

RESEARCH ARTICLE

PRELIMINARY RESULTS OF RADIONUCLIDE MONITORING AND RISK ASSESSMENT FOR BIOTA IN THE MARINE ECOSYSTEM OF BOSNIA AND HERZEGOVINA

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ABSTRACT

The purpose of this paper is to provide an example of radioecological monitoring using the *Mytilus galloprovincialis* L. as an indicator organism, following the example of many Mussel Watch monitoring programs in the world. Using gamma spectrometric measurements and ERICA software for risk assessment, we offer the first results in a radioecological sense for the marine ecosystem of Bosnia and Herzegovina. Organisms that are at risk of manifesting the effects of higher radionuclide activities are birds, mammals, phytoplankton and reptiles. The highest risk coefficient of 5.73E+01 is for phytoplankton. If 5 kg of mussels are consumed by humans on an annual level, observed radionuclides would produce an effective dose of 25.6 μ Sv/a.

Keywords: ERICA risk assessment, Mussel Watch, Neum Bay, radioactivity

INTRODUCTION

The marine ecosystem of Bosnia and Herzegovina is insufficiently researched and monitored in every sense. This ecosystem, which is under great anthropogenic pressure, is actually a determinant of Bosnia and Herzegovina as a Mediterranean country. It is an essential part of the landscape and species biodiversity, but also an important source of renewable resources from aquaculture. As a prerequisite for coastal tourism, it is one of the essential determinants of the economy and income for the local community. Radiation monitoring in the Adriatic Sea has been taking place for many years, with the exception of our country. In neighboring Croatia, it takes place for ecological, sanitary and state security reasons.

The Neum and Mali Ston Bays, or rather, the part of them that belongs to BiH, are examples of semi-enclosed, large, shallow bays (Natura 2000 code 116), which are under great anthropogenic pressure. These two bays were protected as “special marine reserve” in 1983. The area that belongs to BiH was under the second class of protection. Unfortunately, after the establishment of borders between the newly formed states in the early 1990s, protection on the Croatian side was continued and improved, while it was completely suspended in Bosnia and Herzegovina. The Mali Ston Bay, as a special marine reserve, was declared a strict reserve (Milanović et al. 2015; Official Gazette of the Dubrovnik County, No. 09/02).

The influence of the Neretva river and other inland water bodies on this area which fully belongs to the category of coastal waters, is manifested by the lower salinity of the water and the presence of a large number of hot springs. Brackish water favors the development of bivalves (Copeland, 1996). In addition to the fact that inland waters largely determine the specificity of the coastal ecosystem, i.e. its physical and biocenological characteristics, they are also a potential source of contamination with heavy metals, plastics, radionuclides, organic substances, and microbiological pathogens (Jurina et al., 2013). Every year, 283 tons of plastic waste reaches the Adriatic Sea via the Neretva River, which is the fifth largest polluter in the Mediterranean (Guerranti et al., 2020). With its flow through terrestrial ecosystems that are contaminated in different ways, the river erodes waste and creates conditions for the accumulation of pollutants in sediment and water, and then for bioaccumulation and biomagnification in biocenoses (Chen et al., 2009).

Waste is so present in the seabed of the bay that it seems to be an indispensable part of the underwater landscape up to 200 meters from the shore. Untreated wastewater and a large number of bathers in the season are a potential source of microbiological contamination of the bay. Algal blooms are always a danger to humans, swimmers or consumers of aquaculture products. Also, heavy metals, radionuclides and microbes are potential

hazards if they accumulate in aquaculture products. Just as these pollutants accumulate and increase in the biota, climate change increases all these pressures through changes in the biotope and then in the biocenoses. As an example, we cite the effects of climate change and invasive alien species that can change relationships in ecosystems on a large scale. There are two reasons why biomonitoring is necessary in the management of this marine resource. The first is sanitary, that is, the safety of people during their stay in the water and when consuming food from local aquaculture. Another reason is the preservation of ecosystems and associated biocenoses. Assessment of the quality of the coastal ecosystem and the conservation status of the species in it are mandatory for BiH as a Mediterranean country. First of all, the first step is to choose the most efficient and economically acceptable programs and monitoring methods. This is actually the goal of this paper, to propose one such method (Bechard, 2007; Burgiel and Muir, 2010; Carvalho, 2018).

