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Description of bivalve community structure in the Croatian part of the Adriatic Sea - hydraulic dredge survey

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Hydraulic dredge surveys of bivalve communities in the Croatian part of the Adriatic Sea were conducted from the Island of Rab in the north to the river Neretva estuary in the south during 2007 and 2008. The main objective of the study was to describe distribution and community structure of bivalves on soft sediments along the eastern Adriatic, primarily focusing on commercially important species in five main bivalve harvesting areas. A total of 105 hydraulic dredge samples were collected at depths ranging from 1 to 11 m. Sampled bivalves were separated in the field and frozen for later laboratory analysis that included species identification, abundance and biomass determination. Live specimens of 54 bivalve taxa were collected during this study, while 87 taxa were represented by empty shells. Shells of the non-indigenous bivalve Anadara demiri *were recorded for the first time in the Croatian part of the Adriatic Sea. In terms of biomass and abundance the dominant species were* Acanthocardia tuberculata, Callista chione, Chamelea gallina, Glycymeris bimaculata, G. glycymeris, G. violascens, Laevicardium oblongum, Modiolus barbatus, Mytilus galloprovincialis, Ostrea edulis *and* Venus verrucosa. *Statistically significant differences were noted in bivalve communities in the five main sampling areas including the island of Rab, Pag bay, Kaštela bay, Cetina estuary and Neretva estuary.*

Key words: bivalvia, distribution, Adriatic Sea, hydraulic dredge

INTRODUCTION

Although bivalves are an ecologically and economically important marine group of organisms relatively little is known about their distribution and community structure in the eastern Adriatic Sea. Previous studies focused primarily on compiling lists of species for specific regions (HRS-BRENKO *et al.*, 1998; ŠILETIĆ, 2006) or aspects of the biology and ecology of selected species (MLADINEO *et al.*, 2007; PEHARDA *et al.*, 2007).

Methods for surveying the distribution and abundance of bivalves include the use of quadrants, benthic corers, grab samplers, dredging and trawling gear, and underwater photography and TV (GOSLING, 2003). Each of these methods has its advantages and disadvantages depending on the main objectives of the survey, the surface area to be surveyed, substrate type and target species (GOSLING, 2003). Sampling with a dredge enables the surveying of wider geographic areas in a reasonable time and provides general information about the marine communities (CASTELLI *et al.*, 2004). In the eastern Adriatic, JUKIĆ *et al.* (1998) conducted a survey using a hydraulic dredge and provided general data on the distribution of several commercially important bivalves such as *Chamelea gallina*, *Venus verrucosa* and *Callista chione*.

In Croatia, bivalves are primarily harvested by SCUBA and apnea diving, while Rampon (beam trawl) and hydraulic dredge use is limited to the northern open Adriatic Sea. In the last decade an increase in exploitation of natural bivalve populations has occurred in the Croatian part of the Adriatic (MATIJACA, pers. comm.) and there is the potential that overexploitation of this important marine resource will occur in the near future. Therefore, the objective of the present study was to determine the distribution of bivalves on soft sediments along the eastern Adriatic and to describe their community structure, primarily focusing on commercially important species in the five main bivalve harvesting areas. The aim of the study was to collect baseline data needed for setting up a permanent monitoring of bivalve resources.

MATERIAL AND METHODS

Field surveys were conducted by hydraulic dredge "vongolara" during 2007 and 2008 in order to collect data on composition, distribution and biomass of shellfish communities in the eastern Adriatic. In total, 105 quantitative samples were collected at depths ranging from 1 to 11 m, from the island of Rab in the north to the Neretva river estuary in the south (Fig. 1). Sampling started in August 2007 in the Neretva area, continued in May 2008 in the Cetina river estuary and in Kaštela bay and ended with sampling around the islands of Pag and Rab in October and November 2008. Sampling locations were chosen according to previous studies (JUKIĆ *et al.* 1998) and current information on bivalve harvesting (FURČIĆ, pers. comm.). The number of hauls at different locations was determined on site depending on size of the area surveyed, sediment type and results of previous hauls. The horizontal dredge opening was 2.2 m and the length of haul varied from 25 to 40 m. Cutting depth of the blade was 15 cm and average haul duration was 5 minutes. Three types of grid distances (parallel bar spacing) were used, depending on sampling site and substrate: 11 mm (1), 20 mm (2) and 8 mm (3).

Collected samples were frozen and stored for laboratory analysis that included species identification, abundance and biomass determination. Biomass (wet weight) and abundance values were reported per square meter (g/m^2 and ind/m^2, respectively). Abundance and biomass values are presented as mean values per location. In the laboratory, the collected bivalves were identified according to TEBBLE (1966), NORDSIECK (1969), PARENZAN (1974, 1976), D'ANGELO & GARGIULLO (1987), POUTIERS (1987) and POPPE & GOTO (2000), while for classification and nomenclature purposes the European Register of Marine Species was used (COSTELLO *et al*., 2001). Live individuals of each species were counted and weighed, while the presence of empty shells by species was noted.

Grain-size fractions of surface sediment were determined with the combined method of sieving and hydrometering. Sediment type was determined according to the FOLK (1954) classification. Gravimetric methods were used to determine organic matter and carbonate content (VDOVIĆ, 1990; LORING & RANTALA, 1992). Sediment data are presented as general descriptions of the surveyed sites and due to unbalanced sampling design no attempt was made to statistically link sediment and bivalve data.

Bivalve assemblage structures at five main sampling areas including the island of Rab (Sahara beach, Rajska beach, Kamporska draga, and Barbat channel), Pag bay, Kaštela bay (Pantan, Jadro mouth and Barbarinac), Cetina estuary and Neretva estuary were analyzed using the PRIMER software package (CLARKE & WARWICK, 1994). Biomass data, expressed as wet weight of bivalves, were transformed using log(x+1) transformation and the Bray-Curtis similarity matrix was used to generate a 2-dimensional ordination plot with the non-metric multidimensional scaling (nMDS) technique. ANOSIM 1-way test was applied for testing differences in species assemblages between sampling stations (CLARKE & WARWICK, 1994). The probability value was set at 0.05.

