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Species diversity of marine bivalves on a potential mariculture sites along Montenegrin coast (south-east Adriatic Sea)

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ABSTRACT

This study presents the results on marine bivalve diversity at potential mariculture sites along the open coastline of Montenegro. The research was conducted at six locations during the spring and autumn of 2022 and 2024, using SCUBA diving along defined transects. All visible taxa were collected by hand and identified in the laboratory. A total of 59 marine bivalve taxa from 23 families were identified. Most of the collected material consisted of empty shells, with only two live specimens sampled *Arca noae* and *Laevicardium crassum*. The most numerous family was Veneridae, which included 12 species. The dominant species, based on specimen number, were: *Acanthocardia tuberculata*, *Arca noae*, *Barbatia barbata*, *Lithophaga lithophaga*, *Papillicardium papillosum*, *Rocelaria dubia*, *Striarca lactea*, and *Venus verrucosa*. Commercially and potentially commercially important species included: *Arca noae*, *Callista chione*, *Chamelea gallina*, *Flexopecten flexuosus*, *Flexopecten glaber*, *Mimachlamys varia*, *Mytilus galloprovincialis*, *Ostrea edulis*, *Polititapes aureus*, *Ruditapes decussatus*, and *Venus verrucosa*. At all of the investigated locations, the protected bivalve species *Lithophaga lithophaga* was recorded, which is negatively impacted by illegal exploitation. The critically endangered species *Pinna nobilis* was not recorded at any of the study sites. The non-indigenous species *Fulvia fragilis* was observed near cape Mendra (location Valdanos 1).

Keywords: aquaculture, diversity, Molluscs, Adriatic Sea, Montenegro

INTRODUCTION

Mariculture sector in Montenegro remains underdeveloped despite its natural potential. Shellfish cultivation is currently limited to Boka Kotorska Bay, where 19 farms are operational (MONSTAT, 2024). According to Mandić *et al*. (2021), defining new mariculture zones for production requires meeting several key criteria, including environmental, administrative, and socio-economic conditions. One of the fundamental principles

for selecting suitable zones is the concept of AZA (Allocated Zones for Aquaculture), which was adopted as a specific resolution by the General Fisheries Commission of the Mediterranean (GFCM) of the Food and Agriculture Organization of the United Nations (FAO) (ibid.). Montenegro has accepted these recommendations and begun a detailed analysis of potential new mariculture zones along the open part of its coast (ibid.).

With support from the Ministry of Agriculture, Forestry, and Water Management of Montenegro, the Institute of Marine Biology has been analyzing new mariculture zones along the open coastline since 2019. This analysis includes physico-chemical water analysis, biodiversity assessments (phytoplankton, zooplankton, ichthyoplankton, phytobenthos, zoobenthos), sediment analysis (heavy metal content and granulometry), sea currents, bathymetry and marine litter (see Mandić *et al*., 2020). As part of biodiversity analysis, a detailed study of bivalves diversity began in 2022.

Historically, most studies on marine bivalve diversity have focused on Boka Kotorska Bay (e.g., Stjepčević, 1967; Karaman & Gamulin-Brida, 1970; Parenzan, 1971; Stjepčević *et al*., 1977; Stjepčević & Parenzan, 1980; Stjepčević *et al*., 1982; Igić, 1983; RAC/SPA-UNEP/MAP, 2011; 2013; Mačić *et al*., 2014; Petović & Marković, 2016; Petović *et al*., 2017; 2021; UNEP/MAP-RAC/SPA, 2016; Petović & Mačić, 2017; Petović, 2018; Gvozdenović *et al*., 2019a; 2019b; 2022; Peraš *et al*., 2018; 2020; 2022a; 2022b; Spagnolo *et al*., 2019; UNEP/MAP-PAP/RAC-SPA/RAC & MSDT, 2019; Canessa *et al*., 2024). Data on marine bivalve diversity along Montenegro's open coastline are limited, with studies primarly focused on topics such as the effect of trawling on the benthic communities (Petović & Marković, 2013; Petović *et al*., 2016), monitoring of invasive species (Petović *et al*., 2019a; Petović & Mačić, 2021), macrozoobenthos diversity (Petović *et al*., 2017; 2021), and marine cave biodiversity (Mačić *et al*., 2019; 2024; Petović *et al*., 2019b).