In 1975, Professor Edward D. Goldberg proposed the “Mussel Watch” program, which would use mussels to assess trends in chemicals of environmental importance in the coastal ocean, and after that, many “Mussel Watch”- type monitoring programs appeared on the local, regional, national and international levels with success, but within the initial limitations pointed out by Professor Goldberg.

Mussel *Mytilus galloprovincialis* L. is sedentary, widely distributed marine organism able to filter up to 80 l of seawater per day in optimal conditions (water temperature, food availability, reproductive cycle). High rates of accumulation of dissolved and particulate matter from seawater makes them a good bio-indicator species for environmental pollution studies as they directly reflect the level of contamination in habitat (Brenner et al., 2014; Krmpotić et al., 2015). Mussels extract and concentrate elements from the environment in which they grow but lack the ability to eliminate radioisotopes from its body (Assunta et al., 2008).

Most programs have evolved with their own

characteristics, building on experience from previous or ongoing programs. In the neighboring Mediterranean countries, the monitoring of radionuclides, heavy metals, plastics, and the state of the ecosystem was carried out based on the principles and recommendations of Professor Goldberg (Babarro et al., 2020; De Donno et al., 2008; Kilic et al., 2014; Krmpotić et al., 2015; Nonova and Tosheva, 2016; Orešćanin et al., 2006; Rozmarić et al., 2013; Thebault et al., 2008; Winterbourn et al., 2016). NOAA's National Status and Trends Program's Mussel Watch is still active in the USA (Farrington et al., 2016).

Considering these facts and the fact that until now there has been no monitoring of this type in Bosnia and Herzegovina, in the year 2022 we conducted experimental seasonal monitoring for spring and autumn at four locations in the Bosnia and

Herzegovina's coastal waters. This study presents preliminary results of radionuclide monitoring and biota impact assessment to demonstrate the simplicity and effectiveness of this method in monitoring selected descriptors of marine ecosystem quality in biological and public health terms.

MATERIALS AND METHODS

Sampling and sample preparation

Sampling of sediment and mussels was carried out at the locations shown in Figure 1.

Seawater samples were collected in 25 l containers at a depth of 1 m and evaporated to approximately 250 ml, resulting in a mixture of water and salt. The residue was weighed and sealed in 200 ml