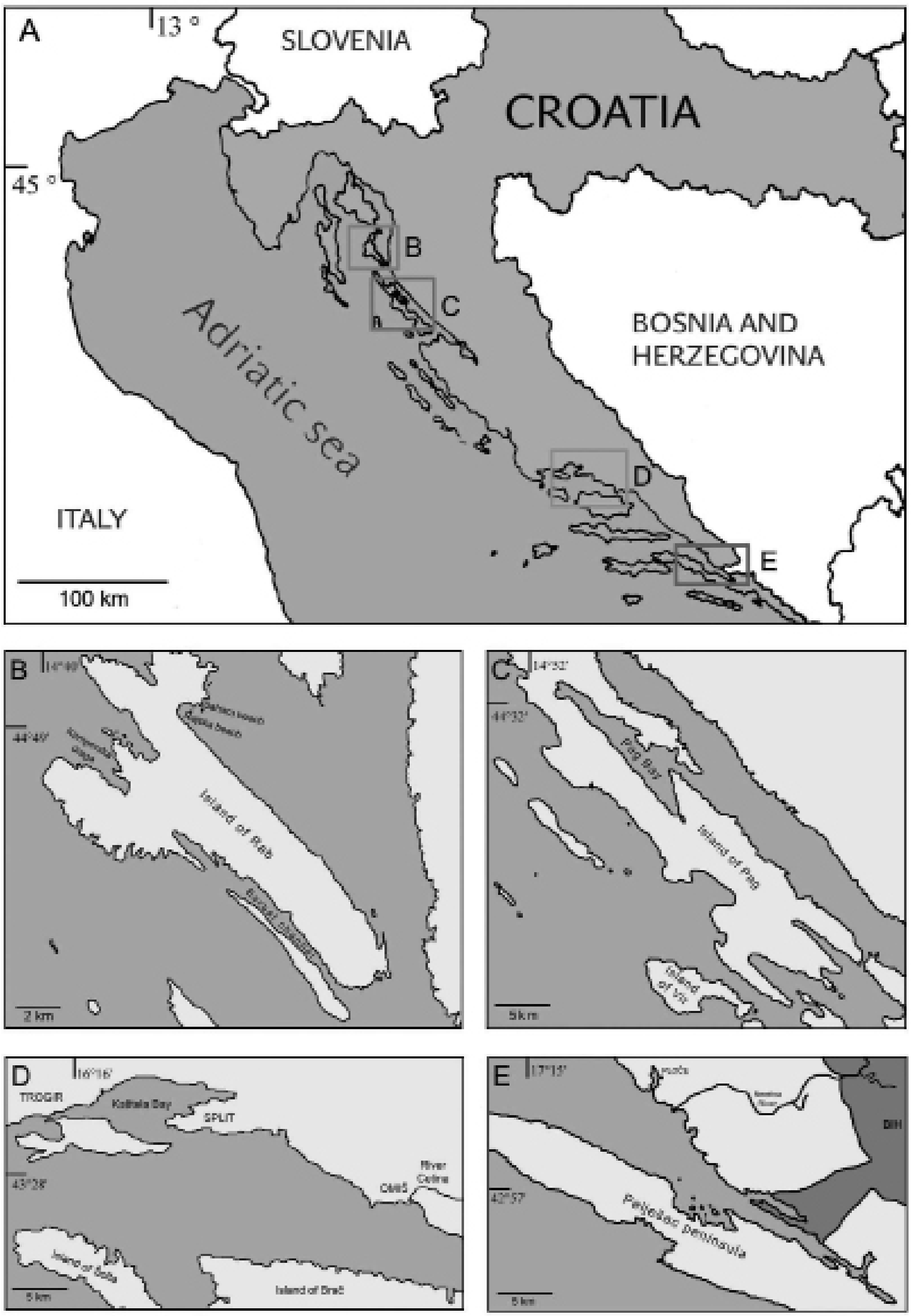

Fig. 1. Geographic location of the investigated area: A. Adriatic Sea, B. Island of Rab, C. Island of Pag, D. Kaštela bay and Cetina estuary and E. Neretva river estuary

Table 1. Sediment characteristics at sampling areas. Dredge type - grid distances used: 11 mm (type 1), 20 mm (type 2), 8 mm (type 3), Mz – mean particle size

Location	Area	Date	Dredge type	N of hauls	N of sed. samples	Mz (μm)	Gravel (%)	Sand (%)	Mud (%)	Sediment type*	Organic matter (g/kg)	Carbonate (g/kg)
Sahara beach	Rab	11.08.	3	3	2	50.31	2	49	49	(g)mS	33.44	120.00
Rajska beach	Rab	11.08.	3	3	1	130.61	0	96	4	S	7.99	30.00
Kamporska Draga	Rab	11.08.	2	4	2	106.47	0	82	18	mS	12.45	73.64
Barbat channel	Rab	10.08.	2	4	2	507.35	16	75	9	gmS	15.67	768.34
Pag bay	Pag	10.08.	2	16	6	557.54	16	69	15	gmS	13.72	798.82
Vir		10.08.	2	3	1	59.81	5	61	34	(g)mS	33.64	728.50
Pag-Vir		10.08.	2	2	1	248.27	2	89	9	(g)S	26.30	775.07
Jasenovo bay		10.08.	2	6	1	46.61	4	54	42	(g)mS	35.91	699.38
Starigrad-Paklenica		10.08.	2	5	3	1122.68	29	42	29	gmS	29.96	781.01
Nin bay		10.08.	2	7	2	160.41	5	84	11	gmS	10.74	659.99
Stara Povljana		10.08.	2	7	5	501.03	23	60	17	gmS	24.54	750.12
Vlašić bay		10.08.	2	7	2	224.73	3	84	13	(g)mS	14.43	742.87
Pantan	Kaštela	05.08.	1	3	1	21.25	3	54	43	(g)mS	41.90	603.00
Jadro mouth	Kaštela	05.08.	1	3	1	20.38	4	52	44	(g)mS	62.20	537.00
Barbarinac	Kaštela	05.08.	1	3	2	30.45	5	46	49	(g)sM	40.20	700.00
Cetina estuary	Cetina	05.08.	1-2	19	3	70.24	4	62	34	(g)mS	26.60	672.27
Neretva estuary – sand	Neretva	08.07.	1	8	-							
Neretva estuary – sea grass	Neretva	08.07.	1	2	-							

*Sediment types: S-sand; mS-muddy sand; gmS- gravelly muddy sand; (g)S- slightly gravelly sand; (g)sM-slightly gravelly sandy mud; (g)mS- slightly gravelly muddy sand

RESULTS

Sediment characteristics including data on sediment composition, sediment type, organic matter content and carbonates are presented in Table 1. Sediment types determined included slightly gravelly muddy sand, gravelly muddy sand, sand, muddy sand, slightly gravelly sand, and slightly gravelly sandy mud. Organic matter content was highest (more than 40g/kg) in samples from three locations in Kaštela bay. It is interesting to note that carbonate content in sediment was very low (less than 150g/kg) in the area around the island of Rab in comparison to other sampling locations.

