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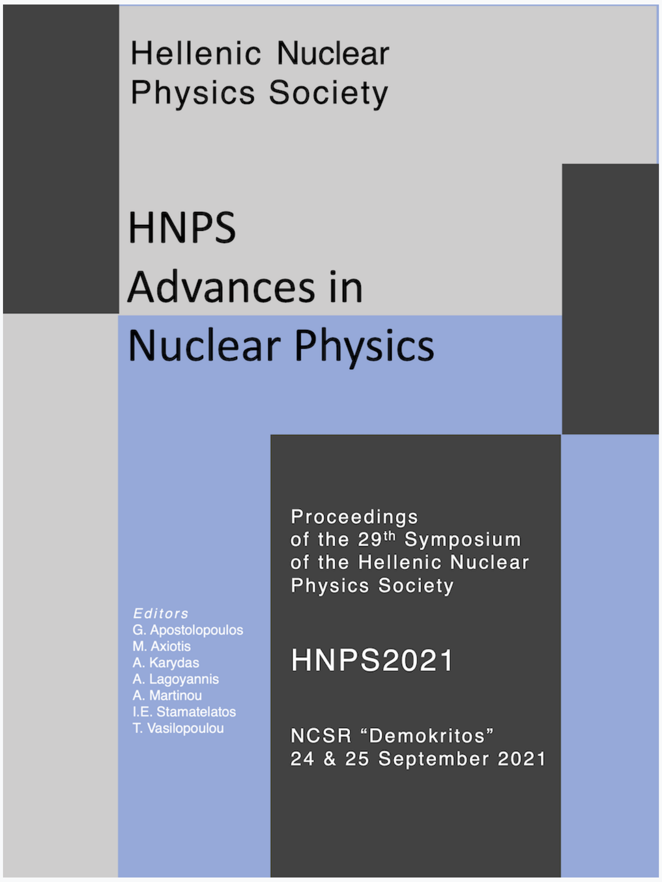


# Dose rate assessment of 137Cs to mussels and pelagic fish from the combined use of field measurements, satellite data and the ERICA Assessment Tool

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# Dose rate assessment of $^{137}$Cs to mussels and pelagic fish from the combined use of field measurements, satellite data and the ERICA Assessment Tool

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**Abstract** Cesium-137 ($^{137}$Cs) is the most important indicator of radioactive pollution in the marine environment due to its half-life (Tph: 30.2 years), its high fission yield, its solubility (70% in ionic form) and its bioavailability (similar to potassium). Soluble radionuclides, like $^{137}$Cs, in the seawater are associated with physicogeochemical and biological parameters of the marine environment (e.g. temperature, water density, biota exchange processes, water mass translocation etc.). Considering this characteristic, we investigate the potential relation between $^{137}$Cs activity concentration and sea surface temperature (SST). The parameter of SST is selected, as the element of cesium in the seawater is conservative and its horizontal and vertical dispersion depends on the water mass translocation and water currents. Water mass translocation and water currents are processes that are both governed by the SST. SST also influences the uptake of $^{137}$Cs in some marine organisms as it makes it more bioavailable and affects the biological retention time and the elimination rate. The study area is the Gulf of Corinth (Greece). $^{137}$Cs in the Gulf of Corinth originates from water runnoff from the land (Chernobyl fallout from 1986) and a small influence exists from the Ionian and Aegean Sea water currents. A total of 17 measurements spanning 2004-2005, of $^{137}$Cs activity concentrations were retrieved from the Environmental Radioactivity Laboratory (ERL) database of NCSR "D". Furthermore, SST measurements issued from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS). Databases of $^{137}$Cs activity concentrations and SST are used for regression analysis and definition of a linear model. The estimated $^{137}$Cs activity concentrations obtained by the model are then compared with the newest measured values obtained by seawater samples from September and November 2018 (a total of 8 seawater samples). Estimated concentrations present a relative difference of about 9% to the measured values. In order to conduct the risk assessment analysis in the studied area, the dose rates are calculated for marine organisms. The selected marine organisms are mussels and pelagic fish that are abundant in the area and have significant commercial value, with mussels also being an important bioindicator of marine pollution. The total dose rates in these organisms (resulting by both the internal and external exposure) vary from $3.30\times10^{-1}$ to $5.40\times10^{-1}$ μGy/year for the mussels and from $2.97\times10^{-1}$ to $4.86\times10^{-1}$ μGy/year for pelagic fish, which are much lower that the intervention levels, indicating low impact due to the $^{137}$Cs exposure.