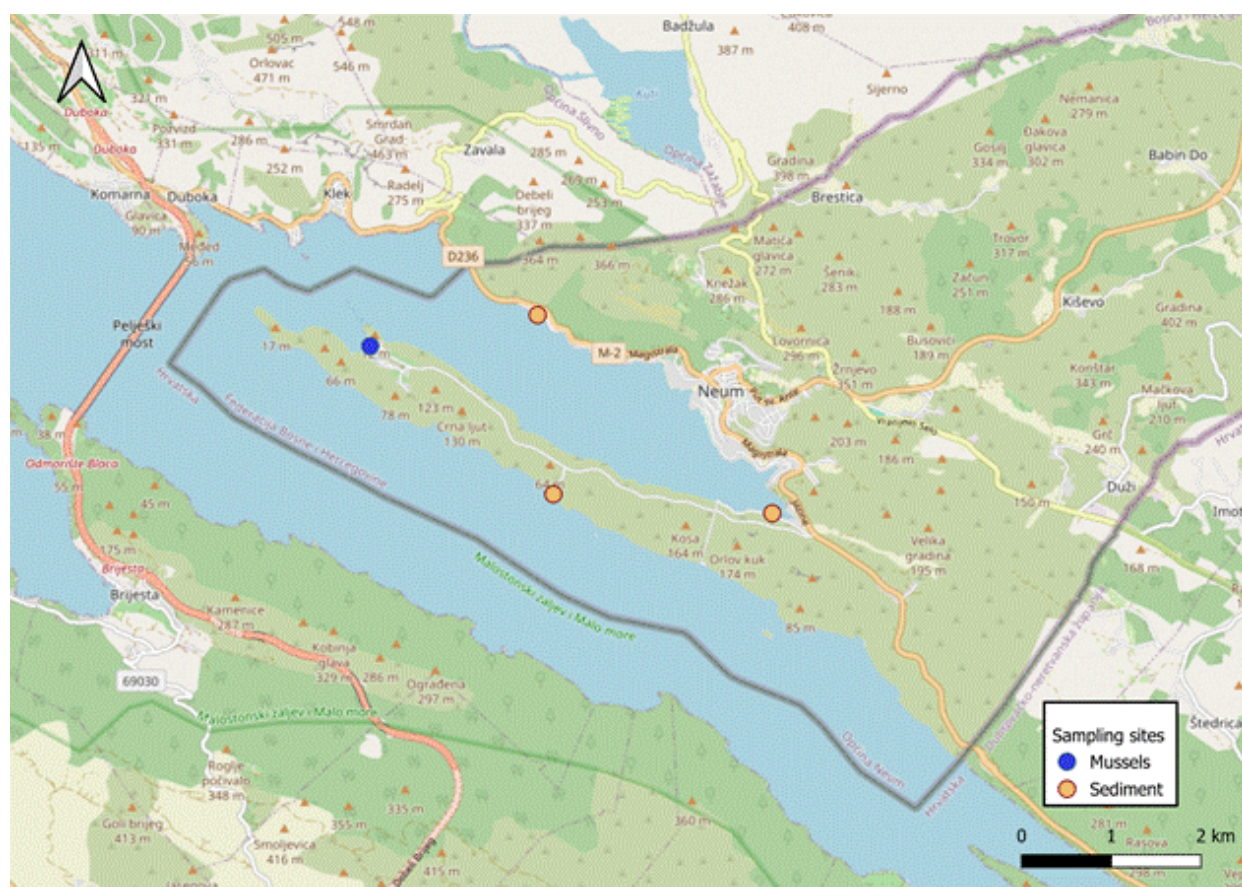


Figure 1 Map of the investigated area with sampling sites

cylindrical plastic containers. The samples were stored for one month before measurement (Petrinec et al., 2012).

Sediment samples were collected in a canister for underwater sampling, then dried in the laboratory at 80-105°C and homogenized. The dried samples were subsequently packed into cylindrical plastic containers, sealed and measured. Mussels were sampled twice, in spring and autumn, at the location shown in Figure 1. Approximately 7 kg of fresh mussels were collected per sample. The shells were opened using a microwave oven, and soft tissue was extracted for analysis. The mussel tissue was homogenized and air-dried before being further homogenized in a blender and fully dried in an oven at 80-105°C. Finally, the dried mussels were homogenized again and packed into appropriate containers, as described in detail in the next section (Petrinec et al., 2012).

Measurements - Gamma ray spectrometry

For gamma spectrometry analysis, samples were packed in 200 ml cylindrical plastic containers 36 mm high and 90 mm in diameter, sealed and measured for 350000 s. Gamma spectrometry analysis was used to determine the activity concentrations of observed radionuclides. The gamma spectrometric analysis was conducted using a BSI (Baltic Scientific Instruments) HPGe gamma spectrometer equipped with a P-type detector. The detector was protected by a 15 cm thick lead shield lined inside with copper and cadmium foil. The detector has a relative efficiency of 50% at the energy of 1332 keV emitted by Co-60, and it provides a resolution (FWHM) of 1.9 keV at 1332keV. The levels of all reported radionuclides were determined from their specific gamma lines or from gamma lines of their daughter products. Quality control procedures were included in the operating activities of the laboratory accredited by BAS EN ISO/IEC 17025:2018. Gamma spectrometric system was calibrated for energy and absolute efficiency using standard “multinuclide mix” certified reference material (CRM) containing energies from 59.54 keV (Am-241) to 1836.07 keV (Y-88). This

procedure was validated using IAEA reference materials of different composition collected by participation in ALMERA proficiency tests, which is mandatory for ISO/IEC 17025:2018 accredited laboratory. The activity concentrations of radionuclides were determined using calculations previously described in the article by Gradašćević et al., 2023.

