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Overview of total mercury in the coastal waters of Greece: a decade of monitoring under the Water Framework Directive (WFD)

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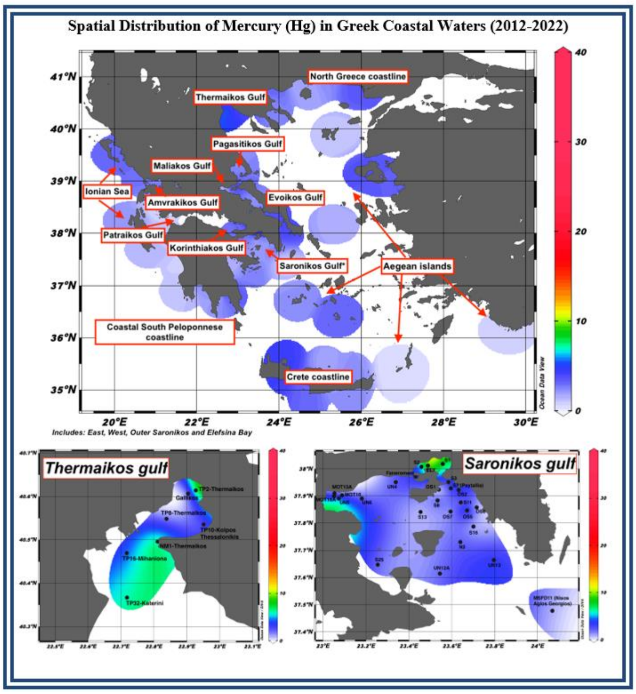
Graphical abstract



Abstract

Mercury (Hg) is an environmentally hazardous metal and pollutant in key European legislation pertaining to the marine environment (the Water Framework Directive WFD and the Marine Strategy Framework Directive - MSFD). Despite the environmental importance of Hg there is limited knowledge on levels in Greek waters. This paper presents the first attempt to evaluate total mercury (THg) levels in the coastal waters of Greece in a decade of monitoring (2012-2022), and identify trends and spatial patterns. These results represent the first seawater Hg data reported by Greece under the WFD, highlighting the importance of this work in understanding Hg pollution in Greek coastal waters. The THg levels measured in all areas were well below the European Legislation threshold of 70 ng/L (EC 2013/39). The overall dataset median was 1.65 ng/L. Increased levels of Hg were found, as expected, near the major cities of Greece (Athens, Thessaloniki) and the major rivers of Northern Greece, as well as in some of smaller ports (Piraeus, Rafina, Lavrio etc.). The area that stands out as a distinct 'hot spot' is the Saronikos Gulf, particularly Elefsina Bay, where Hg concentrations are significantly elevated.

Keywords: THg, Greece, coastal waters, WFD, Cold vapour atomic fluorescence spectroscopy

1. Introduction

Mercury (Hg) is recognized as one of the most toxic elements for both wildlife and humans, exhibiting a complex biogeochemical cycle. In the environment, Hg occurs in three oxidative states: Hg^0, Hg^{+1}, and Hg^{+2}, along with inorganic and organic forms [such as ionic Hg (II) complexes, elemental Hg, dissolved gaseous Hg (DGM), methylmercury (MHg), and dimethylmercury (DMHg)]. Natural processes (e.g., erosion, volcanic activity, hydrothermal vents) and anthropogenic activities (e.g., fossil fuel combustion, mining, industrial waste) contribute to Hg accumulation in the environment. Hg is notable for its high mobility across environmental compartments and its re-emission into the atmosphere, as existing Hg forms in water, soil, and sediments are naturally converted into volatile elemental Hg. It accumulates in marine organisms and biomagnifies through food webs, leading to higher concentrations in top predators, such as predatory fish (Rainbow 1995; Rajar *et al.* 2007; UNEP 2013; Kehrig 2010; Davis 2016).

The study of Hg is especially relevant to the Mediterranean region due to its elevated geological background levels (Kotnik *et al.* 2017; Ogrinc *et al.* 2007). Reports indicate that fish in the Mediterranean contain higher Hg concentrations than those from other seas (Cossa & Coquery, 2005). Hg accumulated in aquatic organisms can be transferred to humans through the consumption of fish and seafood, where Hg levels often exceed the safe limits for human intake. Prolonged consumption of contaminated seafood can result in the buildup of toxic metals in vital organs, posing significant health risks (Horvat *et al.* 1999; Storelli *et al.* 2005; Kousteni *et al.* 2006; Damiano *et al.* 2011; Renieri *et al.* 2014). As a result, Hg is considered a priority element in the environmental monitoring of biotic and abiotic components in the Mediterranean.

At the European level, Hg is classified as a priority pollutant under environmental legislation, including the Water Framework Directive (WFD) 2000/60/EC and the Marine Strategy Framework Directive (MSFD) 2008/56/EC. In the Mediterranean, Hg is a contaminant of concern under the Mediterranean Action Plan (MEDPOL) of the Barcelona Convention and is included in the IMAP (Integrated Monitoring and Assessment Programme of the Mediterranean Sea and Coast) programme framework. The Minamata Convention on Mercury, a global treaty under the United Nations Environment Programme, came into force in 2017 to protect human health and the environment from the adverse effects of Hg.

