seabed (NP - Natural Population 42°51'49 N, 17°40'59 E) at depths ranging from 2 to 4 m. Each month, 20 specimens had their tissue processes stopped by injecting 70% ethanol into the mantle cavity. Stomach contents were later collected through a slit in the digestive gland by Pasteur pipette and fixed with a few drops of 36% formalin

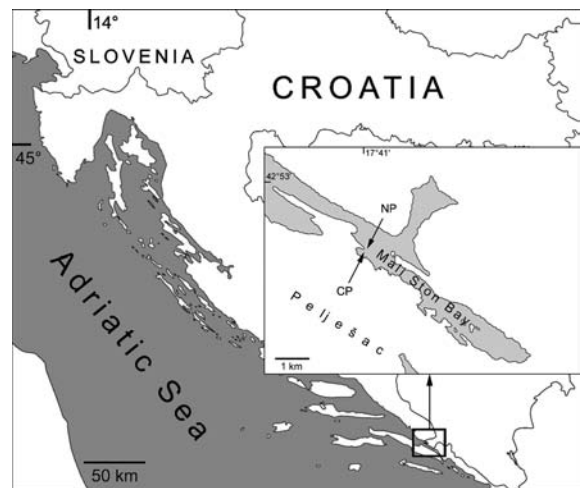


Fig. 1. Study sites in Mali Ston Bay (CP-cultured populations; NP-natural populations)

(for detailed procedure see PEHARDA *et al.*, 2012). For size analysis of zooplankton we used all bivalve specimens that had zooplankton in their stomach content. This made a total of 236 individuals of *M. galloprovincialis*, 186 individuals of *O. edulis*, 149 individuals of *M. barbatus* and 110 individuals of *A. noae*. Mean lengths (with SD) of analyzed specimens were: *M. galloprovincialis* 65.1±4.3 mm, *Ostrea edulis* 59.9±6.5 mm, *Modiolus barbatus* 51.3±3.2 mm and *A. noae* 56.1±3.9 mm. Water column zooplankton was contemporaneously sampled at CP station using a fine plankton net (diameter: 35 cm; mesh size: 53 µm) hauled vertically from near-bottom (depth of 7 m) to the surface. Samples were preserved in 2.5% formaldehyde-seawater solution, previously buffered with CaCO₃. Zooplankton organisms from stomach content and from subsamples of water column (1/16 of the sample) were observed under a binocular photomicroscope (Olympus SZX 12) with an integrated camera. A digital image of each recorded zooplanktonic organism was taken. Measurement was performed using AxioVision software for image processing and the maximum linear size of each organism was established. Descriptive statistics for the size of each group of zooplankters were obtained. In comparisons amongst species and seasons, statistical tests were only performed on zooplankton groups for which it was measured more than 30 specimens