Dose estimation and modeling

The ERICA assessment tool was one of the products of the ERICA project (Environmental Risk from Ionizing Pollutants: Assessment and Management, 2004–2007). The ERICA Integrated Approach and the ERICA Tool are two important outcomes of the project. Three components make up the ERICA integrated approach: assessment, risk characterization and management. ERICA tool consists of three compartments (Tiers), designed for use in all ecosystems with multiple scenarios. ERICA Integrated Approach and the ERICA Tool offer an affordable, accessible and user-friendly method of conducting a radiological risk assessment, while still providing a very significant scientific basis for a complex decision-making process in an interdisciplinary context of environmental issues (Prlić et al., 2017).

Level (Tier) 2 of the ERICA Risk Assessment Tool was used for dose calculations and risk assessment. Average sediment and mussels' activity concentrations for specific radionuclides and concentration of Cs-137 in seawater are used as input data for estimating concentration rates and activity dose to marine biota represented by all available reference organisms in ERICA database (Table 1, Table 2). Since the ERICA Assessment Tool database lacks data for concentration ratios for all reference organisms for K-40, the isotope is excluded from the calculation. All parameters are left as predefined. This includes all concentration ratios for the various reference organisms, occupancy factors, which indicate which habitat a particular organism lives in (water surface, water, sediment surface, and sediment), and radiation weighing factors (10 for alpha, 1 for beta and gamma, and 3 for low beta). Dose rate screening

values are set to 40 $\mu\text{Gy/h}$ for terrestrial animals, birds, amphibians and reptiles, and 400 $\mu\text{Gy/h}$ for plants and other aquatic organisms. It has previously been suggested that below these values (of chronic exposures) no measurable population effects would occur. Uncertainty factor is set to $\text{UF}=3$, this tests for 5% probability of exceeding the dose value, assuming that the risk quotient distribution is exponential (IAEA 1992; USDOE 2002; UNSCEAR 1996).

RESULTS

The results of radionuclide activity concentrations and dose assessments are summarized in Tables 1 to 3. Table 1 shows ERICA assessment outcomes, including measured activity concentrations in sediment, Cs-137 levels in seawater, and estimated activities for other radionuclides in water medium. Table 2 presents radionuclide activity concentrations in mussels (*Mytilus galloprovincialis* L) collected during spring and autumn, allowing comparison of seasonal variations in this area. Table 3 summarizes the assessment of activity concentrations in marine organisms (in Bq/kg fresh weight), including the calculated risk quotient and total dose rate. This allows evaluation of potential radiological risks to marine biota.

Table 1 ERICA - Results for measurement of activity concentration in sediment and for Cs-137 in water, and assessment of activities for water medium (all others).

Isotope	Activity Concentration in water [Bq L ⁻¹]	Activity Concentration in sediment [Bq kg ⁻¹ d.w.]
Th-234	3.84E-01	4.08E+01
Cs-137	3.62E+00	3.86E+04
Pb-210	1.75E-01	5.94E+01
Ra-226	1.78E-01	3.11E+01
Ac-228	2.11E+01	9.76E+00
U-238	3.51E-01	9.35E+02
Ba-137m	3.42E+00	3.65E+04
Bi-210	1.75E-01	5.94E+01
Po-218	1.78E-01	3.11E+01
Bi-214	1.78E-01	3.11E+01
Pb-214	1.78E-01	3.11E+01
Po-214	1.78E-01	3.11E+01
Pa-234m	3.84E-01	4.08E+01