Live specimens of 54 bivalve taxa were collected during this study, while 87 taxa were represented by empty shells (Table 2). All species identified in this study have been previously noted at other locations in the eastern Adriatic, with the exception of two empty shells (shell lengths 34.3 and 38.0 mm) of the non-indigenous bivalve *Anadara demiri* (Fig. 2) collected at the Jadro river mouth in Kaštela bay and whose finding represents the first record for the Croatian part of the Adriatic.

Fig. 2. Photograph of shell of non-indigenous bivalve Anadara demiri *(Piani, 1981) collected at the Jadro river mouth, Kaštela bay*

Table 2. List of bivalve taxa represented by live specimens (●) and empty shells (¤) according to sampling location: 1. Sahara beach, 2. Rajska beach, 3. Kamporska draga, 4. Barbat channel, 5. Pag bay, 6. Vir, 7. Pag-Vir, 8. Jasenovo bay, 9. Starigrad-Paklenica, 10. Nin bay, 11. Stara Povljana, 12. Vlašić bay, 13. Pantan, 14. Jadro mouth, 15. Barbarinac, 16. Cetina estuary, 17. Neretva estuary-sand, 18. Neretva estuary-sea grass

Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Abra sp.								¤	¤									
Acanthocardia tuberculata (Linnaeus, 1758)	● ¤	● ¤	● ¤		● ¤			¤		● ¤	¤	● ¤			● ¤	● ¤	● ¤	● ¤
Acanthocardia aculeata (Linnaeus, 1767)			¤		●							● ¤				●		
Acanthocardia paucicostata (Sowerby, 1841)	¤				¤			¤	¤			¤		● ¤	● ¤	●	¤	¤
Acanthocardia sp.													●			●		
Anadara demiri (Piani, 1981)														¤				
Anodontia fragilis (Philippi, 1836)								¤	¤		¤			¤		¤		
Anomia ephippium Linnaeus, 1758					¤							¤	¤	¤				
Arca noae Linnaeus, 1758	¤				●¤	●¤	¤	¤	● ¤	¤	¤		●		¤	●		
Azorinus chamasolen (da Costa, 1778)	¤	¤			¤	¤		¤	● ¤	¤		¤		¤	¤	¤		
Barbatia barbata (Linnaeus, 1758)	¤																	
Callista chione (Linnaeus, 1758)	●¤	●¤	●¤	●¤	●¤	●¤	● ¤	● ¤	● ¤	● ¤	● ¤	● ¤			¤	● ¤	● ¤	
Cerastoderma glaucum (Poiret, 1789)											¤	¤		● ¤	¤		¤	● ¤
Chama gryphoides Linnaeus, 1758						¤												
Chamelea gallina (Linnaeus, 1758)	● ¤	● ¤	● ¤		¤						¤	¤	¤	●		● ¤	● ¤	● ¤
Chlamys sp.	¤				¤	¤	¤	¤	¤	¤	¤	¤	● ¤	● ¤	● ¤	● ¤	¤	
Chlamys varia (Linnaeus, 1758)		¤	¤		¤	¤			¤	¤	¤			● ¤	● ¤		¤	
Clausinella fasciata (da Costa, 1778)					● ¤										● ¤	●		

Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Corbula gibba (Olivi, 1792)	●				● ¤				● ¤		¤			¤				
Ctena decussata (O.G. Costa, 1829)					●						¤							
Diplodonta rotundata (Montagu, 1803)												¤						
Donax sp.					● ¤						¤					¤		
Donax trunculus Linnaeus, 1758	● ¤	● ¤	¤		●											¤	● ¤	¤
Dosinia exoleta (Linnaeus, 1758)				●	● ¤		● ¤	¤	● ¤		¤	● ¤	●		● ¤	● ¤		
Dosinia lupinus (Linnaeus, 1758)	● ¤	● ¤	¤		● ¤	¤	¤	¤		●	¤				● ¤	●	● ¤	¤
Ensis ensis (Linnaeus, 1758)	●	●			● ¤						¤				●	● ¤		
Ensis siliqua (Linnaeus, 1758)														¤				
Gari depressa (Pennant, 1777)	¤			● ¤	● ¤	¤	● ¤	¤	● ¤	●	¤		● ¤	¤	● ¤	●		
Gari fervensis (Gmelin, 1791)	● ¤	¤	● ¤		¤		¤	¤							¤	● ¤	●	
Gastrana fragilis (Linnaeus, 1758)					¤	¤		¤	¤		¤	¤		● ¤	● ¤			
Gastrochaena dubia (Pennant, 1777)				● ¤	¤	¤					¤	¤						
Glans trapezia (Linnaeus, 1767)													¤					
Glycymeris bimaculata (Poli, 1795)					● ¤						●					● ¤		
Glycymeris glycymeris (Linnaeus, 1758)				●	● ¤	● ¤	● ¤			● ¤	● ¤							
Glycymeris sp.			¤					¤			¤					¤	¤	
Glycymeris violacescens (Lamarck, 1819)			●		¤	● ¤	● ¤	● ¤		● ¤						● ¤	● ¤	¤
Gouldia minima (Montagu, 1803)								¤			¤							
Gregariella petagnae (Scacchi, 1832)											¤							
Flexopecten hyalinus (Poli, 1795)	¤																	
Hiatella arctica (Linnaeus, 1767)				●	¤										¤			
Irus irus (Linnaeus, 1758)											¤							
Laevicardium crassum (Gmelin, 1791)					¤		¤			¤								
Laevicardium oblongum (Gmelin, 1791)				● ¤	● ¤	¤		¤			¤	● ¤			¤	●		
Limaria tuberculata (Olivi, 1792)					¤			¤		¤	● ¤		● ¤	● ¤	¤			
Loripes lacteus (Linnaeus, 1758)			● ¤		¤	¤		¤		¤	¤			¤		¤	● ¤	¤
Lucinella divaricata (Linnaeus, 1758)					¤											¤		
Lutratia magna (da Costa, 1778)														¤	¤	¤		
Mactra stultorum (Linnaeus, 1758)	● ¤															●	¤	
Modiolus adriaticus (Lamarck, 1819)								¤	●					● ¤	¤	●		
Modiolus barbatus (Linnaeus, 1758)					¤	¤	¤	¤		¤	¤	¤	● ¤	●		¤	¤	
Mysia undata (Pennant, 1777)															¤			
Mytilaster minimus (Poli, 1795)											¤						¤	
Mytilus galloprovincialis Lamarck, 1819		¤			¤					¤	¤	¤		● ¤	¤	●	¤	●
Nucula sp.									¤					● ¤				●
Nuculana pella (Linnaeus, 1767)									¤									
Ostrea edulis Linnaeus, 1758	¤		● ¤			¤		¤	¤	¤	¤	● ¤	●	● ¤	● ¤	● ¤	¤	● ¤
Paphia sp.									¤		¤	¤	● ¤	● ¤	● ¤	● ¤	¤	● ¤
Parvicardium exiguum (Gmelin, 1791)								¤										
Pecten jacobaeus (Linnaeus, 1758)	¤				¤	¤			¤		¤	¤			●	● ¤		
Pholas dactylus Linnaeus, 1758										¤	¤							
Pinna nobilis Linnaeus, 1758	¤			¤				¤			¤	¤						

Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Pitar rudis (Poli, 1795)	¤				¤	¤		¤	¤		¤		● ¤	● ¤	● ¤	●		
Plagiocardium papillosum (Poli, 1795)					● ¤		¤	¤	¤		¤		¤			¤		
Pseudochama gryphina (Lamarck, 1819)						¤												
Pseudochama sp.											¤							
Ruditapes decussatus (Linnaeus, 1758)											¤	¤		¤	●	● ¤	¤	
Scrobicularia plana (da Costa, 1778)														¤			¤	
Solecurtus strigilatus (Linnaeus, 1758)	¤	¤			¤		¤	¤		¤		¤				¤		
Solemya togata (Poli, 1795)			¤															
Solen marginatus Pulteney, 1799	¤		¤							¤				¤			● ¤	
Spisula sp.	¤		¤															
Spisula subtruncata (da Costa, 1778)	● ¤	● ¤									¤				● ¤	● ¤	● ¤	●
Spondylus gaederopus Linnaeus, 1758					¤	¤	¤											
Striarca lactea (Linnaeus, 1758)				●								¤						
Tellina donacina Linnaeus, 1758					¤			¤	¤			¤		¤	¤	● ¤		
Tellina incarnata Linnaeus, 1758	● ¤	● ¤	¤								¤	¤				¤		
Tellina nitida Poli, 1791	¤	¤								¤				¤			● ¤	● ¤
Tellina planata Linnaeus, 1758	¤	¤	¤			¤										¤		
Tellina serrata Brocchi, 1814					¤				● ¤		●							
Tellina sp.																¤		
Tellina tenuis da Costa, 1778					● ¤	¤		¤			¤	¤					● ¤	¤
Thracia papyracea (Poli, 1791)	¤				● ¤			¤									● ¤	¤
Thracia pubescens (Pulteney, 1799)					¤		¤											
Thracia sp.			¤		¤	¤					¤	¤			●	●		
Timoclea ovata (Pennant, 1777)																●		
Venus casina Linnaeus, 1758																●		
Venus verrucosa Linnaeus, 1758	¤			● ¤	● ¤	● ¤	● ¤	● ¤	● ¤	● ¤	● ¤	● ¤	● ¤	● ¤	● ¤	● ¤		

In terms of both biomass and abundance, the most represented species were *Acanthocardia tuberculata, Callista chione*, *Chamelea gallina*, *Glycymeris bimaculata*, *G. glycymeris*, *G. violascens*, *Laevicardium oblongum*, *Modiolus barbatus*, *Mytilus galloprovincialis*, *Ostrea edulis* and *Venus verrucosa*. Their distribution varied with respect to sampling location (Table 3). The most commercially important bivalve *V. verrucosa* was found at 13 of 18 sampling locations and its highest biomass and abundance values were recorded at two locations in Kaštela bay - Pantan (25 g/m^2 and 1.95 ind/m^2, respectively) and Barbarinac (20 g/m^2 and 0.63 ind/m^2, respectively). Relatively high biomass values of this species, presented as wet weight estimates, were also recorded at Starigrad Paklenica (8.87 g/m^2) and Pag bay (5.77 g/m^2). Corresponding abundance values were 0.26 ind/m^2 and 0.17 ind/m^2, respectively. Smooth callista (*C. chione*) was found at 14 sampling locations and at 8 locations biomass values greater than 10 g/m^2 and abundance values greater than 0.266 ind/m^2 were recorded. The highest values for biomass and abundance of this species were found in Barbat channel (54 g/m^2 and 0.99 ind/m^2) and Pag bay (71 g/m^2 and 1.38 ind/m^2). Significant quantities of commercially important *C. gallina* were noted only in the Neretva estuary (19.22 g/m^2 and 6.61 ind/m^2 on sandy substrate), while significant quantities of *O. edulis* were collected in front of the Jadro river mouth in Kaštela bay (72 g/m^2, 2.03 ind/m^2). With respect to other bivalve species, only species from the genus *Glycymeris* had biomass values higher than 10 g/m^2. In Nin bay the biomass of *G. violascens*

Table 3. Biomass (g/m2) and abundance (ind/m2) (in brackets) of most represented species according to sampling location. 1. Sahara beach, 2. Rajska beach, 3. Kamporska draga, 4. Barbat channel, 5. Pag bay, 6. Vir, 7. Pag-Vir, 8. Jasenovo bay, 9. Starigrad-Paklenica, 10. Nin bay, 11. Stara Povljana, 12. Vlašić bay, 13. Pantan, 14. Jadro mouth, 15. Barbarinac, 16. Cetina estuary, 17. Neretva estuary-sand, 18. Neretva estuary-sea grass