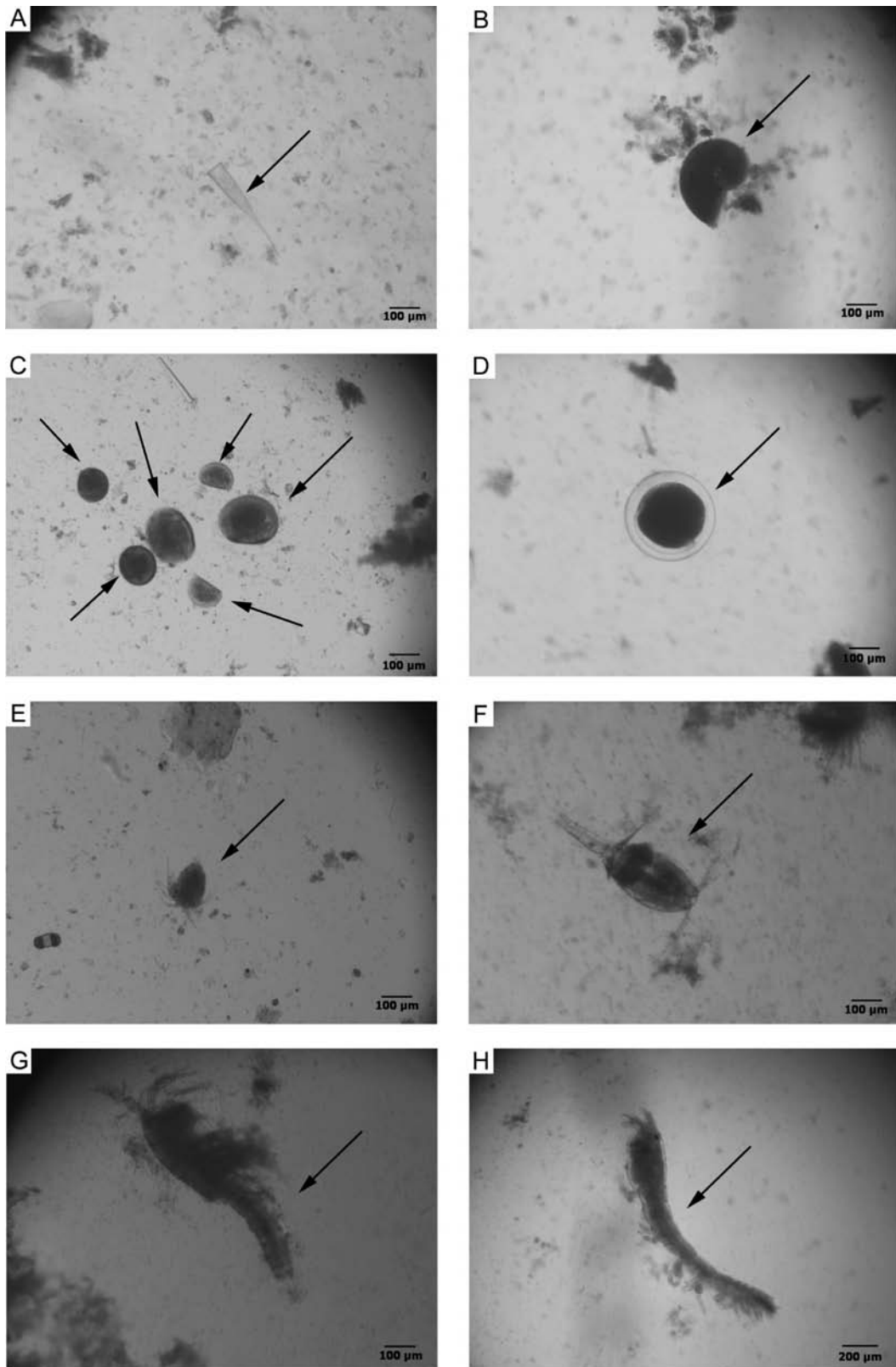


Fig. 2. Images of zooplankton from bivalve stomach contents (a) tintinnid, (b) gastropod larvae, (c) bivalve larvae, (d) egg, (e) nauplius, (f) calanoid copepod, (g) harpacticoid copepod, (h) anisopod

Bivalve species		<i>Mytilus galloprovincialis</i>			<i>Ostrea edulis</i>			<i>Modiolus barbatus</i>			<i>Arca noae</i>		
Zooplankton group	N	mean ± st. dev. (µm)	range (µm)	N	mean ± st. dev. (µm)	range (µm)	N	mean ± st. dev. (µm)	range (µm)	N	mean ± st. dev. (µm)	range (µm)	
Foraminifera	6	153.0±61.9	93.6-244.9	-	-	-	10	147.0±55.9	84.9-270.7	5	155.1±45.5	84.1-210.5	
Tintinnids	247	117.9±72.0	64.4-360.4	45	123.7±82.1	70.6-373.5	55	112.7±66.0	75.7-365.9	5	75.3±6.4	69.2-86.2	
Copepod nauplii	65	171.6±54.3	94.1-326.7	32	211.8±83.0	87.4-481.6	-	-	-	2	174.9±55.7	135.5-214.3	
Copepodits and adult copepods	308	399.9±97.3	208.7-922.9	452	431.9±114.9	160.5-1108.8	24	396.6±80.9	249.8-556.2	14	366.3±76.0	241.8-519.5	
Gastropod larvae	219	142.9±39.6	78.2-320.7	14	204.2±60.0	116.8-303.5	13	212.8±70.0	120.1-299.9	2	141.9±10.9	134.2-149.7	
Bivalve larvae	3298	143.9±34.3	66.7-439.6	940	145.8±36.8	70.1-381.5	319	147.0±33.9	73.3-348.0	74	150.4±28.5	96.5-239.9	
Unidentified egg	321	113.3±48.7	60.1-284.0	84	111.9±55.2	65.0-245.3	115	120.5±54.4	61.2-295.5	159	133.9±53.5	60.8-284.4	
Anisopoda	-	-	-	1	1398.5	-	-	-	-	-	-	-	
Total zooplankton		158.3±81.8	60.1-922.9		228.5±151.6	65.0-1398.5		150.6±73.2	61.2-556.2		150.7±71.4	60.8-519.5	

Table 1. Sizes (maximum linear dimensions) of zooplankters present in the stomach content of four bivalve species collected at Mali Ston Bay, Croatia

during the research period. Exception was made only for comparison of copepods size among *M. barbatus* and *A. noae* where test was performed on data set with less than 30 measured zooplankters. Seasonal differences in size of ingested zooplankton within species were tested using the Kruskal-Wallis test, while Mann-Whitney U tests were performed to test differences between species. Selection ratio was calculated as ratio of zooplankton size in stomach content and size of zooplankton from water column.

RESULTS

A variety of zooplankton taxa were present in the stomach contents of the four studied bivalve species (Fig. 2). Zooplankton ingested by *Mytilus galloprovincialis* and *Ostrea edulis* suspended in the water column showed a wider size range than those ingested by bottom living *Modiolus barbatus* and *Arca noae* (Table 1). Sizes of contemporaneous water column zooplankton are given in Table 2 while Table 3 presents calculated selection ratio. Although there were differences in zooplankton size in the stomach content of the four bivalve species studied (Fig. 3), they were not all statistically significant. Size of all ingested zooplankton significantly differed between *O. edulis* and

