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Radioactivity in the Mediterranean flora of the Kaštela Bay, Croatia

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ABSTRACT

This study refers to background activity concentrations of ^{238}U, ^{226}Ra, ^{232}Th, ^{208}Tl, ^{40}K, and ^{137}Cs in soil and plants of the Kaštela Bay, Croatia and related plant-soil concentration ratios (CR's). Fourteen different Mediterranean plant species growing in natural conditions have been included and were divided into three major plant groups (grasses and herbs, shrub, tree). Radionuclide activity concentrations were determined by means of high resolution gamma-ray spectrometry. Soil parameters (pH, electrical conductivity, and organic matter content) were also analysed. CR ranges were within one order of magnitude for ^{40}K (10^{-2}–10^{-1}), ^{238}U, and ^{226}Ra (10^{-3}–10^{-2}), and two orders of magnitude for ^{232}Th, ^{208}Tl, and ^{137}Cs (10^{-4}–10^{-2}). There was no statistical difference between the plant groups in radionuclide uptake. Overall statistical analyses indicated a moderate negative relationship between soil concentrations and CR values, and no relationship with soil parameters, except a negative one for ^{137}Cs. Comparison with literature showed more agreement with studies that were done in the Mediterranean than with ICRP and IAEA databases. Our data not only describe the natural radioactivity of the Bay, but also create a dataset that could be relevant for further radioecological assessments of the Kaštela Bay.

1. Introduction

Due to the complexity of natural processes, it is difficult to predict the behaviour of a particular radionuclide within a given ecosystem and/or organism. For many radioactive elements, concentration ratios (CR's) are available for only about 10% of different plant/soil combinations and generally exhibit large variability in radionuclide transfer even within plants of same taxonomic rank (Hinton et al., 2013; Howard et al., 2013a; Vandenhove et al., 2009). Furthermore, naturally occurring radionuclides have received less research attention compared to artificially produced radionuclides that have been the focus since the first atmospheric nuclear weapon tests (Mitchell et al., 2013; Shtangeeva, 2010; Vandenhove et al., 2009). The majority of current knowledge on behaviour and transfer of natural radionuclides have been acquired through studies on polluted sites (Chen et al., 2005; Vera Tomé et al., 2002) and areas with elevated natural background radiation (Termizi Ramli et al., 2005) or in studies with "spiked" soils (Vandenhove et al., 2007; Vandenhove and Van Hees, 2007). Fewer data are available from unpolluted sites (Beresford et al., 2008; Shtangeeva, 2010).

In this study, we focus on the background activity concentrations of radionuclides in the soil of Kaštela Bay, Croatia, and their transfer into the local Mediterranean flora. The bay is located on the eastern coast of the middle Adriatic Sea. In the second half of the 20th century, it was exposed to different types of pollution, including radioactivity originating from coal used to power a nearby factory (no longer in operation). This coal comprised naturally occurring radionuclides (mainly from uranium and thorium decay chains), whereas its combustion products, i.e. ash and slag of elevated radioactivity, were disposed locally. Over the years, the disposal site for the ash and slag has been colonised by different Mediterranean plants. To put the transfer of radionuclides from the coal ash and slag to vegetation into context, we needed data on the radioactivity and transfer of radionuclides from soil to plant in natural background conditions of the Bay.

For Mediterranean ecosystems, studies on the distribution of radionuclides and their transfer from soil to plant have been mostly performed around disused uranium mines or nuclear power plants (Baeza et al., 2001; Rodriguez et al., 2010; Vera Tome et al., 2002, 2003). Therefore, we were motivated to carry out our study to establish a dataset on background soil and plant activity concentrations and related CR values for Kaštela Bay against which data from contaminated site can be compared. Howard et al. (2013b) identified which ICRP reference plant–radionuclide combinations can be designated as high priority for future research needs. These

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are Pine Tree/^{238}U, and Wild Grass/^{226}Ra, ^{232}Th, ^{238}U, which overlap with the radionuclides and plants in our study. These authors also suggested that variation in soil-to-plant radionuclide transfer can be caused by different soil types, and therefore site-specific assessment might be justified in some cases. Since, the Mediterranean region is more diverse in soil types than any other climatic region (Verheye and de la Rosa, 2009), site–specific assessment based on field-experiment results, not extrapolated CR values, might also be justified for this Bay.

Our study focused on natural radionuclides ^{238}U, ^{226}Ra, ^{232}Th, ^{208}Tl, ^{40}K, and an anthropogenic radionuclide with high variability in radionuclide transfer from soil to plants, ^{137}Cs (IAEA, 2009). It includes a total of 14 different Mediterranean plant species growing in natural background conditions. The aim was to collect data on activity concentrations in soil and plants and calculate the resultant transfer of radionuclides between them. The purpose of these data was not only to describe natural radioactivity of the Bay, but also to create a dataset that could be important for further radioecological assessments of Kaštela Bay.

2. Description of the area

Kaštela Bay (Fig. 1) is a synclinal fold transgraded in the Post-pleistocene stage, made of Eocene flysch and Eocene marly limestone (Hidroelektra-projekt, 2004). It is a semi-enclosed bay in the middle Adriatic Sea (Ujević et al., 2000).