Location	***Acanthocardia tuberculata***	***Callista chione***	***Chamelea gallina***	***Glycymeris bimaculata***	***Glycymeris glycymeris***	***Glycymeris violascens***	***Modiolus barbatus***	***Mytilus galloprovincialis***	***Laevicardium oblongatum***	***Ostrea edulis***	***Venus verrucosa***
1	**1.51** (0.256)	**26.86** (0.606)	**0.47** (0.625)								
2	**2.64** (0.189)	**25.00** (0.447)	**0.26** (0.247)								
3	**12.26** (0.527)	**14.08** (0.266)	**0.01** (0.013)			**0.17** (0.0129)				**0.15** (0.013)	
4		**54.32** (0.994)			**0.49** (0.006)				**0.23** (0.018)		**4.01** (0.061)
5	**4.44** (0.145)	**70.81** (1.379)		**8.81** (0.056)	**0.85** (0.006)				**0.13** (0.003)		**5.77** (0.170)
6		**1.06** (0.033)			**7.66** (0.065)	**0.29** (0.013)					**1.14** (0.019)
7		**2.51** (0.065)			**15.27** (0.097)	**2.10** (0.039)					**0.40** (0.006)
8	**0.20** (0.011)	**2.26** (0.028)				**0.66** (0.015)					**1.80** (0.025)
9		**2.20** (0.055)									**8.87** (0.256)
10	**1.58** (0.079)	**17.50** (0.304)			**1.94** (0.009)	**62.00** (1.590)					**0.84** (0.027)
11		**3.50** (0.044)		**0.38** (0.002)	**5.21** (0.050)						**0.97** (0.032)
12	**0.73** (0.025)	**14.69** (0.266)							**0.45** (0.021)	**0.70** (0.008)	**3.39** (0.076)
13							**146.97** (5.56)			**0.35** (0.020)	**25.23** (1.950)
14			**0.11** (0.037)				**0.56** (0.037)	**1.34** (0.049)		**72.06** (2.027)	**0.35** (0.025)
15	**0.13** (0.024)									**0.97** (0.032)	**20.27** (0.633)
16	**4.42** (0.099)	**24.32** (0.570)	**1.65** (0.315)	**8.89** (0.142)		**3.92** (0.077)		**8.78** (0.226)	**0.24** (0.023)	**4.02** (0.090)	**0.40** (0.010)
17	**0.45** (0.132)	**1.65** (0.059)	**19.22** (6.613)			**1.61** (0.109)		**1.45** (0.049)			
18	**0.98** (0.048)		**79.91** (11.250)							**1.74** (0.047)	

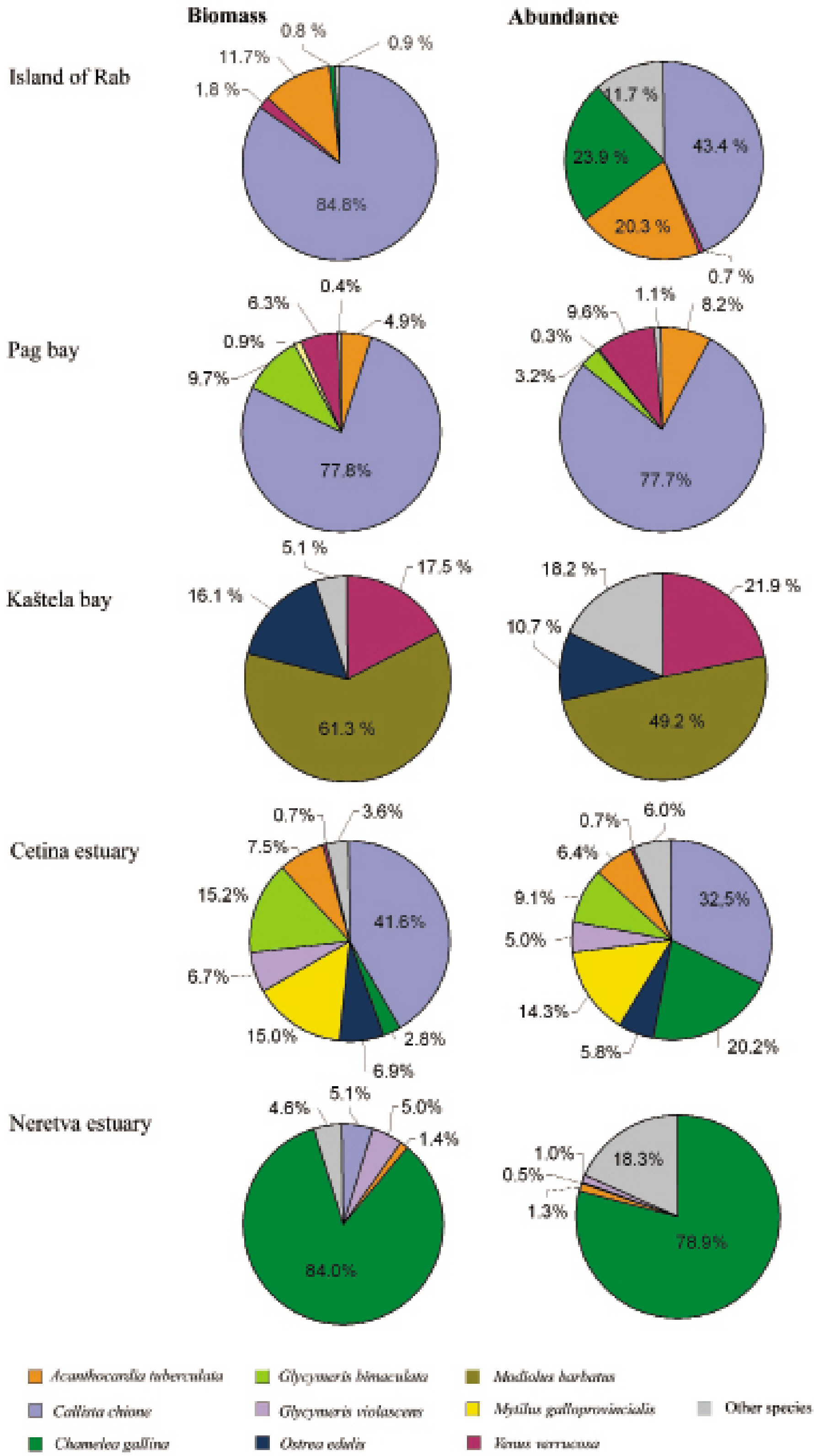

Fig. 3. Percentage contribution of species in terms of biomass and abundance at the five main sampling areas

