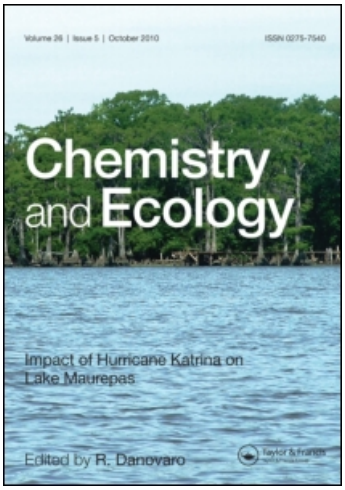

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^{137}Cs Inventory in Abiotic Component and Biota From the Aegean and Ionian Sea - Greece

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^{137}Cs INVENTORY IN ABIOTIC COMPONENT AND BIOTA FROM THE AEGEAN AND IONIAN SEA – GREECE

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This study deals with ^{137}Cs dispersion and behaviour in the Aegean and Ionian Sea based on work done during the period 1984–1994, as a brief general review. Sea water, sediment and marine biota were analysed and measured by gamma spectrometry and the activity concentrations of ^{137}Cs were evaluated with consideration to the sources of pollution. According to ^{137}Cs levels the period is distinguished into three sub-periods, the pre-Chernobyl, the early Chernobyl influence and the late Chernobyl influence period. During the early period of the Chernobyl accident the ^{137}Cs levels in the Greek marine environment increased roughly up to an order of magnitude if compared with the pre-accident ones. Since 1988, the late impact of the accident is focused mainly in the North Aegean Sea, at the Dardanelles mouth, due to the Black Sea outflow.

KEY WORDS: Eastern Mediterranean, ^{137}caesium, sea water, sediments, biota.

INTRODUCTION

The derived levels of ^{137}Cs in sea water in the Aegean and Ionian Sea before 1986, due to the world wide fallout, varied to an average value of 3 Bq m^{-3} (Florou, 1992). During April 1986, the total caesium deposition in the Aegean Sea, an area of 203 000 km^2 due to the Chernobyl accident, has been estimated to be 8.2×10^{14} Bq, of which 2/3 was ^{137}Cs (Kritidis and Florou, 1990), 0.5×10^{12} Bq was discharged to the North Aegean Sea from the Black Sea through the straits of Dardanelles (Egorov *et al.*, 1994).

The average deposition on ^{137}Cs in the Aegean Sea (including Cretian Sea) is estimated to be 4 kBq m^2, while the respective value for a part of the Ionian Sea of 24 300 km^2 (zone of 50 km, including also the Corinthic Gulf) is 2.5 kBq m^2 (Florou *et al.*, 1994).

Six years after the impact of the Chernobyl radioactive plume, the Black Sea discharge to the Aegean Sea through the Dardanelles mouth seem to be the main source of pollution in the eastern Mediterranean (Aarkrog *et al.*, 1994). The activity concentration of ^{137}Cs in the surface layer at Dardanelles mouth during 1993 is up to 120 Bq m^{-3} decreasing according to the surface current circulation pattern (Florou and Kritidis, 1994). The main influence of the Black Sea discharge is seen mainly in the northern part of the Basin, following the general cyclonic flow pattern of the Black Sea mass, which may be traced periodically in the south Aegean Sea

and in the south eastern Ionian Sea near the western Cretian Arc Straits (Miller, 1963).

In the present study, the dispersion of ^{137}Cs in the surface layer in the Aegean and Ionian Sea is evaluated. The concentrations in the marine sediments and the biota are also evaluated in consideration with several environmental and biological parameters. The study period covered a ten-year investigation, since 1984, in selected areas around the Greek peninsula (Fig. 1).