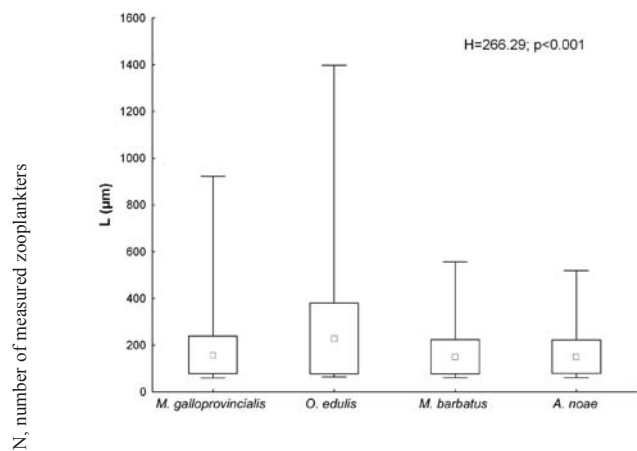


Fig. 3. Sizes of all zooplankters found in the stomachs of the four investigated bivalve species. The square points represent mean values, boxes are standard deviations, while whiskers represent the range between minimum and maximum sizes

Table 2. Sizes of the zooplankton present in water column

Zooplankton group	N	mean \pm st. dev. (μm)	range (μm)
Zooplankton groups found also in bivalve stomach contents			
Foraminifera	18	137.2 \pm 108.4	64.1-460.6
Tintinnids	318	174.6 \pm 99.9	49.2-623.6
Copepod nauplii	1065	143.9 \pm 44.3	55.3-441.5
Copepodites and adult copepods	791	421.6 \pm 168.3	148.4-2324.4
Gastropod larvae	32	181.4 \pm 105.5	60.1-634.2
Bivalve larvae	533	134.9 \pm 38.8	59.3-327.4
Crustacean larvae	8	1837.5 \pm 1014.3	677.8-4089.6
Zooplankton groups found only in the water column			
Actinula larvae	7	237.1 \pm 58.9	167.4-319.3
Polychaete larvae	29	245.5 \pm 240.9	86.3-1226.9
Cnidaria larvae	1	735.8	-
Pilidium larvae	1	705.1	-
Echinodermata larvae	7	593.3 \pm 433.5	232.8-1515.1
Cladocera	12	420.9 \pm 163.8	290.6-817.8
Hydrozoa	7	1654.9 \pm 1611.8	619.9-4956.7
Tunicata	20	1019.3 \pm 427.3	354.7-1964.0
Total zooplankton		242.5 \pm 231.3	49.2-4956.7

N, number of measured zooplankters

Table 3. Selection ratio for investigated bivalve species calculated as ratio of mean size of zooplankton found in stomach content and mean size of zooplankton in water column

Zooplankton group	<i>Mytilus galloprovincialis</i>	<i>Ostrea edulis</i>	<i>Modiolus barbatus</i>	<i>Arca noae</i>
Foraminifera	1.12	-	1.07	1.13
Tintinnids	0.68	0.71	0.65	0.43
Copepod nauplii	1.19	1.47	-	1.22
Copepodites and adult copepods	0.95	1.02	0.94	0.87
Gastropod larvae	0.79	1.13	1.17	0.78
Bivalve larvae	1.07	1.08	1.09	1.11

Table 4. Results of Mann-Whitney U test of difference amongst sizes of zooplankters ingested by bivalves (4 species) and zooplankters of the water column

	<i>M. galloprovincialis</i>	<i>O. edulis</i>	<i>M. barbatus</i>	<i>A. noae</i>
<i>O. edulis</i>				
All zooplankton	***			
Tintinnids	n.s.			
Copepod nauplii	**			
Copepodites and adult copepods	***			
Gastropod larvae	-			
Bivalve larvae	*			
Unidentified eggs	n.s.			
<i>M. barbatus</i>				
All zooplankton	n.s.	***		
Tintinnids	n.s.	n.s.		
Copepod nauplii	-	-		
Copepodites and adult copepods	-	-		
Gastropod larvae	-	-		
Bivalve larvae	*	n.s.		
Unidentified eggs	n.s.	n.s.		
<i>A. noae</i>				
All zooplankton	n.s.	***	n.s.	
Tintinnids	-	-	-	
Copepod nauplii	-	-	-	
Copepodites and adult copepods	-	-	n.s.	
Gastropod larvae	-	-	-	
Bivalve larvae	-	-	n.s.	
Unidentified eggs	***	**	*	
Water column				
Tintinnids	***	***	***	-
Copepod nauplii	***	***	-	-
Copepodites and adult copepods	n.s.	***	-	-
Gastropod larvae	n.s.	-	-	-
Bivalve larvae	***	***	***	***
Unidentified eggs	-	-	-	-

* p<0.05; ** p<0.01; ***p<0.001; n.s., non significant; -, test was not performed

the other three species (Table 4). The largest zooplanktonic organisms ingested by all species except *O. edulis* were calanoid and harpacticoid copepods whose maximal length was 922.9 µm in stomach content of *M. galloprovincialis*, 1108.8 µm in *O. edulis*, 556.2 in *M. barbatus* and 519.4 in *A. noae*. In the stomach contents of *O. edulis* the biggest zooplankter was an anisopod crustacean (Anisopoda) that was 1398.5 µm

in length. In the water column, besides zooplankton groups that were also found in bivalve stomachs, other larger zooplanktonic taxa (e.g. tunicata, echinodermata larvae and hydrozoa) were present (Table 2). Sizes of bivalve larvae in the water column and in the stomach contents of suspended bivalve species differed significantly with respect to season, while such differences were not observed for stomach contents of