**Keywords** Artificial radionuclides, Satellite data, Activity concentration, Marine organisms, Radiological risk assessment

## INTRODUCTION

An innovative system is created for radiological risk assessment in the area of Gulf of Corinth. The Gulf of Corinth is a marine embayment that separates continental Greece from the Peloponnese [1,2]. Cs-137 in the Gulf of Corinth originates from water runoff from the land (Chernobyl fallout from 1986) and a small influence exists from the Ionian and Aegean Sea water currents [1,3,4,5].

So far, is not possible to monitor soluble radionuclides (i.e. $^{137}$Cs) in the marine environment by using EO (Earth Observation). Nevertheless, radionuclides in the marine environment are known to be

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associated with the physical-biogeochemical parameters of the natural environment. Considering this attribute, we investigate the potential relation between $^{137}$Cs activity concentration and sea surface temperature (SST). The investigation of $^{137}$Cs with the SST parameter, in particular, has been chosen due to the fact that, the element of Cs in the seawater is conservative and its dispersion depends on seawater density and water mass transportation [6,7,8]. SST has a great role in the sea water density and water mass transportation [9,10]. SST is also important as it seems to influence the biological retention time of the pollutants and consequently the elimination rate of the pollutants from the organisms [11]. The potential relation of $^{137}$Cs activity concentration and SST, will result in a model crucial for the creation of a multidisciplinary system of radiological risk analysis for the Gulf of Corinth. Radiological risk assessment for pelagic fish and mussels, is important as anthropogenic activities like fishery facilities and professional fishermen with boats, bauxite mining and bauxite processing are taking place in the Gulf [5,12,13,14]. Thus, the objectives of this study are the following: (i) to examine the relation of $^{137}$Cs activity concentration from the database of the Environmental Radioactivity Laboratory (ERL) of NCSR "D" and SST from Moderate Resolution Imaging Spectroradiometer (MODIS) (NASA) for the creation of a model using $^{137}$Cs activity concentration and SST data, (ii) to validate the resulting linear model with new $^{137}$Cs measurements, and (iii) to conduct a preliminary the risk assessment in the marine area of the Corinthian Gulf using the ERICA Assessment Tool for the most representative organisms of that region, pelagic fish and mussels.

## MATERIALS AND METHODS

### *Study Area*

The Gulf of Corinth is a marine embayment with an average width of 30 km and maximum depth of about 900m (in the central part), that separates continental Greece from the Peloponnese (Fig. 1). The Gulf waters present a variating SST of 13ºC in the winter and 26ºC in the summer, with thermal stratification during the summer [1,2]. The anthropogenic activities in the gulf include fishery facilities and professional fishermen with boats, bauxite mining and bauxite processing. Furthermore, the Gulf is a part of Natura 2000 areas presenting high biodiversity and productivity of marine habitats [5,12,13,14].

Cs-137 in the Gulf of Corinth originates from water runoff from the land (Chernobyl fallout from 1986) and a small influence exists from the Ionian and Aegean Sea water currents. Sediment $^{137}$Cs activity concentration in Gulf after the year 2000 was about 1.1 ± 0.5 to 4.6 ± 1.9 Bq Kg$^{-1}$ [1,3-5].

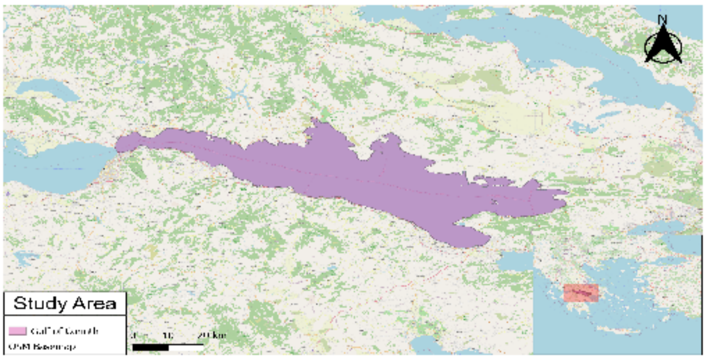


**Fig. 1**. *Map of the study area (Basemap provided by OpenStreetMap (OSM) contributors)*

### *Statistical Analysis*

As can be seen in the schematic representation of the methodological steps of this study in Fig. 2, the investigation of the relation between the $^{137}Cs$ activity concentration and SST parameter includes the analysis of field measured data of $^{137}Cs$ activity concentration in seawater combined with the analysis of SST data, also in seawater, derived by the MODIS satellite system.