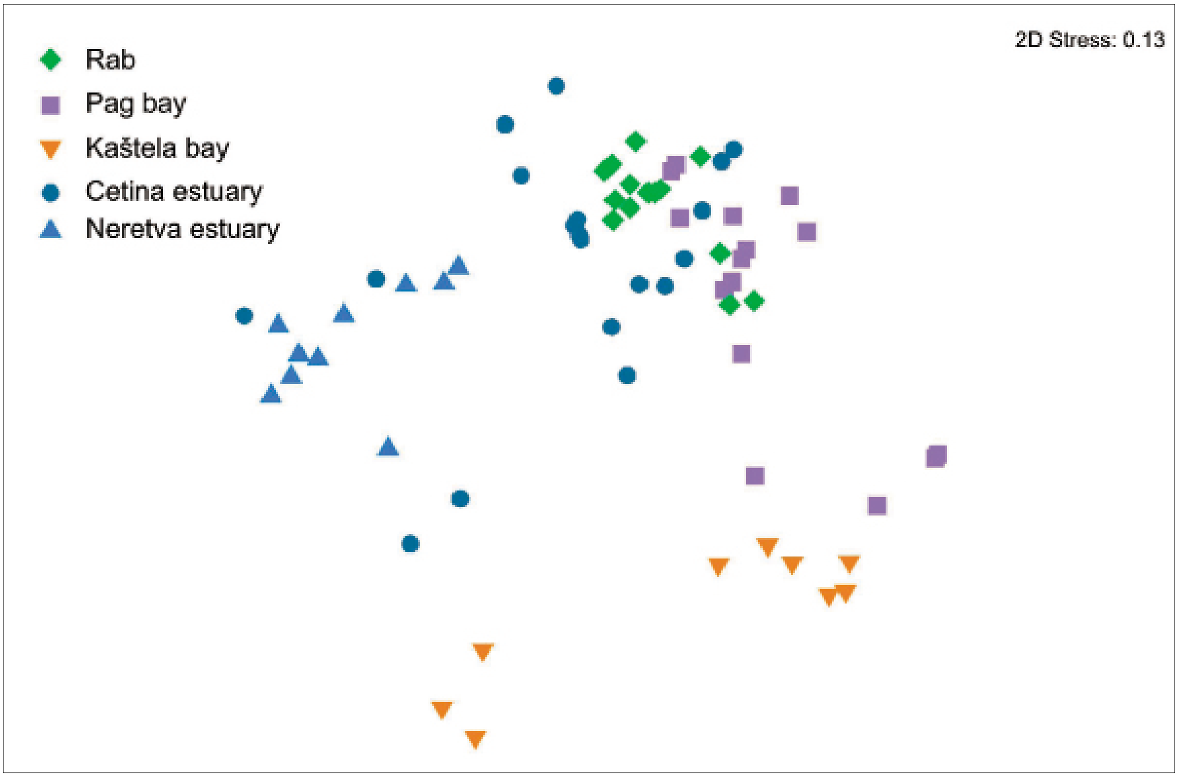

Fig. 4. nMDS plot of bivalve biomass data (log transformed) from the five main sampling areas

was 62 g/m^2, while at the sampling location between the islands of Pag and Vir biomass of *G. glycymeris* was 15 g/m^2.

Data on community composition were analyzed and presented according to five main sampling areas: island of Rab, Pag bay, Kaštela bay, Cetina river estuary and Neretva river estuary (Fig. 3). In the area around the island of Rab, including the locations Sahara beach, Rajska beach, Kamporska draga and Barbat channel, smooth callista (*Callista chione*) was the dominant species both in terms of biomass (85%) and abundance (43%). The second most important species in terms of biomass was *Acanthocardia tuberculata* (12%) while other species contributed only 3,5% to the bivalve biomass. In this area surveys were conducted using smaller bar spacing on the dredge which explains a higher contribution of other, predominantly smaller, species in terms of abundance (12%) while in terms of biomass they contributed less than 1%.

In Pag bay, *Callista chione* was the dominant species in dredge samples, both in terms of biomass (78%) and abundance (78%). Commercially important warty venus (*Venus verrucosa*) contributed 6% to the bivalve biomass and 10% in terms of abundance. Other species collected included *Glycymeris bimaculata*, *Glycymeris glycymeris* and *Acanthocardia tuberculata.* In total, 16 bivalve species were identified in samples collected in Pag bay including *Arca noae* and *Ensis ensis*.

In Kaštela bay surveys were conducted at three different locations including adjacent the area known as Pantan, in an area known as Barbarinac and in an area near the river Jadro. These three areas differed in bivalve community composition. In Pantan the dominant species was *Modiolus barbatus*. In the Barbarinac area *Venus verrucosa* dominated the bivalve community, while near the river Jadro *Ostrea edulis* was the only commercial species represented by live individuals. Besides the three above-listed species, 24 species were identified in Kaštela bay including *Acanthocardia tuberculata*, *Arca noae*, *Cerastoderma glaucum*, *Chamelea gallina*, *Chlamys varia*, *Ensis ensis*, *Mytilus galloprovincialis*, *Paphia* sp., *Pecten jacobaeus* and

Ruditapes decussatus. It is important to note that in this area a high proportion of empty shells was collected.

Unlike in other areas where only few species dominated bivalve communities, in the Cetina river estuary a total of eight species had higher biomass and abundance including: *Callista chione* (42 and 33%, respectively), *Glycymeris biomaculata* (15 and 9%), *Mytilus galloprovincialis* (15 and 14%), *Acanthocardia tuberculata* (8 and 6%), *Ostrea edulis* (7 and 6%), *G. violascens* (7 and 5%), *Chamelea gallina* (3 and 20%) and *Venus verrucosa* (1 and 1%). In this area a total of 32 bivalve species were collected by hydraulic dredge including *Arca noae*, *Chlamys* sp., *Ensis ensis*, *Ostrea edulis*, *Paphia* sp., *Pecten jacobaeus* and *Ruditapes decussates*.

In the Neretva river estuary the dominant species was *Chamelea gallina,* contributing 84% to the total bivalve biomass and 79% to bivalve abundance. A total of 12 bivalve species were represented by live individuals in dredge samples collected in the Neretva river estuary including *Callista chione*, *Glycymeris violascens* and *Acanthocardia tuberculata*.

In most cases samples were characterized by low species richness and they were usually dominated by one or two species, while up to 5-6 species usually made up over 90% of the bivalve biomass. An exception was in the area of the Cetina river estuary that was characterized by high spatial heterogeneity of habitat and bivalve diversity. High heterogeneity was also recorded in the Kaštela bay area. Statistically significant differences were noted in bivalve community structure, based on bivalve biomass, between the five main sampling areas including the island of Rab, Pag bay, Kaštela bay, Cetina estuary and Neretva estuary (Fig. 4, Table 4). Although significant, a few ANOSIM R values were not high enough to indicate clear differences between locations. The smallest R values were recorded when comparing bivalve community structure, in terms of wet biomass, at the island of Rab and the Cetina estuary (R=0.212) and Pag bay and the Cetina estuary (R=0.250) indicating that although observed differences were statistically significant, bivalve communities at these locations were in fact rather similar. On the other hand, R values higher than 0.9 were recorded for comparison of community structure between Rab and Kaštela, and Kaštela and Neretva indicating high differences in bivalve community composition between these locations. It is interesting to note that a dredge with the same type of grid distance was used for the surveys in Kaštela bay and the Neretva estuary.