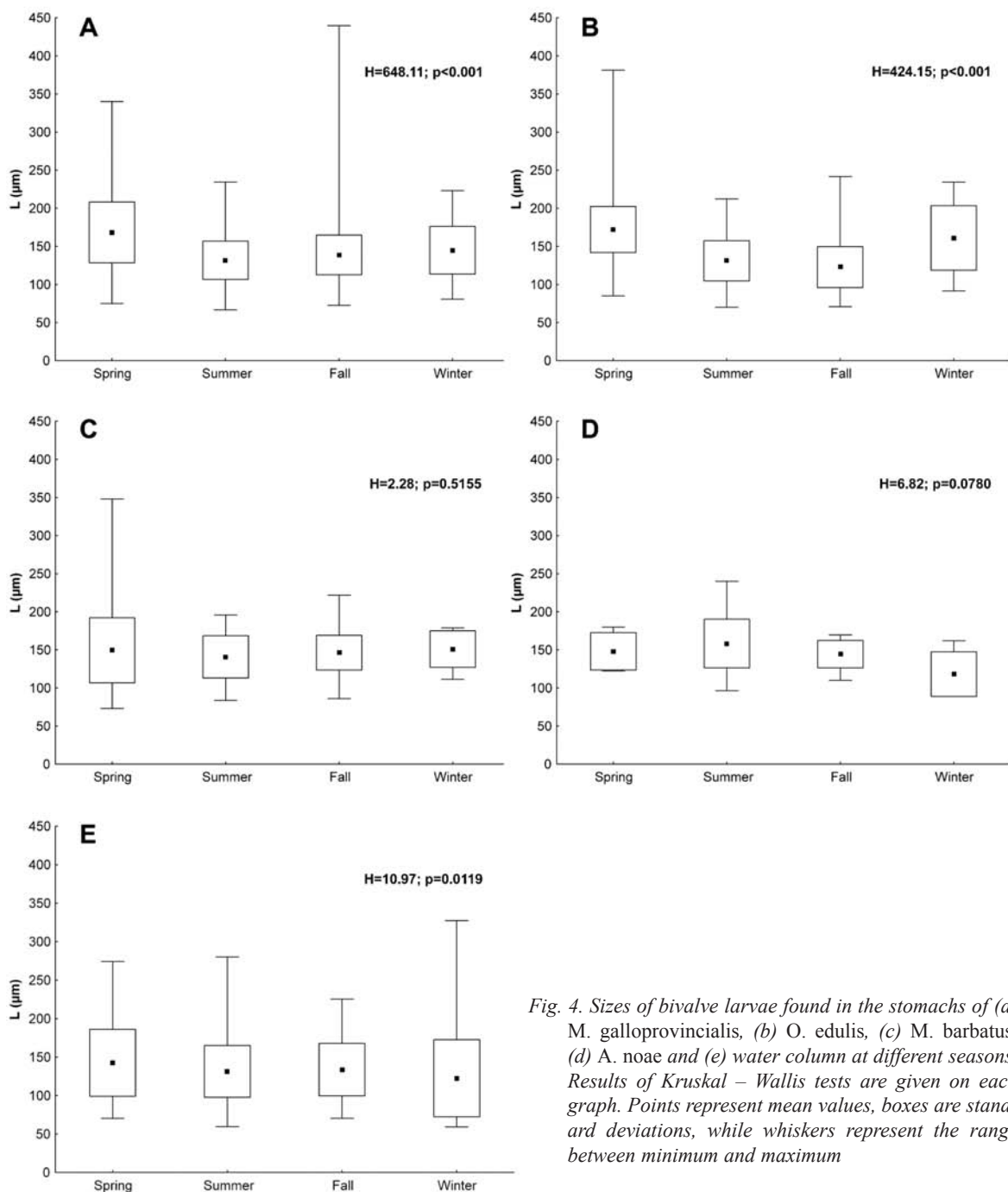


Fig. 4. Sizes of bivalve larvae found in the stomachs of (a) *M. galloprovincialis*, (b) *O. edulis*, (c) *M. barbatus*, (d) *A. noae* and (e) water column at different seasons. Results of Kruskal – Wallis tests are given on each graph. Points represent mean values, boxes are standard deviations, while whiskers represent the range between minimum and maximum

bivalves (*M. barbatus*, *A. noae*) sampled from the seabed (Fig. 4). Furthermore, Kruskal – Wallis tests revealed significant seasonal differences between size of copepods in the water column and in the stomach contents of *M. galloprovincialis*, while size of copepods ingested by *O. edulis* did not show similar significant seasonal

differences (Fig. 5). Due to the low number of copepods in the stomach contents of *M. barbatus* and *A. noae*, seasonal comparisons were not possible. Detailed results of zooplankton size comparisons among the stomach contents of all species and of the water column are presented in Table 4.