Table 2 Results of radionuclide measurements in mussels for spring and autumn

Isotop	Spring Kg f.w.	Bq/ uncertain- ty	A u t u m n Bq/Kg f.w.	uncertainty	Mean	SEM
BE-7	9.81	0.98	5.80	0.84	7.80	0.64
TH-234	18.51	2.74	14.06	3.40	16.28	2.18
K-40	117.34	6.88	136.24	6.19	126.79	4.63
CS-137	0.03	0.02	0.04	0.02	0.04	0.01
PB-210	6.12	1.04	6.25	0.96	6.18	0.71
RA-226	0.18	0.06	0.27	0.24	0.22	0.12
AC-228	0.13	0.12	0.17	0.10	0.15	0.08
U-238	1.11	0.67	1.26	0.68	1.19	0.47

Table 3 Assessment of activity concentrations in organisms (Bq/kg fresh weight) with Risk quotient and Total Dose Rate

ncentration in or- ganisms Bq/Kg f.w.	Benthic fish	Bird	Crustacean	Macroalgae	Mammal	Mol- lusc-bi- valve	Pelagic fish	Phyto- plankton	Polychaete	Reptile	Anemones	V. plant	Zooplankton
Th-234	2.14E+01	2.14E+01	1.26E+02	5.33E+02	2.14E+01	1.63E+01	2.14E+01	1.96E+05	1.12E+02	2.14E+01	1.68E+02	5.33E+02	1.20E+03
Cs-137	2.95E+02	1.72E+03	1.88E+02	3.08E+02	7.65E+02	4.00E-02	2.95E+02	3.08E+01	6.48E+02	1.72E+03	8.41E+02	3.76E+01	4.73E+02
Pb-210	5.29E+03	3.30E+03	3.53E+03	1.65E+02	3.30E+03	6.18E+00	5.29E+03	7.72E+04	6.98E+03	3.30E+03	6.98E+03	1.65E+02	2.85E+03
Ra-226	2.45E+01	2.85E+01	1.53E+01	2.96E+01	2.85E+01	2.20E-01	2.45E+01	1.20E+02	8.34E+01	2.85E+01	1.53E+01	2.96E+01	5.35E+00
Ac-228	2.45E+02	2.22E+02	1.32E+02	6.42E+03	2.22E+02	1.50E-01	2.45E+02	3.81E+05	1.77E+02	2.22E+02	1.76E+02	6.42E+03	1.26E+03
U-238	1.61E+00	4.39E+01	2.21E+00	2.39E+01	4.39E+01	1.19E+00	1.61E+00	7.66E+01	3.45E+02	4.39E+01	3.45E+02	8.25E+01	9.03E-01
Ba-137m	3.84E-03	3.08E-02	9.03E-02	3.05E-02	3.08E-02	1.20E-01	3.84E-03	2.95E-02	1.20E-01	3.08E-02	9.03E-02	1.16E-01	9.03E-02
Bi-210	4.50E+00	4.50E+00	1.90E+00	5.48E-01	4.50E+00	1.90E+00	4.50E+00	5.48E-01	1.90E+00	4.50E+00	1.90E+00	5.48E-01	1.90E+00
Po-218	9.65E-01	1.18E+00	2.69E+00	1.07E-01	1.18E+00	7.28E-01	9.65E-01	2.75E+00	6.07E+00	1.18E+00	6.07E+00	1.07E-01	1.28E+00
Bi-214	1.47E-02	1.47E-02	6.21E-03	2.30E-03	1.47E-02	6.21E-03	1.47E-02	2.30E-03	6.21E-03	1.47E-02	6.21E-03	2.30E-03	6.21E-03
Pb-214	3.34E+00	2.09E+00	2.23E+00	3.11E-01	2.09E+00	1.95E-03	3.34E+00	1.46E+02	4.41E+00	2.09E+00	4.41E+00	3.11E-01	1.80E+00
Po-214	8.53E-07	1.04E-06	2.38E-06	9.47E-08	1.04E-06	6.43E-07	8.53E-07	2.43E-06	5.36E-06	1.04E-06	5.36E-06	9.47E-08	1.13E-06
Pa-234m	1.42E-02	1.29E-02	7.69E-03	3.79E-01	1.29E-02	6.80E-03	1.42E-02	2.26E+01	1.03E-02	1.29E-02	1.02E-02	3.79E-01	7.31E-02
Risk quotient (Unitless)	2.80E-01	1.84E+00	1.87E-01	9.47E-01	1.84E+00	1.62E-02	2.65E-01	5.73E+01	4.00E-01	1.84E+00	3.61E-01	9.50E-01	3.00E-01
Total Dose Rate per organism μGy/h	1.12E+02	7.34E+01	7.47E+01	3.79E+02	7.34E+01	6.48E+00	1.06E+02	2.29E+04	1.60E+02	7.37E+01	1.44E+02	3.80E+02	1.20E+02