This study focuses on the diversity of marine bivalves at six potential mariculture sites along the Montenegro's open coastline, aiming to assess the feasibility of farming certain bivalve species in these new locations.

MATERIAL AND METHODS

Research was conducted during the spring and autumn of 2022 and 2024 year at six locations (Drobni pijesak, Cape Crni, Štrbina, Valdanos 1, Valdanos 2 and Valdanos 3) along the open coast of Montenegrin (Tab. 1, Fig. 1). Locations Valdanos 1, Valdanos 2 and Valdanos 3 are situated near Cape Mendra. Sampling was caried out by SCUBA diving, with all visible bivalve taxa collected by hand along a 200 m^2 transect, positioned perpendicular to the coast. The collected material was identified in the laboratory using: Poppe & Goto (2000), Riedl (2002), Milišić (2007), Doneddu & Trainito (2010), Huber (2010), Prvan & Jakl (2016) and Peharda Uljević *et al*. (2022). Taxonomy and nomenclature followed the World Register of Marine Species – WoRMS (https://www.marinespecies.org/).

RESULTS AND DISCUSSION

A total of 59 marine bivalve taxa from 23 families were identified. Of these, 24 taxa were recorded at Drobni pijesak, 44 at Cape Crni, 25 at Štrbina, 20 at Valdanos 1, 15 at Valdanos 2, and 7 at Valdanos 3 (Tab. 2). These results indicate high diversity, even though the research was conducted over a short period and

Table 1. Detailes about sampling locations along Montenegrin coast

Location	Latitude (N)	Longitude (E)	Maximum depth (m)	Sampling date	Bottom type
Drobni pijesak	42.236517	18.549364	12	02.06.2022; 14.10.2022	Mosaic of rocky and sandy bottom with the presence of *Posidonia oceanica*
Cape Crni	42.138322	19.015919	14	01.06.2022; 14.10.2022	Mosaic of rocky and sandy bottom with the presence of *Posidonia oceanica*
Štrbina	42.136319	19.032833	12	01.06.2022; 14.10.2022	Mosaic of rocky and sandy bottom with a few shoots of *Posidonia oceanica*
Valdanos 1	41.952083	19.145650	12	20.06.2024; 15.10.2024	Mosaic of rocky and sandy bottom with the presence of *Posidonia oceanica*
Valdanos 2	41.938783	19.158400	8	20.06.2024; 15.10.2024	Mosaic of rocky and sandy bottom
Valdanos 3	41.928853	19.174778	10	21.06.2024; 16.10.2024	Mosaic of rocky and sandy bottom