METHODOLOGY

The methodology sequence is described as: sampling of sea water, sediment and marine biota from 30 stations in the Greek Seas (Fig. 1), appropriate physical and/or chemical and radiochemical treatment of the samples (EML, 1978 & 1992) and

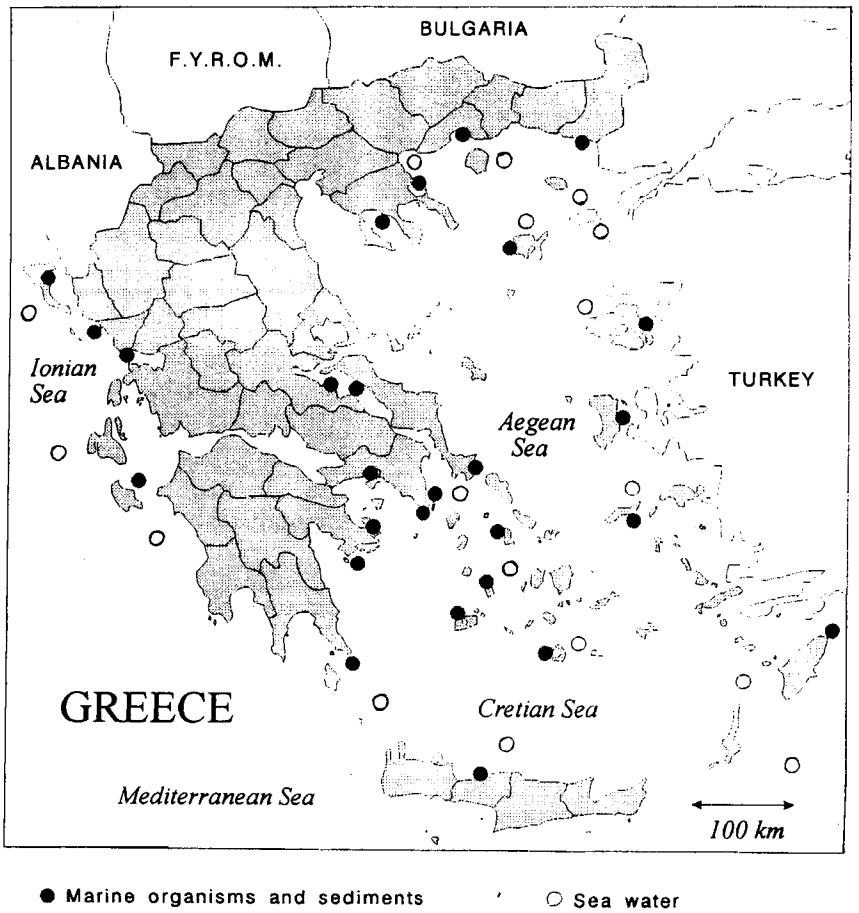

Figure 1 The network of marine sampling stations.

finally gamma spectrometry with Hp Ge detectors of 20% relative efficiency and computerized multichannel analyser of 4000 channels (in a total area of 2000 keV–energy calibration 2 keV per channel). ORTEC software was used for the analyses of the spectra obtained.

RESULTS AND DISCUSSION

Based on the summarized results shown in Table 1 and illustrated in Figure 2, we can make some comments on ^{137}Cs activity concentrations in marine environmental components.

Sea Water The activity concentrations of ^{137}Cs in sea water have increased during the period of Chernobyl accident influence (April 1986–1987) up to an order of magnitude for the Aegean Sea, and a respective increase for the Ionian Sea was about 50% compared with that of Aegean Sea. According to our measurements during 1993, the late impact of the Chernobyl influence is focused in the north Aegean Sea (Fig. 2), where the Black Sea waters interact with the Aegean Sea waters and are diluted. As the Black Sea waters enter into the Aegean Sea, the upper layer

Table I ^{137}Cs activity concentrations (Bq m^{-3} and Bq kg^{-1} wet weight respectively) in marine components.