According to the WFD and its derivative directives (2008/105/EC and 2013/39/EU), Hg is classified as a priority hazardous substance. The Environmental Quality Standard (EQS) for Hg in all water types (inland, coastal, and transitional) is set at 70 ng/L. The MSFD addresses marine chemical pollution through Descriptor 8 ("Concentrations of contaminants are at levels not giving rise to pollution effects") and Descriptor 9 ("Contaminants in fish and other seafood for human consumption do not exceed levels established by Community legislation or other relevant standards"). The MSFD also introduces the goal of achieving 'Good Environmental Status' (GES) in European Seas. To assess GES, established EQS values should be combined with biological effects on aquatic organisms and potential human health risks through dietary exposure (Tzempelikou *et al.* 2021).

This study presents the first comprehensive evaluation of Hg levels and spatial distribution in Greece's coastal waters, based on 10 years of monitoring (2012–2022).

2. Materials and methods

2.1. Sampling and study area

The dataset of the present study is derived from water samplings conducted during 10 years of monitoring (2012, 2013, 2014, 2015, 2017, 2018, 2019, 2020, 2021 and 2022). Except for the year 2017 the sampling stations were within the Greek WFD operational and surveillance network. The WFD network covers the major coastal areas and gulfs of Greece (Cretan coast, Messiniakos, Lakonikos, Argolikos, Kyparisiakos, Patraikos, Amvrakikos Gulfs, Ionian Sea islands and mainland sites, Korinthiakos, Saronikos, Evoikos, Maliakos, Pagasitikos, Thermaikos Gulfs, sites of the Northern Greece coastline and finally ports and sites on selected Aegean Sea islands). The 2017 campaign focused only on subareas of Saronikos Gulf. Selected maps of coastal areas are provided in the supplementary material (**Figures S1 to S5**) and detailed station information are given in **Table S1**. The samplings were conducted with the oceanographic vessels R/V Aegaeo and R/V Philia of HCMR and water samples for THg were collected with Niskin bottles from two depths, surface (2 m) and bottom, using ultraclean handling (EPA 1669). For most locations bottom depths ranged from 6 m to 100 m except for 7 out of 86 stations where the maximum depth exceeded 100m. In total, 733 water samples were collected and analyzed for THg.

2.2. Hg chemical analysis and statistical data evaluation

In this study we present concentrations of THg, i.e. all BrCl-oxidizable Hg forms including Hg (II), Hg (0), strongly organo-complexed Hg (II) compounds, adsorbed particulate Hg, and several tested covalently bound organo-mercurials (e.g., CH_3HgCl, $(CH_3)_2Hg$, and $C_6H_5HgOOCCH_3$) (EPA 1631) and species found in an unfiltered seawater sample. The method of determination (EPA 1631) consists of oxidation of all species to Hg (II), purge and trap onto a gold trap, desorption, and cold-vapor atomic fluorescence spectrometry (CVAFS) by a TEKRAN 2500 total Hg analyzer. The Laboratory of Environmental Chemistry (LEC) performs very low Hg concentrations (above 0.5ng/L) analysis using state of the art equipment in clean room facilities and participates in the national WFD coastal zone monitoring since 2012 in collaboration with the Hellenic Centre for Marine Research (HCMR). More specifically, the analyses were carried out in a Class 10000 clean room. The limit of quantification (LOQ) for THg referred by the method is 0.5 ng/L but in the Laboratory of Environmental Chemistry the application and experimentation with low level samples produced an LOQ of 0.2 ng/L. On each analytical day a reference solution (OPR Ongoing Precision and Recovery) is prepared and analyzed with a frequency of one after every seven unknown samples and a reference material or a matrix spike is analyzed at least once a day for recovery estimation. Indicatively, for the analysis of 56 samples of the October 2020 campaign over two analytical shifts, 8 replicates of the OPR solution gave a relative standard deviation (RSD) of 8% and a recovery of 98% and 4 replicates of diluted reference material gave a recovery of 101%. The method specifications (EPA 1631) allow for maximum RSD of 21% and recovery range 77-123%.

Exploratory statistical analysis of the Hg data was carried out with SPSS V29.0. Data normality was checked using Kolmogorov-Smirnov and Shapiro-Wilk tests and significant differences identification among data sets was carried out using non-parametric tests (Kruskal-Wallis 1-way ANOVA test along with pairwise comparisons). To further investigate (and exclude) the presence of outliers and extreme values across the sub-areas, the Interquartile Range (IQR) method was employed. This method inherently focuses on the central 50% of the data by calculating the range between the 25th percentile (Q1) and the 75th percentile (Q3). Outliers are defined as values below Q1 - 1.5IQR or above Q3 + 1.5IQR (McGill *et al.* 1978). Based on this method, specific upper limits for each sub-area were established and 9 from 733 samples in total (1,23%) were excluded.