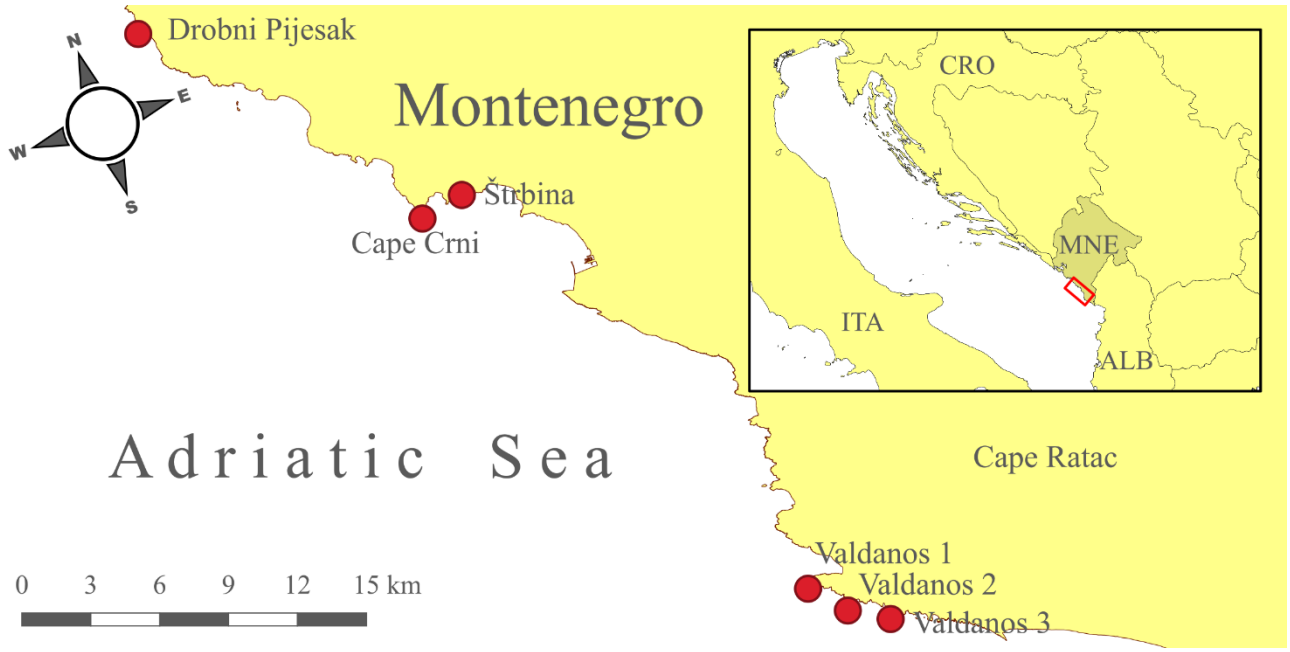

Figure 1. Sampling sites along the open coast of Montenegro

as part of a larger project not exclusively focused on bivalves. According to Gvozdenović *et al*. (2022), 165 marine bivalve are known to inhabit the Montenegrin part of the Adriatic Sea. The 59 taxa identified in this study represent 33.3% of the known taxa. Additionaly, 89 marine bivalve taxa are listed along the Montenegrin open coastline (Petović *et al*., 2021), meaning the 59 taxa identified here account for 66.3% of that total. The diversity observed in this study closely aligns with the findings of Petović *et al*. (2021), which is expected given the similar ecological conditions.

Compared to the study conducted in Croatian coastal waters, where 87 marine bivalve taxa have been described across five main sampling areas from the Island of Rab to the Neretva River estuary (Peharda *et al*., 2010), the number of identified taxa is quite similar. However, it is important to note that the depth of investigation in both studies was nearly identical (maximum depth of 14 m), but the seabed type differed, and the sampling methodologies were completely different (hydraulic dredge vs. SCUBA diving). Furthermore, Peharda *et al*. (2010) conducted their research over two years and collected a total of 105 samples, whereas only 12 samples were collected in this study, with six samples taken in 2022 and six in 2024.

In the coastal waters of Albania, several studies have explored the diversity of macrozoobenthos, including bivalves, primarily in rocky shore habitats. For example, 67 mollusc species were identified in Vlora Bay (Kasemi *et al*., 2014), while 21 bivalve species were recorded at Shën Pjetër, Kallm, Spille, and Triport (Ruci *et al*., 2014), and 26 bivalve species from 15 families were reported in Triport alone (Saçaj *et al*., 2024). Due to differences in habitat types, rocky shores in Albanian studies versus predominantly sandy bottoms in our study, as well as varying sampling methodologies, direct comparisons are limited. However, the dominance of Veneridae in our data reflects the influence of sandy substrates, which are less represented in the Albanian surveys.

The most abundant family identified was Veneridae, with 12 species, followed by Cardiidae with seven species and Pectinidae with six species (Tab. 2). The dominant species, based on specimen number, were: *Acanthocardia tuberculata*, *Arca noae*, *Barbatia barbata*, *Lithophaga lithophaga*, *Papillicardium papillosum*, *Rocelaria dubia*, *Striarca lactea*, and *Venus verrucosa*, which aligns with the bottom type of the studied locations. Each investigated site had similar bottom characteristics, with rocky substrates down depths of approximately 5-6 m, followed by sandy bottoms featuring *Posidonia oceanica* (Linnaeus) Delile, 1813 meadows. However, *P. oceanica* meadows were absent at Valdanos 2 and Valdanos 3 (Tab. 1). *A. noae*, *B. barbata*, *L. lithophaga*, *R. dubia*, and *S. lactea* prefer hard bottoms, while *A. tuberculata*, *P. papillosum*, and *V. verrucosa* are more commonly found on sandy, gravel, or muddy substrates (Poppe & Goto, 2000; Huber, 2010).