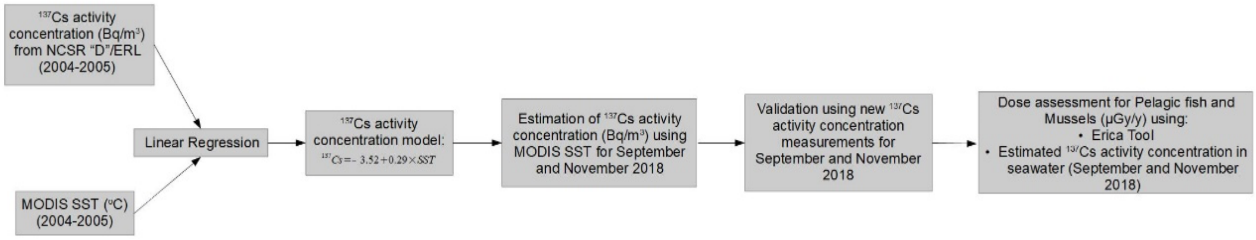


**Fig. 2**. *Flowchart of the methodology*

The statistical regression analysis is performed by single linear regression using MODIS SST as the independent variable and the $^{137}Cs$ activity concentration as the dependent variable. The regression is performed for the period April 2004-March2005 using 17 conjoined measurements of the independent and the depended variables (from ERL measurements). From this regression a linear model for the estimation of $^{137}Cs$ activity concentration from SST is derived. The validation of the model is performed by estimating the $^{137}Cs$ activity concentration using MODIS SST data (September and November 2018). Afterwards the estimated $^{137}Cs$ data are compared to 8 new $^{137}Cs$ activity concentration measurements for September and November 2018.

### *Dose Rate assessment to mussels and pelagic fish*

The risk analysis for this marine region assessment is performed using the ERICA Assessment Tool (version. 1.3.1.51, 12/07/2019) [15]. The total absorbed dose rate, that incorporates the external and internal exposure to radionuclides, is calculated by the modeled activity concentration of $^{137}Cs$ in sea water. Taking into consideration the ecological characteristics of the specific ecosystem, the risk assessment is performed based on the most representative and abundant species found in this region, the pelagic fish and mussels.

## RESULTS AND DISCUSSION

### *Model*

The relation of $^{137}Cs$ activity concentration and MODIS SST seems to be best described by a linear model (Fig.3). The resulting model has an $R^2$ value of 0.71 indicating a good relation between the $^{137}Cs$ activity concentrations and the SST. This positive correlation might be due to the fact that the Gulf is a semi closed system making the seawater evaporation an important oceanographic process. Thus, as seawater evaporates due to higher SST, the $^{137}Cs$ activity concentration rises [4,5,9,10]. The resulting equation is: $^{137}Cs = -3.52 + 0.29 \text{ x (SST)}$.

### *Validation*

Concerning the model validation process, the modeled-estimated $^{137}Cs$ values are close to the measured $^{137}Cs$ values presenting a relative absolute difference of 9% (Fig. 4). Apart from the relative absolute difference, the modeled data also seem to be in range with the measured data, presenting $^{137}Cs$ activity concentration values from 2.0 to 3.8 Bq/m$^3$ and 2.4 to 3.7 Bq/m$^3$ respectively. Thus, it is observed that in the Gulf of Corinth the model using MODIS SST corresponds well.

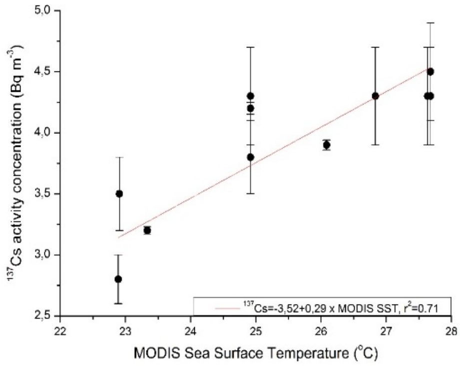


**Fig. 3**. *Regression of $^{137}$Cs activity concentration and MODIS SST in the Gulf of Corinth. The studied data refer to measurements performed by the ERL/NCSR "D" during for 2004-2005. The data retrieved by the MODIS satellite system for the SST parameter refer to that period (2004 to 2005), as well.*