Table 4. Results of one way ANOSIM pairwise test of bivalve biomass data from the five main locations. Global R=0.532, p=0.001

Groups	**R**	**p**
Rab vs. Pag bay	0.273	0.001
Rab vs. Kaštela	0.960	0.001
Rab vs. Cetina estuary	0.212	0.002
Rab vs. Neretva estuary	0.990	0.001
Pag bay vs. Kaštela	0.606	0.001
Pag bay vs. Cetina estuary	0.250	0.001
Pag bay vs. Neretva estuary	0.887	0.001
Kaštela vs. Cetina estuary	0.766	0.001
Kaštela vs. Neretva estuary	0.981	0.001
Cetina vs. Neretva estuary	0.410	0.001

DISCUSSION

Sediment composition is one of the important factors that regulate the distribution of bivalves (DAME, 1996). In the present study, pronounced differences in sediment composition between sampling locations were noted with respect to carbonate content (Table 1). Specifically, sediments at near coast stations around the island of Rab had low carbonate content, while sediments from other locations had significantly higher carbon content. According to LUŽAR-OBERITER *et al.* (2008) carbonate particles in beach sands where their content is less than 10% are primarily composed of recent organism shell fragments and redeposited foraminifera from Eocene sandstones. Beach sands are predominantly composed of siliciclastic material as a result of Eocene clastic sediments and

Pleistocene sands weathering. GREEN *et al.* (2009) recently documented dissolution mortality of bivalve juveniles on sediments with low carbonate content. The bivalve community from Rab differed significantly from bivalve communities sampled in other parts of the Adriatic during this study. However, from data collected in this study it is not possible to determine whether this was influenced by sediment composition or other factors. Future studies should analyze the impact of carbonate content on bivalve community structure in this area as well as the impact of such sediment on bivalve shell composition and individual growth rates.

The main objective of this research was the assessment of populations of commercially important bivalves in the eastern Adriatic while the methodology used was not appropriate for assessing the bivalve biodiversity of surveyed locations. However, data collected, when interpreted with caution, contributes to the knowledge on bivalve distribution in the eastern Adriatic. Furthermore, the hydraulic dredge used in the study is not an adequate tool for sampling all species of bivalves. This is particularly the case for bivalves such as *Ostrea edulis* and *Mytilus galloprovincialis* that live on hard substrates and at shallower depths. Data on these species need to be interpreted with caution and as relative values rather than absolute. Similar is the case for small sized bivalve species that may have passed through the dredge bars and were therefore not collected. There is a possibility that variations in spacing between dredge bars (8 mm, 11 mm and 20 mm), that were used at different locations, influenced data collected and that differences in bivalve community structure observed at studied locations are the artifact of the sampling design. We believe that this was especially the case for bivalve abundance data collected and have therefore performed more detailed analysis only on biomass data.

According to ZAVODNIK (1999) 224 bivalve species live in the Croatian part of the Adriatic. In this study 87 bivalve taxa were collected and identified, representing 39% of known species. Empty shells of the non-indigenous bivalve *Anadara demiri* were found for the first time in the Croatian part of the Adriatic Sea - near the river Jadro mouth in Kaštela bay. In the Mediterranean Sea, *A. demiri* has been recorded for the first time in Turkish waters at the beginning of the 1970s (DEMIR, 1977). Later it was discovered in Greece (ZENETOS, 1994) as well as in the Italian part of the Adriatic Sea (MORELLO & SOLUSTRI, 2001). Since its introduction this species has been found to be locally abundant (MORELLO *et al.*, 2004; ÇINAR *et al.*, 2006; ÇINAR *et al.*, 2008). Recently ALBANO *et al.* (2009) conducted a morphological and molecular analysis on specimens from Italy, Greece and Turkey and concluded that the taxa *Anadara demiri* is a junior synonym of *Anadara transversa* (Say, 1822) from the Gulf of Mexico. Since this is the first finding of this non-indigenous bivalve species in the Croatian part of the Adriatic, a targeted field survey should be conducted in the near future in Kaštela bay, and especially in the part of the bay near the mouth of the river Jadro where empty shells of *A. demiri* were collected, in order to determine if live specimens are present and their distribution and population structure.

The most important commercial species *Venus verrucosa* had a wide distribution but did not show very high biomass and abundance values. This can partially be attributed to methodology used since this species lives on a mixed substrate of gravel, sands and rocks where sampling with the methods applied in this study was not feasible. However, data collected are representative for this fishing gear type and can be used for comparative purposes if the same sampling methodology is applied in future monitoring surveys. Other factors that may have influenced the population structure of this species is commercial exploitation. This species is collected by commercial SCUBA divers and its populations are subjected to different harvesting pressures in different parts of the eastern Adriatic (MATIJACA pers. comm.). *Venus verrucosa* is a relatively slow growing species that reaches sexual maturity at lengths greater than 25 mm and two years of age, and can live for over 10 years (MARANO *et al.*, 1982; ARNERI *et al.*, 1998; HERVAT *et al.*, 2006). Due to intensive exploitation and relatively slow growth rates this species is susceptible to overexploitation and its populations need to be closely monitored.

Although data on exploitation of *Callista chione* in the Croatian part of the Adriatic Sea are not reported in the official statistics, according to data collected in the field through communication with commercial divers this species has been occasionally exploited in recent years, especially in Pag bay and the area near the Cetina river estuary (PEHARDA pers. comm.). In the present study, biomass and abundance values of *C. chione* varied with respect to location and the highest values were found in Pag bay. In coastal areas of the northern Euboikos Gulf (Aegean Sea, Greece), *Callista chione* is exploited by a small-scale fishery. In a survey conducted by SCUBA divers the average population density of this species was found to be 6 ind/m^2 (METAXATOS, 2004). Observed differences in abundance of *C. chione* between our study and that of METAXATOS (2004) can be at least partially attributed to differences in methodologies. That is, in her study METAXATOS (2004) counted bivalves larger than 7 mm, while the hydraulic dredge used in our study did not sample such small individuals. In the eastern Adriatic, the only previous study that analyzed the distribution of *C. chione*, including its biomass and abundance, is that of JUKIĆ *et al.* (1998). Unfortunately, the differences in standardization of data make difficult a comparison between our and their results. However, it is interesting to note that in their survey conducted from the Neretva estuary in the south to Susak island in the north, they found the highest values around the island of Rab while they did not sample in Pag bay. Biomass and abundance values determined for *C. callista* in the eastern Adriatic in the present study indicate that this species can be commercially exploited by SCUBA divers. Finally, due to relatively slow growth and long life of this species (LEONTARAKIS & RICHARDSON, 2005; MOURA *et al.*, 2009) harvesting needs to be closely monitored in order to prevent overexploitation.