Commercially and potential comercially important species included: *A. noae*, *Callista chione*, *Chamelea gallina*, *Flexopecten flexuosus*, *Flexopecten glaber*, *Mimachlamys varia*, *Mytilus galloprovincialis*, *Ostrea edulis*, *Polititapes aureus*, *Ruditapes decussatus*, and *V. verrucosa*.

In all samples empty shells were dominant. However, at Cape Crni and Valdanos 2, we sampled one live specimen each of *Laevicardium crassum* and *A. noae*, respectivelly. Additionally, on all studied locations, live specimens of *R. dubia* were observed on rocks, characterized by the two small holes they create on the rock surface. The near absence of living specimens in our survey

is likely due to the limitations of SCUBA diving methodology, which may miss living specimens buried in the sand. While empty shells provide important information about species presence, death assemblages are known to preserve valuable data on regional diversity (Weber & Zuschin, 2013). Similar findings of higher proportions of dead individuals in bivalve samples have been reported along the Adriatic coast (Zavodnik & Kovačević, 2000; Peharda *et al*., 2002; 2004; 2010; Gvozdenović *et al*., 2019a). Kidwell & Flessa (1996) also noted that dead mollusc assemblage typically have twice as many species as live ones.

The presence of *L. lithophaga* was also confirmed by the characteristic holes it creates in rocks, and some empty shells were collected. Although illegal exploitation of *L. lithophaga* has been largely suppressed and is under tighter control, poachers still target this species due to its high market value. It remains a delicacy, with some restaurants along the Montenegrin coast offering it on a "secret menu" (personal observation), despite it being protected under Montenegrin law (Official Gazette of Montenegro 76/06, 2006). This species is also listed in Annex IV of the EU Habitat Directive, requiring strict protection (EU, 1992), in Appendix II of the Bern Convention as strictly protected fauna species (EU, 1979), and in Annex II of the Barcelona Convention as an endangered species (Barcelona Convention, 1976). Furthermore, species is protected from over-exploitation, Annex II of the CITES (CITES, 2025).

The noble pen shell, *Pinna nobilis* Linnaeus, 1758 was not observed at any location during the survey. Before a mass mortality event, *P. nobilis* was sporadically distributed along the Montenegro's open coastline, however very dense populations were present in Boka Kotorska Bay, particularly in areas such as Sveti Stasije, Orahovac, and Sveta Nedjelja. Once abundant across the Mediterranean Sea, *P. nobilis* is now critically endangered, clasiffied under IUCN criteria A2be+4be (Kersting *et al*., 2019). The mass mortality event caused by the parasite *Haplosporidium pinnae* has led to a dramatic decline of the species in recent years (Katsanevakis *et al*., 2019; Panarese *et al*., 2019; Grau *et al*., 2022).

At Valdanos 1, the non-indigenous species *Fulvia fragilis* was observed. First identified in Montenegro and Adriatic Sea off St. Marko Island (Boka Kotorska Bay) (Gvozdenović *et al*., 2019b). *F. fragilis* is a Lessepsian migrant but may also spread through shipping activities. To date, six non-indigenous marine bivalve species have been recorded in Montenegro (Gvozdenović *et al*., 2019b; Petović *et al*., 2019a; 2021; Petović & Mačić, 2021). Non-indigenous species pose a significant threat to biodiversity and are a key focus of European Union policy, as their abundance, distribution, and impact on native biodiversity are critical data points.