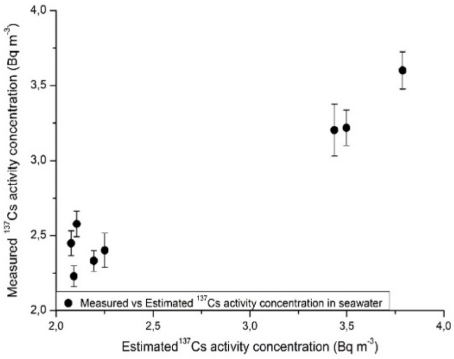


**Fig. 4**. *Measured vs Estimated $^{137}$Cs activity concentration for September and November 2018.*

## *Dose rates*

The dose rates for pelagic fish seem to follow the trends and distribution of $^{137}$Cs activity concentration in the Gulf of Corinth area. The dose rate in the studied organisms, pelagic fish and mussels that derive by the exposure solely to $^{137}$Cs range from 0.28 to 0.51 μGy/y and 31.5 to 57.0 μGy/y respectively (Fig. 5). As it can be seen, these values are far below the intervention levels (indicatively: 10 μGy/h), indicating low impact due to $^{137}$Cs exposure [16,17,18]. However, the integrated risk assessment should normally consider the exposure to all radionuclides.

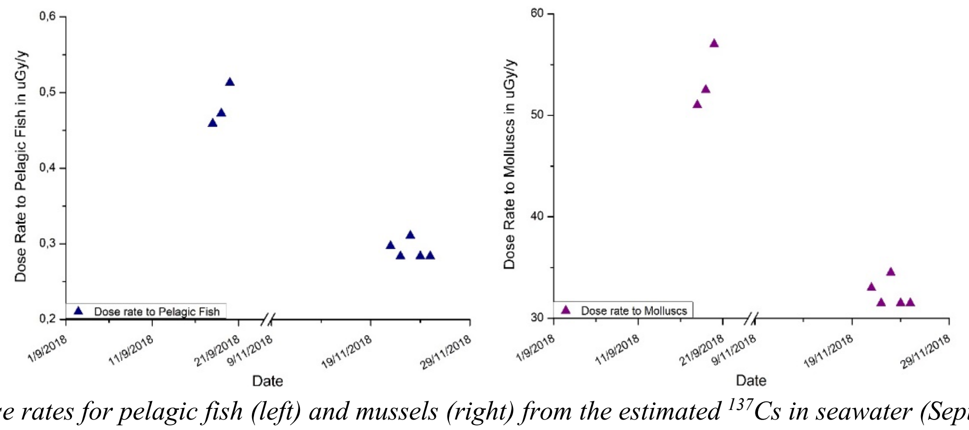


**Fig. 5**. *Dose rates for pelagic fish (left) and mussels (right) from the estimated $^{137}$Cs in seawater (September and November 2018)*

## CONCLUSIONS

In this study, the relation of $^{137}$Cs activity concentration in sea water (taken by field measurements) with the temperature of sea water (taken by MODIS satellite system) was investigated for the creation of a model that will allow for the estimation of $^{137}$Cs activity concentration. The goal is to perform the radiological risk analysis in the marine environment. The correlation of activity concentration with sea water temperature was successfully expressed by a linear model ($R^2$=0.71). By our data it was shown that the model that was created using MODIS SST is capable of estimating the $^{137}$Cs activity concentration in the marine area of the Corinthian Gulf, with a very good performance. Moreover, the application of the created model together with the dose rate calculation tool (ERICA Assessment Tool) indicated that the dose rates in mussels and pelagic fish in the Gulf of Corinth are below the intervention levels, exhibiting low impact due to the $^{137}$Cs exposure.

In conclusion, by this study it is observed that, the combined use of ERICA Assessment Tool and satellite remote sensing marine data is innovative and could be used in more environmental and radiological risk assessment applications. Future work could include: the creation of similar models, when needed, the optimization of the models, the use of more marine parameters and the creation of an online webGIS platform for radiological risk assessment. Furthermore, future work should include the application of the methodology in other areas.

### Acknowledgements

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