Table 5. Review of available data on size of ingested zooplankters by different bivalve species

Bivalve species	Location	Position	Mean size of bivalves	Mean size of ingested zooplankters	Maximal size of ingested zooplankters	Source
<i>M. edulis</i>	Great Cumbrae Island, Scotland	Suspended	2.03 cm	~ 440 μ m	-	LEHANE & DAVENPORT, 2002
<i>M. edulis</i>	Great Cumbrae Island, Scotland	Suspended	3.54 cm	~ 540 μ m	-	LEHANE & DAVENPORT, 2002
<i>M. edulis</i>	Great Cumbrae Island, Scotland	Suspended	5.32 cm	~ 580 μ m	up to 3 mm	LEHANE & DAVENPORT, 2002
<i>M. edulis</i>	Great Cumbrae Island, Scotland	Benthic	3.18 cm	~ 480 μ m	-	LEHANE & DAVENPORT, 2002
<i>M. edulis</i>	Great Cumbrae Island, Scotland	Benthic	5.31 cm	~ 500 μ m	-	LEHANE & DAVENPORT, 2002
<i>M. edulis</i>	Bantry Bay, Ireland	Suspended	5.89 cm	-	up to 6 mm	LEHANE & DAVENPORT, 2006
<i>A. opercularis</i>	Great Cumbrae Island, Scotland	Benthic	6.34 cm	~ 320 μ m	-	LEHANE & DAVENPORT, 2002
<i>A. opercularis</i>	Great Cumbrae Island, Scotland	Suspended	6.38 cm	~ 450 μ m	-	LEHANE & DAVENPORT, 2002
<i>C. edule</i>	Great Cumbrae Island, Scotland	Suspended	1.82 cm	~ 220 μ m	-	LEHANE & DAVENPORT, 2002

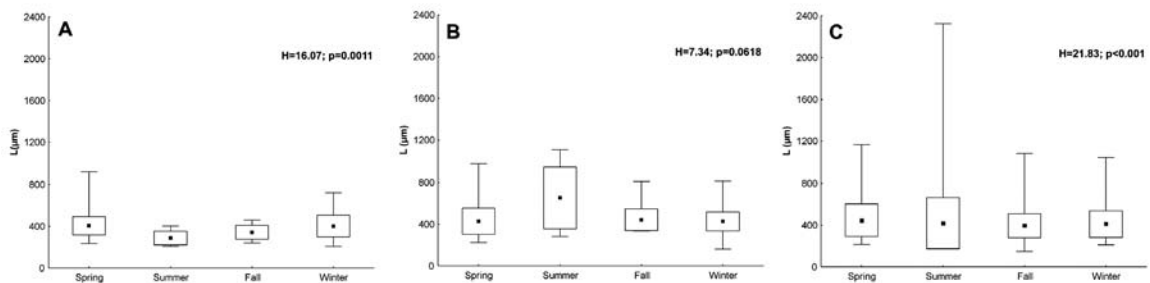


Fig. 5. Size of calanoid and harpacticoid copepods found in the stomachs of (a) *M. galloprovincialis*, (b) *O. edulis* and (c) water column at different seasons. Results of Kruskal – Wallis tests are given on each graph. Points represent mean values, boxes are standard deviations, while whiskers represent the range between minimum and maximum

DISCUSSION

Bivalves as filter feeding organisms have a direct impact on the phytoplankton communities (e.g. NOREN *et al.*, 1999; OGILVIE *et al.*, 2003) and for a long time it was assumed that their impact on the zooplankton is only indirect through competition for the phytoplankton as a food source. During the last decade studies on the zooplankton as additional food source revealed that bivalves are capable of removing different fraction of zooplankton and thus also have a direct impact on their abundance (e.g. MAAR *et al.*, 2008; DAV-

ENPORT *et al.*, 2011; PEHARDA *et al.*, 2012). In the aquaculture areas, like the Mali Ston Bay, where bivalves are present in the high densities, knowledge about impact of bivalves on the plankton communities is crucial for understanding of ecosystem functioning and sustainable aquaculture. Our data confirmed that all four investigated species are capable to ingest zooplankton of different sizes and thus can have impact on zooplankton community structure. All four bivalve species were also able to ingest larval stages of benthic organisms, including gastropods and bivalves, what can have negative impact on their

recruitment. Further on, study showed that suspended species, *Mytilus galloprovincialis* and *O. edulis* consumed larger sized zooplankton than bottom living species. Size of bivalves, position in the water column, turbidity of water, filtration rate, and different selection process are some of the factors that might affect the size structure of zooplankton ingested (e.g. HAWKINS *et al.*, 1999; JAMES *et al.*, 2001; LEHANE & DAVENPORT, 2002; OGILVIE *et al.*, 2003; ALFARO, 2006; TROOST *et al.*, 2009; JONSSON *et al.*, 2009). Comparing our data (Table 1) with data available for other bivalve species (Table 5) it is clear that all four species investigated in this study consumed much smaller size zooplankton. Furthermore, the largest organism recorded in stomach content in our study was four times smaller than the largest zooplankters so far reported from *M. edulis* stomach contents. In a recent study DAVENPORT *et al.* (2011) found that diet composition of noble fan shell *Pinna nobilis* Linnaeus, 1758 differed significantly with respect to shell size, while in the case of *Mytilus edulis* (LEHANE & DAVENPORT, 2002) there were no significant differences in prey lengths observed among different size classes of mussels. Differences in prey length were noticed in two groups of similarly-sized *Aequipecten opercularis* - suspended scallops consumed prey of greater length in comparison with those living on the seabed (LEHANE & DAVENPORT, 2002). Taken together, these observations suggest that there is no simple linkage between bivalve and prey sizes.