Marine Component	*1984–1985* *Bq m^{-3}*	*1986–1987* *(since May-86)* *Bq kg^{-1} w.w*	*1988–1995* *Bq kg^{-1} w.w*
			I
Sea water	2.70 ± 0.28	10 times higher	20.7 ± 14.7 (a) 9.2 ± 2.5 (b)
		II	
Sediment	2.42 ± 0.34	4.54 ± 1.99	1.88 ± 0.96
III	IV	V	VI
Algae	0.57 ± 0.65	1.21 ± 0.87	< 1.0
	VII		
Fish	0.34 ± 0.07	10.14 ± 7.45 (c)	0.65 ± 0.37
		VIII	
Mussel	0.68 ± 0.06	7.10 ± 1.80 (c)	0.46 ± 0.14

I. Measurement of 1993 a: Aegean Sea b: Ionian Sea
II. Maximum value observed during the end of 1987, 18.60 ± 3.57 (excluded from the mean).
III. Chlorophyceae, Rhodophyceae, Phaeophyceae
IV. 0.05 – 2.32 Bq m^{-3}
V. Observed minimum 0.09 and maximum 20.0 excluded from the mean.
VI. 0.05 – 0.95 Bq kg^{-1}
VII. Observed maximum 3.00 ± 0.50 excluded from the mean.
c: Values of 1986. Values of 1987 are in the same range with those of the period 1988–1995.
VIII. Observed maximum 28.0 ± 3.0 excluded from the mean.

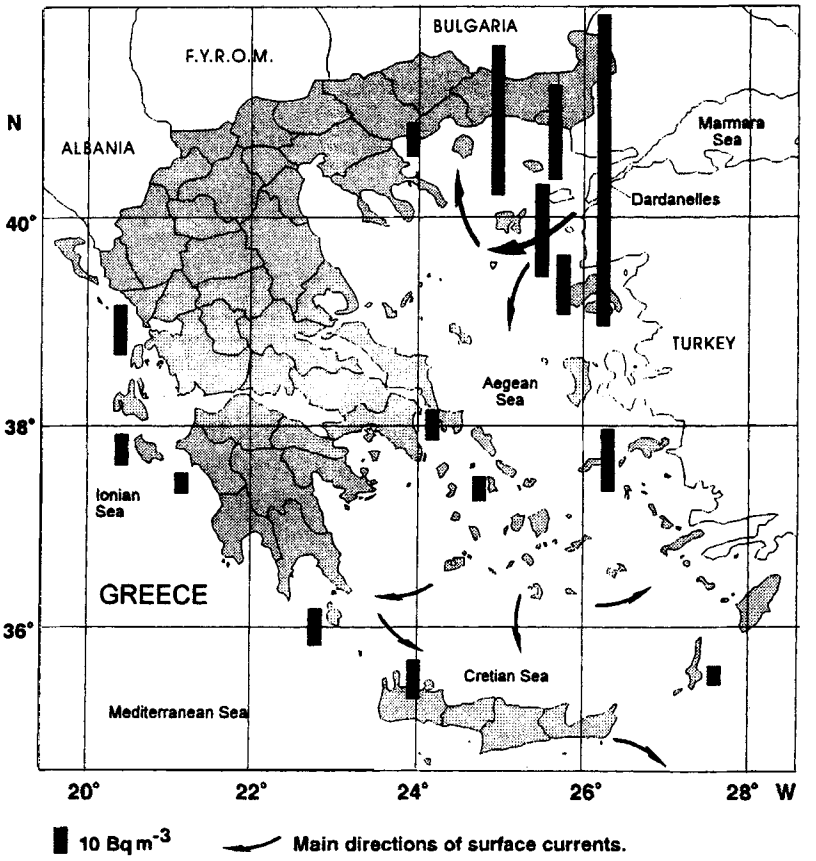

Figure 2 Concentrations of ^{137}Cs and main directions of surface currents in the Aegean Sea.

of the northern and the western part of the Aegean Sea is greatly affected by the Black Sea water flux (Zodiatis, 1994).