In a previous study conducted by JUKIĆ *et al.* (1998) it was shown that in the eastern Adriatic Sea *Chamelea gallina* has a limited distribution. Dense settlement of this species occurred only in the Neretva river estuary. In the period from 1990 to 1993, in a survey also conducted with a hydraulic dredge, average biomass was significantly higher and recorded values were up to 213 g/m^2 (JUKIĆ *et al.*, 1993). Significant reduction in biomass of *Chamelea gallina* in the Neretva river estuary probably occurred due to several reasons of which the most important are excessive exploitation, hydrographic conditions and impact of the river Neretva including changes in geomorphology of the estuary and chemical composition. However, data are not available to support this and future studies should look at ecosystem level changes at this location.

The economic importance of species of the genus *Glycymeris* (dog cockles) is negligible in Croatia. They are only occasionally harvested and primarily as fish bait or for the souvenir trade (LEGAC & FABIJANIĆ, 1994). Species of the Glycymerididae in the eastern Adriatic Sea were reviewed by LEGAC & HRS-BRENKO (1999). According to these authors three species of *Glycymeris* live in the eastern Adriatic Sea and these were recorded in the present study. *G. bimaculata* is common in the eastern Adriatic and it is distributed from Istria to Dubrovnik (LEGAC & HRS-BRENKO, 1999). In Pag bay, abundance of this species was estimated at 1.2 ind/m^2 at 2.7 m depth and at 0.6 ind/m^2 at 2.9 m with a method of counting siphon openings by SCUBA divers (LEGAC & FABIJANIĆ, 1994). *G. glycymeris* is a common species in the Adriatic that burrows in sediments including mud, sand and sand with gravel, while *G. violacescens* is considered a less common species and it burrows in sandy bottoms (LEGAC & HRS-BRENKO, 1999). In this study pronounced differences were noted in the distribution of three species of dog cockles along the eastern Adriatic. *G. bimaculata* was found at three locations, *G. glycymeris* at six locations and *G. violacescens* at seven locations. It is interesting to note that according to LEGAC & HRS-BRENKO (1999) *G. violacescens* is a less common species in the Adriatic Sea while in this study it was recorded with relatively high biomass (62 g/m^2) and abundance values (1.59 ind/m^2) in Nin bay. The formerly abundant *G. bimaculata* in Pag bay was recorded in low abundance (0.06 ind/m^2) in the present study. Unfortunately we are not aware of any other study in the Mediterranean related to biomass and abundance of these three species so comparison is not possible.

Permanent monitoring of bivalve stocks should be established using data collected in this research. It should include data on commercially important bivalve species as well as data on bivalve community composition and distribution of non-indigenous species. Monitoring should also be conducted in the open north Adriatic where commercial exploitation of bivalves with hydraulic dredge takes place and should include a study on impact of dredging on the macrobenthic community (MORELLO *et al.*, 2005). Data collected through such monitoring are necessary for the assessment of the exploitation state of certain species in specific areas, and for management actions related to exploitation and protection. Subsequently, comparative analysis of age and growth of commercially important species of bivalves from different parts of the Adriatic should be conducted in order to provide a scientific basis for sustainable bivalve management and protection.

CONCLUSIONS

Hydraulic dredge surveys of bivalves conducted in the area from the island of Rab in the north to the river Neretva estuary identified 54 bivalve taxa represented by live specimens and 87 bivalve taxa represented by empty shells. Non-indigenous bivalve *Anadara demiri* shells were found for the first time in the Croatian part of the Adriatic Sea. Data on biomass and abundance of commercially important bivalves, including *Venus verrucosa* and *Callista chione*, are presented. Significant differences were noted in bivalve community structure between sampling areas. The results obtained are important for setting up a longer-term monitoring study necessary for gaining understanding of the complexity of benthic successional dynamics in the area as well as for providing a basis for the sustainable management of bivalve communities.

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Opis strukture zajednica školjkaša u hrvatskom dijelu Jadranskog mora - istraživanje hidrauličnom dredžom

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SAŽETAK

Istraživanje zajednica školjkaša provedeno je tijekom 2007. i 2008. godine duž istočne obale Jadrana, od otoka Raba na sjeveru do ušća rijeke Neretve na jugu. Glavni cilj istraživanja bio je opis raspodjele i strukture zajednica školjkaša na mekim dnima duž istočne obale Jadrana, sa posebnim naglaskom na gospodarski važne vrste školjkaša u pet glavnih izlovnih područja. Hidrauličnom dredžom prikupljeno je ukupno 105 uzoraka na dubinama od 1 do 11 m. Prikupljeni školjkaši na terenu su odvojeni i zamrznuti za daljnju laboratorijsku analizu koja je uključivala identifikaciju vrsta te analizu brojnosti i biomase. U prikupljenim uzorcima 54 vrste školjkaša bile su zastupljene sa živim primjercima, dok je iz ljušturnih ostataka identificirano 87 vrsta školjkaša. Ljušture alohtone vrste školjkaša *Anadara demiri* zabilježene su po prvi puta u hrvatskom dijelu Jadrana. Maseno i brojčano najzastupljenije vrste bile su: *Acanthocardia tuberculata, Callista chione*, *Chamelea gallina*, *Glycymeris bimaculata*, *G. glycymeris*, *G. violascens*, *Laevicardium oblongum*, *Modiolus barbatus*, *Mytilus galloprovincialis*, *Ostrea edulis* i *Venus verrucosa*. Statistički značajna razlika zabilježena je u zajednicama školjkaša na pet glavnih područja istraživanja uključujući otok Rab, Paški zaljev, Kaštelanski zaljev te ušća rijeka Cetine i Neretve.

Ključne riječi: školjkaši, rasprostranjenost, Jadransko more, hidraulična dredža