Furthermore, as it was expected, in our study the mean size of all zooplankters from the water column was higher than the mean sizes ingested by bivalves. However, when we observed selection ratio of different components of the zooplankton community, we found that ratio was >1 for some groups, particularly bivalve larvae and copepod nauplii, what indicate larger size of those groups in the stomach contents than in the water column, suggesting selection for greater prey size. Results of our study showed that the mean size of ingested bivalve larvae was in fact greater than that found in the water column for all investigated species. Ingestion of bivalve larvae is particularly interesting as

it can be associated with cannibalism and possible population limitation (PEHARDA *et al.*, 2012). LEHANE & DAVENPORT (2004) found that bivalve larvae collected by plankton net near mussel culture lines in Bantry Bay, Ireland were larger on average than those found in stomach samples. Furthermore, differences in respect to bivalve larvae size were noticed for *Perna canalicula* Gmelin, 1791 by ALFARO (2006) who found that mussels consumed greater amounts of smaller than larger bivalve larvae. Our data (Table 1), together with other available data (Table 6), suggest that there are variations in size of ingested bivalve larvae and that there are no consistent findings and differences among species or environmental conditions. However, it can be concluded that the sizes of ingested bivalve larvae indicate that adult bivalves are able to feed on different larval stages and thus may have negative impacts on recruitment. Consequently this can affect bivalve aquaculture production in an area where production still exclusively depends on spat collected from the nature, as the case in Mali Ston Bay.

Copepod nauplii made up one of the most abundant components of zooplankton in the water column, but they were not abundant in the stomachs (PEHARDA *et al.*, 2012). Previous studies described that, with increasing naupliar age and size, their escape speed increases (TITELMAN & KIØRBOE, 2003). Lower clearance rates on later and larger copepod naupliar stages were reported in the case of *M. edulis* (GREEN *et al.*, 2003), perhaps suggesting that they were more difficult to catch. In contrast, in our study, a higher mean size of nauplii was recorded in stomach contents than in the water column, which can be due to easier decomposition of smaller nauplii (CAROTENUTO *et al.*, 2006), but equally could reflect selection for larger prey. The recent study of JONSSON *et al.* (2009) did not find significant differences in escape coefficient between early and late naupliar stages; they also found that larger adult copepods (which are caught by bivalves) showed significantly higher escape coefficient than nauplii, suggesting that it is unlikely that naupliar escape capability has much influence on catchability/selection by bivalve molluscs.

JONSSON *et al.* (2009) also showed that increased turbulence of water decreased copepods' ability to detect and escape an actively filtering mussel and that adult copepods were the only stages that managed to escape at the highest turbulence levels. Beside escape reactions, effect of copepods on siphon closure could be the reason why larger copepods were rarely present in the stomach contents. DAVENPORT *et al.* (2000) recorded different reactions of the inhalant siphon when *M. edulis* were fed upon *Artemia* sp. nauplii (300 µm) and upon harpacticoid copepods *Tigriopus brevicornis* (1-1.2 mm). When nauplii touched the siphon margins there was little or no sign of reaction. In contrast, when larger harpacticoid copepod touched the siphonal tentacles there was immediate siphon closure followed by a degree of shell-valve adduction. This response meant that only *T. brevicornis* that didn't touch the margins of the siphon were ingested. In our study, copepods were the largest zooplankton found in the stomach contents of the bivalve species (except in *O. edulis*), but their size range was lower than that recorded for copepods sampled from the water column. Such size selection in an aquaculture area where bivalves are present at high abundance could cause changes in water column zooplankton composition. This has previously been recorded in the Ría de Vigo, NW Spain by MAAR *et al.* (2008), who identified changes in zooplankton composition around mussel farms, and reported that depletion was most severe for copepod nauplii and copepodites and that relative depletion decreased with increasing zooplankton size.

Above mentioned studies on size of ingested zooplankton pointed out that size selection in favour of smaller organisms occurred; in general this was also confirmed with our results. Like in the other studies, in our study larger organisms were only found sporadically. Furthermore, this study showed inter-species differences in the size of ingested zooplankton, and revealed that *O. edulis* have the ability to feed on larger components of the zooplankton community. In Mali Ston Bay, *O. edulis* and *M. galloprovincialis* are cultured in suspension in the same area and at the similar depths; they thus share the same food sources and compete for food. Although the sizes of ingested zooplankters by these two species overlapped, the ability of *O. edulis* to feed upon larger zooplankters may perhaps decrease competition between the two cultured species, with consequent positive effects on production.

ACKNOWLEDGEMENTS

This research was financed with support from the Croatian "Unity Through Knowledge Grant" 3A "Bivalve feeding, competition and predation – what is at play" and by Croatian Ministry of Science and Technology grant No. 001-0013077-0532 "Biodiversity and sustainable management of pelagic and demersal resources in the Adriatic". The authors are grateful to Maro FRANUŠIĆ, Nela SINJKEVIĆ, Margita RADMAN for technical assistance with sample collection, and to Barbara ZORICA and Vanja ČIKEŠ KEČ for their patience and help in sample processing.