According to the FAO (2010), one of the main goals in aquaculture sector is diversification, particulary the introduction of previously not farmed indigenous species to farming process, which can help reduce fishing pressure on natural populations. Based on the results of this study and previous literature (Ljubičić, 2010; Bolotin *et al*., 2011; Peharda *et al*., 2013; Župan *et al*., 2014; Peharda Uljević *et al*., 2022) several bivalve species could be considered for potential farming, including *Arca noae*, *Callista chione*, *Chamelea gallina*, *Flexopecten flexuosus*, *Flexopecten glaber*, *Mimachlamys varia*, *Modiolus barbatus*, *Polititapes aureus*, *Ruditapes decussatus*, and *Venus verrucosa*.

Table 2. List of identified taxa on investigated locations along Montenegrin coast (+ - empty shells; +* - empty shells and alive specimens; * - alive specimens)

Taxa	**Drobni pijesak**	**Cape Crni**	**Štrbina**	**Valdanos 1**	**Valdanos 2**	**Valdanos 3**
PTERIOMORPHIA						
Order Arcida						
Familia Arcidae						
***Arca noae* Linnaeus, 1758**	+	+	+	+	+*	+
***Barbatia barbata* (Linnaeus, 1758)**	+	+	+	+	+	+
Familia Glycymeridae						
***Glycymeris* spp.**		+	+	+	+	
Familia Noetiidae						
***Striarca lactea* (Linnaeus, 1758)**	+	+	+			
Order Limida						
Familia Limidae						
***Lima lima* (Linnaeus, 1758)**	+		+			
***Limaria hians* (Gmelin, 1791)**		+				
***Limaria tuberculata* (Olivi, 1792)**	+	+				
Order Mytilida						
Familia Mytilidae						
****Lithophaga lithophaga* (Linnaeus, 1758)**	+	+	+	+	+	
***Mytilus galloprovincialis* Lamarck, 1819**	+	+	+	+	+	+
Familia Modiolidae						
***Modiolus barbatus* (Linnaeus, 1758)**	+	+		+		+
Order Ostreida						
Familia Ostreidae						
***Ostrea edulis* Linnaeus, 1758**		+	+			
Order Pectinida						
Familia Anomiidae						
***Anomia ephippium* Linnaeus, 1758**				+	+	
Familia Pectinidae						
***Flexopecten flexuosus* (Poli, 1795)**	+					
***Flexopecten glaber* (Linnaeus, 1758)**	+					

***Flexopecten hyalinus* (Poli, 1795)**		+					
***Manupecten pesfelis* (Linnaeus, 1758)**		+	+	+		+	
***Mimachlamys varia* (Linnaeus, 1758)**		+		+			
***Talochlamys multistriata* (Poli, 1795)**		+					
Familia Spondylidae							
***Spondylus gaederopus* Linnaeus, 1758**	+		+				
HETEROCONCHIA							
Order Carditida							
Familia Carditidae							
***Glans trapezia* (Linnaeus, 1767)**		+					
Order Adapedonta							
Familia Pharidae							
***Ensis ensis* (Linnaeus, 1758)**		+					
***Ensis minor* (Chenu, 1843)**				+			
Order Cardiida							
Familia Cadiidae							
***Acanthocardia paucicostata* (G. B. Sowerby II; 1834)**					+		
***Acanthocardia tuberculata* (Linnaeus, 1758)**	+	+	+	+	+		
****Fulvia fragilis* (Forsskål, 1775)**				+			
***Laevicardium crassum* (Gmelin, 1791)**		+*					
***Papillicardium papillosum* (Poli, 1791)**	+	+	+				
***Parvicardium exiguum* (Gmelin, 1791)**	+						
***Parvicardium scabrum* (R. A. Philippi, 1844)**						+	
Familia Donacidae							
***Donax semistriatus* Poli, 1795**			+		+		
Familia Psammobiidae							
***Gari depressa* (Pennant, 1777)**		+	+		+		