The climate in the Bay is typically Mediterranean. The average annual temperature is 15.9 °C, with a minimum monthly average of 8.0 °C in January, and a maximum of 25.9 °C in July. The average annual rainfall is 820.6 mm, and the average relative humidity is 66%. The area is rather windy, with 75% of winds being stronger than 12–19 kmh^{-1} (Hidroelektra-projekt, 2004).

The Kaštela coast and the northern slopes of the nearby island of Čiovo (see Fig. 1) are covered with maquis of *Orno-Quercetum ilicis* and *Cymbopogoni-Brachypodion* grasslands in karst, and *Clematido-Spartietum* heath and *Vulpio-Lotion* meadows in flysch. The southern slopes of Čiovo island, which are the warmest and driest, are dominated by maquis of *Myrto-Pistacietum lentisci*. The coastal halophytic vegetation in the Pantan lagoon includes *Juncetum maritimi-acuti* and *Bolboschoeno-Scirpetum litoralis*. Elsewhere in the lagoon rocky shores, *Plantagini-Limonietum cancellati* occurs, whereas *Euphorbio-Glaucietum flavi* is found in the beach coves. Since autumn and winter are the rainy seasons in the area, vegetation growth in the Bay is favoured within these periods (Lovrić and Oleg, 1999).

The island of Čiovo is a part of the Bay and has the same geology and vegetation as described above. But, unlike other parts of the Bay, it was not affected heavily by previous industry activities and urbanisation. Also, it has many areas that have not been affected by agriculture at all or have not been used for that purpose in decades. Therefore, we considered it as suitable area for collecting data on background radioactivity. An additional sampling point Pantan lagoon, which is a natural reservation, was added as representative of halophytic vegetation.

The impact of previous industrial activities and waste disposal site of coal and ash on sampling locations can be neglected since they are at a sufficient distance (Dai et al., 2007; Flues et al., 2002). Čiovo is approximately at a 8.5 km aerial distance from the waste disposal site, and Pantan lagoon at 11 km.

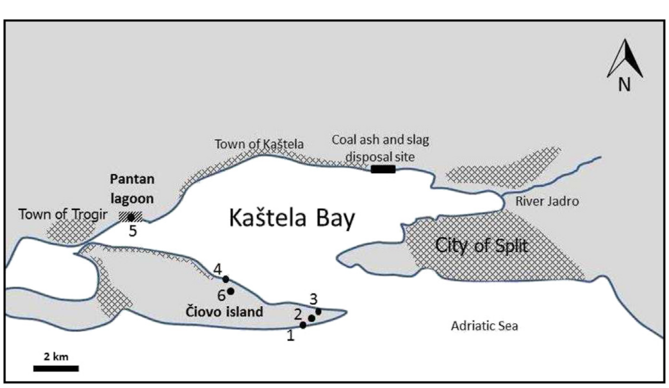

Fig. 1. Kaštela Bay with sampling locations [Čiovo island (1,2,3,4,6) and Pantan lagoon (5)] and marked major urbanised areas.

3. Materials and methods

3.1. Sampling

Sampling of soil and plants was carried out on six locations (see Fig. 1) in March 2011, prior to Fukushima accident releases. Five sampling locations were located on the island of Čiovo, and one in the Pantan lagoon. Sampling was performed in zones which have neither been urbanised nor affected by industry. Specific sampling locations were determined based on the presence of different plant species and site accessibility (e.g., southern slopes of the Čiovo island are very steep and unapproachable).

We collected 6 soil samples and 16 samples of 14 different plant species. While most of the plant samples represent typical terrestrial plants, two (Spiny Rush and Common Reed), collected at the Pantan lagoon, belong to halophytic vegetation. All these plant species can be considered common for the Mediterranean.

The type of terrain determined our sampling method (rocky area with dry soil) and tools used (shovel instead of corer). Soil samples were taken in squares 15 cm × 15 cm, taking approximately the first 10 cm soil layer. Each soil sample for single sampling location represented a composite material taken from a few points over approximately 1 m^2, with a total sample mass of 3–4 kg (fresh mass). Roots and bigger stones were removed immediately.

A minimum of 1 kg (fresh mass) of each plant species was collected within a 10 m radius of the area where the soil was

Table 1
List of plant species collected on island Čiovo and Pantan lagoon. Plant samples are divided into three major groups according to their association with reference plant groups used by Brown et al. (2008).

Latin name	Plant group	Common name	Sampling location
Helichrysum italicum (Roth) G. Don	Grasses & herbs	Curry plant	1
Piptatherum miliaceum (L.) Coss.	Grasses & herbs	Smilo grass	2
Dittrichia viscosa (L.) Greuter	Grasses & herbs	Sticky fleabane	3
Phragmites australis (Cav.) Trin. eX Steud.	Grasses & herbs	Common reed	5
Juncus acutus L.	Grasses & herbs	Spiny rush	5
Pistacia lentiscus L.	Shrub	Mastic	1, 6
Spartium junceum L.	Shrub	Spanish broom	2, 6
Rubus heteromorphus Ripart eX Genev.	Shrub	Blackberry	3
Pittosporum tobira (Thunb.)Aiton	Shrub	Japanese Pittosporum	4
Nerium oleander L.	Shrub	Oleander	4
Ficus carica L.	Tree	Fig	3
Pinus halepensis Mill.	Tree	Pine tree	1
Cupressus sempervirens L.	Tree	Mediterranean cypress	2
Tamarix dalmatica Baum	Tree	Tamarisk	3