REFERENCES

- ALFARO, A.C. 2006. Evidence of cannibalism and benthic-pelagic coupling within the life cycle of the mussel, *Perna canaliculus*. *J. Exp. Mar. Biol. Ecol.*, 329: 206-217. doi: dx.doi.org/10.1016/j.jembe.2005.09.002
- BOUGRIER, S., A.J.S. HAWKINS & M. HERAL. 1997. Preingestive selection of different microalgal mixtures in *Crassostrea gigas* and *Mytilus edulis*, analysed by flow cytometry. *Aquaculture*, 150: 123-134. doi:10.1016/S0044-8486(96)01457-3
- CAROTENUTO, Y., A. IANORA, M. DI PINTO & D. SARNO. 2006. Annual cycle of early developmental stage survival and recruitment in the copepods *Temora stylifera* and *Centropages typicus*. *Mar. Ecol. Prog. Ser.*, 314: 227-238. doi: 10.3354/meps314227
- CRANFORD, P.J. & J. GRANT. 1990. Particle clear-

- ance and absorption of phytoplankton and detritus by the sea scallop *Placopecten magellanicus* (Gmelin). *J. Exp. Mar. Biol. Ecol.*, 137: 105–121. doi: 10.1016/0022-0981(90)90064-J
- DAVENPORT, J., D. EZGETA-BALIĆ, M. PEHARDA, S. SKEJIĆ, Ž. NINČEVIĆ-GLADAN & S. MATIJEVIĆ. 2011. Size-differential feeding in *Pinna nobilis* L. (Mollusca: Bivalvia): Exploitation of detritus, phytoplankton and zooplankton. *Est. Coast. Shelf. Sci.*, 92: 246-254. doi:10.1016/j.ecss.2010.12.033
- DAVENPORT, J., R.J.J.W. SMITH & M. PACKER. 2000. Mussels *Mytilus edulis*: significant consumers and destroyers of mesozooplankton. *Mar. Ecol. Prog. Ser.*, 198: 131-137. doi:10.3354/meps198131
- EZGETA-BALIĆ, D., M. NAJDEK, M. PEHARDA & M. BLAŽINA. 2012. Year-round comparative analysis of food origin in four commercially important bivalves by fatty acid profiling. *Aquaculture*, 334-337: 89-100. doi: 10.1016/j.aquaculture.2011.12.041
- GREEN, S., A.W. VISSER, J. TITELMAN & T. KIØRBOE. 2003. Escape responses of copepod nauplii in the flow field of the blue mussel, *Mytilus edulis*. *Mar. Biol.*, 142: 727–733. doi:10.1007/s00227-002-0996-1
- HAWKINS, A.J.S., M.R. JAMES, R.W. HICKMAN, S. HATTON & M. WEATHERHEAD. 1999. Modelling of suspension-feeding and growth in the green-lipped mussel *Perna canaliculus* exposed to natural and experimental variations of seston availability in the Marlborough Sounds, New Zealand. *Mar. Ecol. Prog. Ser.*, 191: 217–232. doi:10.3354/meps191217
- JAMES, M.R., M.A. WEATHERHEAD & A.H. ROSS. 2001. Size-specific clearance, excretion, and respiratory rates, and phytoplankton selectivity for the mussel *Perna canaliculus* at low levels of natural food. *N. Z. J. Mar. Freshw. Res.*, 35: 73–86. doi: 10.1080/00288330.2001.951697
- JONSSON, A., T.G. NIELSEN, I. HRUBENJA, M. MAAR & J.K. PETERSEN. 2009. Eating your competitor: functional triangle between turbulence, copepod escape behavior and predation from mussels. *Mar. Ecol. Prog. Ser.*, 376: 143-151. doi:10.3354/meps07817
- KRŠINIĆ, F & D. MUŠIN. 1981. Microzooplankton of Mali Ston Bay and Malo more. In: J. Roglić & M. Meštrov (Editors). Proceedings of the symposium on Mali Ston Bay. Dubrovnik, Croatia, 12-24th November 1981, Yugoslav Academy of Science and Arts, Zagreb, pp. 108- 119.
- LANGDON, C.J. & R.I.E. NEWELL. 1990. Utilization of detritus and bacteria as food sources by two bivalve suspension-feeders, the oyster *Crassostrea virginica* and the mussel *Geukensia demissa*. *Mar. Ecol. Prog. Ser.*, 58: 299–310.
- LEHANE, C. & J. DAVENPORT. 2002. Ingestion of mesozooplankton by three species of bivalve; *Mytilus edulis*, *Cerastoderma edule* and *Aequipecten opercularis*. *J. Mar. Biol. Ass. U.K.*, 82: 615–619. doi: 10.1017/S0025315402005957
- LEHANE, C. & J. DAVENPORT. 2004. Ingestion of bivalve larvae by *Mytilus edulis*: experimental and field demonstrations of larviphagy in farmed blue mussels. *Mar. Biol.*, 145: 101-107. doi: 10.1007/s00227-003-1290-6
- LEHANE, C. & J. DAVENPORT. 2006. A 15-month study of zooplankton ingestion by farmed mussels (*Mytilus edulis*) in Bantry Bay, Southwest Ireland. *Est. Coast. Shelf. Sci.*, 67: 645-652. doi: dx.doi.org/10.1016/j.ecss.2005.12.015
- MAAR, M., T.G. NIELSEN & J.K. PETERSEN. 2008. Depletion of plankton in a raft culture of *Mytilus galloprovincialis* in Ría de Vigo, NW Spain. II. Zooplankton. *Aquat. Biol.*, 4: 127-141.
- MACDONALD, B.A. & J.E. WARD. 1994. Variation in food quality and particle selectivity in the sea scallop *Placopecten magellanicus* (Mollusca: Bivalvia). *Mar. Ecol. Prog. Ser.*, 108: 251–264.
- NOREN, F., J. HAAMER & O. LINDAHL. 1999. Changes in the plankton community passing a *Mytilus edulis* mussel bed. *Mar. Ecol. Prog. Ser.*, 191:187–194. doi:10.3354/meps191187
- OGILVIE, S.C., A.H. ROSS, M.R. JAMES & D.R.