***Gari fervensis* (Gmelin, 1791)**		+				
Familia Tellinidae						
***Acropella balaustina* (Linnaeus, 1758)**		+				
***Bosemprella incarnata* (Linnaeus, 1758)**		+	+			
***Moerella donacina* (Linnaeus, 1758)**	+	+				
***Moerella pulchella* (Lamarck, 1818)**		+				
***Peronaea planata* (Linnaeus, 1758)**		+				
Order Gastrochaenida						
Familia Gastrochaenidae						
***Rocellaria dubia* (Pennanrt, 1777)**	*	*	*	*	*	*
Order Lucinida						
Familia Lucinidae						
***Ctena decussata* (O. G.Costa, 1829)**	+	+				
***Loripes orbiculatus* Poli, 1795**	+		+			
Order Myida						
Familia Corbulidae						
***Varicorbula gibba* (Olivi, 1792)**		+				
Order Venerida						
Familia Chamidae						
***Chama gryphoides* Linnaeus, 1758**		+	+			
***Pseudochama gryphina* (Lamarck, 1819)**	+	+	+			
Familia Mactridae						
***Mactra glauca* Born, 1778**		+				
***Mactra stultortum* (Linnaeus, 1758)**				+	+	
***Spisula subtruncata* (da Costa, 1778)**		+	+			
Familia Ungulinidae						
***Diplodonta rotundata* (Montagu, 1803)**		+				
Familia Veneridae						
***Callista chione* (Linnaeus, 1758)**	+	+	+	+	+	

***Chamelea gallina* (Linnaeus, 1758)**			+	+	
***Clausinella fasciata* (da Costa, 1778)**		+			
***Dosinia exoleta* (Linnaeus, 1778)**		+			
***Dosinia lupinus* (Linnaeus, 1758)**			+	+	
***Gouldia minima* (Montagu, 1803)**		+			
***Irus irus* (Linnaeus, 1758)**		+		+	
***Pitar rudis* (Poli, 1795)**	+	+			
***Polititapes aureus* (Gmelin, 1791)**	+	+			
***Ruditapes decussatus* (Linnaeus, 1758)**	+	+	+	+	+
***Timoclea ovata* (Pennant, 1777)**		+			
***Venus verrucosa* Linnaeus, 1758**	+	+	+	+	+

* – Protected under Montenegrin law; Annex IV of the Habitat Directive; Appendix II of the Bern Convention; Annex II of the Barcelona Convention; Appendix II of the CITES

* – Non-indigenous species

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Diverzitet vrsta morskih školjki na potencijalnim lokacijama za marikulturu duž crnogorske obale (jugoistočni Jadran)

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SAŽETAK

U ovom radu su predstavljeni rezultati istraživanja diverziteta morskih školjki na potencijalnim lokalitetima za marikulturu duž otvorenog dijela crnogorskog primorja. Istraživanje je sprovedeno na ukupno šest lokaliteta, tokom proljeća i jeseni 2022. i 2024. godine, metodom autonomnog ronjenja na definisanim transektima. Svi vidljivi taksoni su ručno sakupljeni i determinisani u laboratoriji. Ukupno je identifikovano 59 vrsta školjki iz 23 porodice. Gotovo sav sakupljeni materijal su činile prazne ljušture, sakupljene su samo dvije žive jedinke (*Arca noae* i *Laevicardium crassum*). Najbrojnija je bila porodica Veneridae sa ukupno 12 vrsta. Na osnovu broja jedinki, dominantne vrste su bile: *Acanthocardia tuberculata, Arca noae, Barbatia barbata, Lithophaga lithophaga, Papillicardium papillosum, Rocelaria dubia, Striarca lactea* i *Venus verrucosa*. U komercijalno i potencijalno komercijalno važne vrste se ubrajaju: *Arca noae, Callista chione, Chamelea gallina, Flexopecten flexuosus, Flexopecten glaber, Mimachlamys varia, Mytilus galloprovincialis, Ostrea edulis, Polititapes aureus, Ruditapes decussatus* i *Venus verrucosa*. Na svim lokalitetima je evidentirano prisustvo zaštićene vrste, *Lithophaga lithophaga* koja je pod negativnim pritiskom ilegalnog izlova. Ni na jednom od istraživanih lokaliteta nije evidentirana kritično ugrožena vrsta *Pinna nobilis*. Alohtona vrsta *Fulvia fragilis* je evidentirana u blizini rta Mendra (lokalitet Valdanos 1).

Ključne riječi: akvakultura, diverzitet, mekušci, Jadransko more, Crna Gora