Egorov *et al.* (1994) has assessed the velocity of ^{137}Cs outflow for the 0–50 m depth interval in the Black Sea based on data of 1986–1991, taking into acount the river inflow ($\cong 2.5 \cdot 10^{11}$ m^3 per year) to the north-western Black Sea, atmospheric precipitation and evaporation from the sea surface in a multi year period. According to this estimation, the predicted total ^{137}Cs outflow from the Black Sea into the Sea of Marmara is about $250 \cdot 10^{12}$Bq. Taking into account that the volumetric discharge rates from the Black Sea to the Marmara Sea ($3.6 \cdot 10^{11} m^3$ per year) and from Dardanelles to the Aegean Sea ($4.1 \cdot 10^{11} m^3$ per year) are comparable (Chartier, 1990), and the sedimentation rate of caesium is very low (Noskhin, 1973), this amount of caesium is expected to be discharged to the North Aegean Sea, through the purification process of the Black Sea.

With respect to the generic inventory of ^{137}Cs in the Aegean Sea, the mean estimated value is 20.7 ± 14.7 Bq m^{-3}, while the respective value for the Ionian Sea

is 9.2 ± 2.5 Bq m^{-3} (Table 1). Therefore, we can note that six years after the Chernobyl accident, the ^{137}Cs levels remain higher compared with the pre-accident levels observed.

When considering the dispersion of ^{137}Cs, the higher values are present in the north-eastern part of the basin, where a seasonal reverse of the main current circulation from the Black Sea to the north-west appears (Malanotte-Rizzoli and Bergamasco, 1989).

Sediment The levels of ^{137}Cs in surface sediments from the sub-littoral zone until 1986 varied in the range 1–2 Bq kg^{-1}, with local maxima up to 4 Bq kg^{-1}. The observed variations were due to local factors (geological origin, terrestrial influence) than to the fluctuation of the values of fallout received (Florou, 1992).

The average value of ^{137}Cs during 1986 and 1987 varied within 4–5 Bq kg^{-1} with observed maxima up to 20 Bq kg^{-1}. The influence of the Chernobyl fallout in sediment was detected later when compared with marine organisms, due probably to the low sedimentation rate of caesium.

The observed levels of ^{137}Cs in sediment during the period 1990–1994 varied within 2–4 Bq kg^{-1}. It is noteworthy that values up to 25 Bq kg^{-1} were observed in an area with high sedimentation rate, where industrial and domestic waste are disposed (Elefsis Bay – Saronikos Gulf). Obviously, the terrestrial discharge has a strong influence in the coastal zone of this area.

Organisms The activity concentrations of ^{137}Cs in marine organisms during 1986 increased in general up to an order of magnitude over those observed before the Chernobyl accident. From an overall review of the Chernobyl influence to the marine organisms, we can conclude that there are some organism-indicators (Florou, 1995), which showed an early response to the caesium impact to their environment and bioaccumulated caesium to a greater degree (high concentration factors observed). Thus, the fish taxa, *Diplodus annularis*, *Mugil cephalus*, *Boops boops*, seem to be organism-sentinels for caesium pollution. The alga taxa Chlorophyceae (green algae), and especially *Caulerpa prolifera*, are the respective bioindicator, and our findings also showed that the mussel, *Mytilus galloprovincialis*, could be characterized as a "pollution watch" not only for conservative elements, but also for ^{137}Cs.

CONCLUSIONS

From the brief review of the ^{137}Cs impact to the Greek marine environment we can conclude that the Chernobyl influence enhanced ^{137}Cs activity concentrations up to an order of magnitude to the examined marine environmental components. Marine organisms showed an early response to the caesium impact, whereas others could be characterized as bioindicators for caesium pollution. Sediment showed a delayed increase due to the low sedimentation rate of caesium.

Since 1987 for organisms and 1988 for sediments, the levels of ^{137}Cs were back towards the pre-accident ones. From the point of view of purification process of the Black Sea and pollution of the Mediterranean, the late impact of the Chernobyl

accident is focused in the northern part of the Aegean Sea due to the outcoming Black Sea water mass through the straits of Dardanelles.

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