- SCHIEL. 2003. In situ enclosure experiments on the influence of cultivated mussels (*Perna canaliculus*) on phytoplankton at times of high and low ambient nitrogen. *J. Exp. Mar. Biol. Ecol.*, 295: 23–39. doi: dx.doi.org/10.1016/S0022-0981(03)00275-2
- PEHARDA, M., D. EZGETA-BALIĆ, J. DAVENPORT, N. BOJANIĆ, O. VIDJAK & Ž. NINČEVIĆ-GLADAN. 2012. Differential ingestion of zooplankton by four species of bivalves (Mollusca) in Mali Ston Bay, Croatia. *Mar. Biol.*, 159: 881–895. doi: doi:10.1007/s00227-011-1866-5
- PRINS, T.C., A.C. SMALL & A.J. POWWER. 1991. Selective ingestion of phytoplankton by the bivalves *Mytilus edulis* L. and *Cerastoderma edule* (L.). *Hydrobiol. Bull.*, 25: 93–100. doi: 10.1007/BF02259595
- SHUMWAY, S.E., T.L. CUCCI, R.C. NEWELL & C.M. YENTSCH. 1985. Particle selection, ingestion, and absorption in filter-feeding bivalves. *J. Exp. Mar. Biol. Ecol.*, 91: 77–92. doi: 10.1016/0022-0981(85)90222-9
- TITELMAN, J. & T. KIØRBOE. 2003. Predator avoidance by nauplii. *Mar. Ecol. Prog. Ser.*, 247: 137–149. doi: 10.3354/meps247137
- TROOST, K., P. KAMERMANS & W. WOLFF. 2008. Larviphagy in native bivalves and an introduced oyster. *J. Sea. Res.*, 60: 157–163. doi: dx.doi.org/10.1016/j.seares.2008.04.006
- TROOST, K., E.J. STAMHUIS, L.A. VAN DUREN & W.J. WOLFF. 2009. Feeding current characteristics of three morphologically different bivalve suspension feeders, *Crassostrea gigas*, *Mytilus edulis* and *Cerastoderma edule*, in relation to food competition. *Mar. Biol.*, 156: 355–372. doi: 10.1007/s00227-008-1088-7
- YAHIEL, G., D. MARIE, P.G. BENINGER, S. ECKSTEIN & A. GENIN. 2009. In situ evidence for pre-capture qualitative selection in the tropical bivalve *Lithophaga simplex*. *Aquat. Biol.*, 6: 235–246. doi: 10.3354/ab00131
- ZELDIS, J., K. ROBINSON, A. ROSS & B. HAYDEN. 2004. First observations of predation by New Zealand Greenshell mussels (*Perna canaliculus*) on zooplankton. *J. Exp. Mar. Biol. Ecol.*, 311: 287–299. doi: dx.doi.org/10.1016/j.jembe.2004.05.019

Received: 9 January 2012
Accepted: 26 September 2012

Veličinska struktura zooplanktonskog plijena kod četiri gospodarski značajne vrste školjkaša

Daria EZGETA-BALIĆ^{1*}, Melita PEHARDA¹, John DAVENPORT²,
Olja VIDJAK¹ i Josip BOBAN¹

¹*Institut za oceanografiju i ribarstvo, P.P. 500, 21000 Split, Hrvatska*

²*Fakultet bioloških znanosti, znanosti o Zemlji i okolišu, Sveučilište Cork, Irska*

*Kontakt adresa, e-mail: ezgeta@izor.hr

SAŽETAK

Iako neki školjkaši imaju sposobnost hranjenja zooplanktonom, taj aspekt ekologije školjkaša još uvijek je relativno slabo istražen. Svrha ovog istraživanja bila je pridonijeti poznavanju veličinske strukture zooplanktonskog plijena kod četiri gospodarski značajne vrste školjkaša koje žive na istom području. Istraživanje je provedeno od svibnja 2009. do travnja 2010. u Malostonskom zaljevu – najvažnijem području za uzgoj školjkaša u istočnom dijelu Jadranskog mora. Analizirana je veličina zooplanktona konzumiranog od strane uzgajanih vrsta dagnje *Mytilus galloprovincialis* i kamenice *Ostrea edulis* te vrsta koje na tom području žive u prirodnim populacijama dlakave dagnje *Modiolus barbatus* i kunjke *Arca noae*. Veličina konzumiranog zooplanktona kretala se u rasponu od 60,1 do 1398,5 µm. Veličinski raspon zooplanktona pronađenih u želucima vrsta *M. galloprovincialis* i *O. edulis* suspendiranim u vodenom stupcu bio je veći od zooplanktona pronađenog u želucima vrsta *M. barbatus* i *A. noae*. Statistički značajna razlika u veličini konzumiranog zooplanktona pronađena je između vrste *O. edulis* i tri ostale vrste.

Ključne riječi: školjkaši, Jadransko more, uzgoj školjkaša, ishrana školjkaša, zooplankton