DISCUSSION AND CONCLUSION

Activity concentrations of natural radionuclides Be-7, K-40, Th-234, Ra-226, Ac-228, Pb-210, Tl-208, U-238 and anthropogenic Cs-137 were determined in dry soft tissue of mussels collected in Neum Bay in 2022. Be-7 activity concentrations for all sampling locations were found to range between 31.87 and 14.49 Bq/kg f.w. Activities determined in early spring are higher than those measured in early autumn (40,89% decrease), which can be attributed to its input into the marine environment almost exclusively by atmospheric precipitation (rain/snow) and freshwater from the interior. Seasonal spring-autumn decrease in activity concentration of Be-7 was 40,89 %. The reason for that could be seasonal variation in Be-7

air concentration recorded by the other authors and explained by increased growth of Be-7 aerosols in humid conditions, and consequent higher precipitation on the surface (Young Hyun Cho, 2007). K-40 activity concentrations did not differ significantly, and average activities are 360.99 ± 4.63 Bq/kg f.w. This behavior of K-40 can be attributed to its high and uniform concentration in the oceans, which consequently does not change levels in coastal marine waters (De Donno et al., 2020). As can be seen in the comparative table (Table 4), our results are in agreement with the results of monitoring in Mali Ston Bay, which was carried out from 2009-2013 as part of the project "Radionuclides and trace elements in environmental systems" published in 2015 in the work of Krmpotić et al.

Table 4 Comparison of activity concentrations in *Mytilus galloprovincialis* from Croatian and BiH part of the Adriatic Sea

			Activity concentration Bq/kg dry weight				
	Authors	Location	Be-7	K-40	Ra-226	U-238	Cs-137
Spring	Krmpotić et al. 2009-2013	Mali Ston bay CRO	78.3 ± 45.9	283 ± 58	<3.1	<10.6	<0.3
	Our results 2022	Neum, BiH	31.9 ± 0.9	381.4 ± 6.8	0.6 ± 0.1	3.6 ± 0.7	0.1 ± 0.02
Autumn	Krmpotić et al. 2009-2013	CRO	23.1 ± 12.7	292 ± 42	<2.9	<13.1	<0.4
	Our results 2022	Neum, BiH	14.5 ± 0.8	340.6 ± 6.2	0.7 ± 0.2	3.2 ± 0.7	0.1 ± 0.02

Organisms that are at risk of manifesting the effects of higher radionuclide activities are birds, mammals, phytoplankton and reptiles. The highest risk coefficient is for phytoplankton. The risk coefficient for organisms is in the range of $1.62E-02$ for molluscs-bivalvia, and up to $5.73E+01$ for phytoplankton. Total dose rates are highest for phytoplankton $2.29E+04$ and lowest for molluscs $6.48E+00$. Exceeded doses were in the interval of 10 - 100 μ Sv/h for birds, mammals and reptiles.

For all of these three groups Pb-210 accounts for 74.84 %, Ac-228 for 17.28 % and Ra-226 for 5.42 % of the total dose. In the case of phytoplankton, the doses are exceeded 50 times than the screening limits are set. Ac-228 accounts for 94,24 % of the total dose measured for phytoplankton ($22903,38 \mu$ Gy / h), and Pb-210 accounts for 5.57 % or 1275.48μ Gy/h, which is still 3 times higher than the screening limit of 400 μ Gy/h.

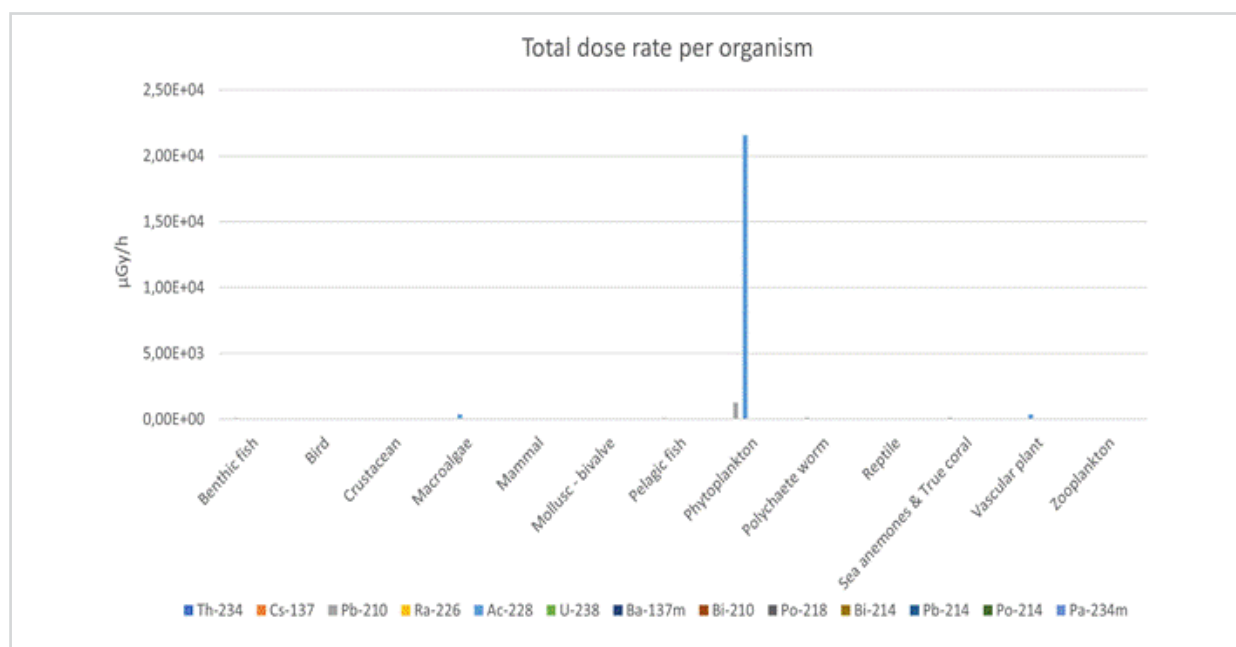


Figure 2 Total dose rate for individual organisms

If 5 kg of mussels are consumed on an annual level, observed radionuclides would produce an effective dose of 25.6 $\mu\text{Sv/a}$. The value indicated higher intake concerning the fact the Po-210, as the primary contributor, has not been included in dose-calculation. It can be concluded on the basis of results shown in Table 5. By comparing the annual effective ingestion doses ($\mu\text{Sv/a}$) from various radionuclides received through mussel consumption in different regions for the adult population, it can be concluded that the value obtained in this study generally aligns with the expected results. Effective dose coefficients for ingestion of radionuclides for members of the public from ICRP 119 (2012) show that Po-210 has a much higher dose coefficient due to its alpha

emissions, making it more dangerous isotope in terms of ingestion exposure. Since the polonium is not observed in this study, it is expected that the dose from gamma-emitting radionuclides in this study will be lower than doses calculated in other studies that included Po-210 as well. For comparison, Rožmarić (2012) calculated the dose due to Po-210 and Pb-210 as $202 \pm 99 \mu\text{Sv/a}$, with an assumption of 2 kg of mussels being consumed. In this study, the dose was calculated on the basis of ingestion of 5 kg of mussels annually, which is the highest value expected. Estimates and further measurements of the annual doses ingested by our citizens and tourists through the ingestion of aquaculture food are necessary.

Table 5 Annual effective ingestion doses ($\mu\text{Sv/a}$) from various radionuclides received through mussel consumption in different regions for the adult population

Study	Region	Observed radionuclides	Dose $\mu\text{Sv/a}$	m (kg) for dose calculation
Rožmarić (2012)	Croatian Adriatic coast	Po-210, Pb-210	202 ± 99	2
Štok (2011)	Slovenian part of the Adriatic Sea	Po-210, Pb-210	8.7	0.09
Trotta (2024)	Apulian coast (Italy)	U-238,U-234, U-235, Po-210,Pb-210, Sr-90	5.3	1
Jia (2020)	Six sampling sites in Italy	U-238,U-234, U-235, Po-210,Pb-210, Th-234, Th-230, Th-228, Ra-226, Ra-224, Ra-228, K-40	131-765	6.16
Fonollosa (2016)	Ebro Delta area, Spain	U-238,U-234, Po-210,Pb-210	100.7	1.15
This study	Adriatic Sea, Bosnia and Herzegovina	Be-7, Th-234, K-40, Cs-137, Pb-210, Ra-226, Ac-228, U-238	25.6	5

Table 6 Proven effects of doses on individual organisms

Effects	
Birds	Increase in infestations with parasites of feather and gastroenterine (no value given)
Mammals	Major effect in percentage of voles infected with ectoparasites and low-fatness voles in population (3- fold increase)
	Moderate decrease of life-span (30% decrease)
	Significant increase of life span (1.3 times the control value) – Mice
	Moderate decrease of otter population density (33% reduction)
	Minor decrease of peripheral blood cells (15-50% reversible reduction)
	Minor decrease of body weight (10% reduction). No statistically significant effect on hair density
Reptiles	No data in FREDERICA for effects observed at this dose rate range
Phytoplankton	No data in FREDERICA for effects observed at this dose rate range
> 10000	Minor stimulating effect on growth (1.2-fold)

The assessment of the risk coefficient indicates several groups at risk that should be paid attention to. If we take into account that phytoplankton is the basis of the trophic chain of the marine ecosystem, we can conclude that the danger of potential bioaccumulation of radionuclides in higher levels of the trophic chain is a serious and already obvious problem that needs attention. Insufficient data on the effects of radiation on living organisms at these doses and for individual groups does not mean that there is no risk for the biota (Table 6), but that we should pay more attention in accordance with the consensus symposium organized by the International Union of Radioecology (IUR) in November, 2015 (Prlić et al., 2017), which offered strong statements regarding the ecological effects of radiation on populations and ecosystems while

moving towards from an anthropocentric to an ecocentric approach in environmental protection.

CONFLICT OF INTEREST

The authors declared that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

Conception: MČ; Design: MČ; Supervision: AA, NG; Materials: MČ, NG; Data Collection and/or Processing: MČ, NM; Analysis and/or Interpretation: MČ, NK, NM, AA; Literature Search: MČ, NK, NM; Writing– Original Draft: MČ, NK, NG; Critical Review: AA, NG

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PRELIMINARNI REZULTATI PRAĆENJA RADIONUKLIDA I PROCJENA RIZIKA ZA BIOTU MORSKOG EKOSISTEMA BOSNE I HERCEGOVINE

SAŽETAK

Cilj istraživanja je, slijedeći primjer mnogih svjetskih programa za praćenje dagnji, prikazati primjer radioekološkog praćenja korištenjem *Mytilus galloprovincialis* L. kao indikatora. Koristeći gama spektrometrijska mjerenja i ERICA softver za procjenu rizika, prikazujemo prve rezultate u radioekološkom smislu koji se odnose na morski ekosistem Bosne i Hercegovine. Organizmi koji su pod rizikom manifestiranja efekata pojačane radionuklidne aktivnosti uključuju ptice, sisare, fitoplankton i reptili. Najveći koeficijent rizika iznosi $5.73E+01$ za fitoplankton. U slučaju godišnje konzumacije 5 kg dagnji od strane čovjeka, ispitivani radionuklidi bi proizveli efektivnu dozu zračenja od $25.6 \mu\text{Sv/a}$.

Ključne riječi: ERICA procjena rizika, Neumski zaljev, praćenje dagnji, radioaktivnost