3. Results and discussion

During the last 10 years, 733 samples from coastal areas of Greece were analyzed for THg. The median Hg concentration of the entire dataset, after applying the IQR method to exclude outliers and extremes was calculated at 1.65 ng/L. The Hg levels measured in all areas were well below the European Legislation threshold of 70 ng/L (EC 2013/39). The measured concentrations of all samples were further examined in detail, in order to identify spatial trends and possible hot spots for Hg. Values above 3.3 ng/L (2 times the dataset median) along with outliers and extremes in each sub-area will be further discussed. The sub-areas, samples and % of values above 3.3 ng/L in each area are presented in **Table 1**. The mean, median and min-max of THg (ng/L) are presented in **Table 2**.

Table 1. Number of samples and % values (in each sub-area) above 3.3 ng/L.

Coastal Area	Total Samples in each Sub-Area	Samples >3.3 ng/L in each Sub Area	
	Number	Number	%
Crete coastline	14	4	29
Aegean islands	55	16	29
Ionian Sea*	52	10	19
Amvrakikos Gulf	44	11	25
Patraikos Gulf	4	1	25
Korinthiakos Gulf	48	13	27
South Peloponnese coastline	77	17	22
Outer Saronikos Gulf	14	3	21
West Saronikos Gulf	22	7	32
East Saronikos Gulf	71	20	28
Elefsina Bay	48	34	71
Evoikos Gulf	62	18	29
Maliakos Gulf	13	0	0
Pagasitikos Gulf	49	17	35
Thermaikos Gulf	70	16	23
North Greece coastline	81	20	25

**Ionian Sea: stations located in islands and on the Ionian coast of mainland Greece*

The area which is clearly differentiated and can be identified as a ‘’hot spot’’ is Elefsina Bay. The mean and median Hg in Elefsina Bay is above 3.3 ng/L, since 71 % of measurements were above this threshold (34 of 48 values). The three outlier values in Elefsina Bay all refer to the station closer to the port (S1). Increased values were measured in the bottom waters of the central and west part (stations EL7 and S2) in summer and autumn months that could be attributed to release from the sediments due to anoxic / hypoxic conditions arising every year (Pavlidou *et al.* 2010). Some elevated values were also found in the surface waters and could be attributed to atmospheric sources of Hg from industries located on the coast of Elefsina Bay and overall fossil fuel combustion from the adjacent urban municipalities of Athens.

In all other areas the median values were close to the dataset median of 1.65 ng/L. However, the mean THg levels in some areas were slightly elevated, affected by several outlier and extreme measurements as seen in **Figure 1**. In the areas of Thermaikos Gulf, Northern Greece coastline, East Saronikos Gulf and Evoikos Gulf several outliers and extremes are observed as well as a significant number of measurements above 3.3 ng/L.

Specifically, in Thermaikos Gulf and the Northern Greece coastline relatively increased THg concentrations were measured in stations affected by the major rivers (Axios, Aliakmonas, Strymonas, Evros), in Thessaloniki Bay, and in the Gulf of Ierissos. The highest value of the entire dataset (that was omitted during the IQR method for the exclusion of extremes and outliers) was measured in the surface water of Ierissos Gulf/ Stratoni (90.2 ng/L) in the March sampling of 2018 (omitted among other extremes and outliers from **Figure 1**). This station also gave an outlier value (15.2 ng/L) in September of 2014.

In Evoikos Gulf some elevated concentrations were measured in Rafina, and Larymna possibly associated with marine traffic and a metallurgic industry, respectively, as well as close to the outlet of Asopos river, due to several industrial activities in the area, such as food and drink production, agrochemical processing, and metalworking. The maximum Hg concentration was measured in the bottom water close to Asopos in 2014 (28.1 ng/L).

In East Saronikos Gulf the increased Hg concentrations are associated with the Wastewater Treatment Plant (WWTP) outfall and atmospheric contributions of the metropolitan city of Athens. Two extreme Hg concentrations were found in the bottom waters of station S7 at the WWTP outfall (12.4 and 17.4 ng/L in autumn and winter months respectively) and one extreme value was also found in E8 station (21.7 ng/L). Station S11 also presented an extreme surface Hg value (18.2 ng/L), which may be affected by runoff from a major coastal highway of Athens. Values of S11 and E8 stations were excluded after applying the IQR method.

Some other examples of elevated concentrations were found in the following areas: In volcanic environments

(Aegean islands, Santorini, Milos islands) Hg levels ranged from 5.5-6.6 ng/L. In smaller ports (Igoumenitsa-Ionian Sea, Gytheio-Peloponnese, Souda-Crete) some elevated values were measured (Souda 12.4 ng/L, Gytheio 7.9 ng/L, Igoumenitsa 15.2 ng/L). In the enclosed bays of Kalloni and Gera in Lesvos Hg levels ranged from 7.5 to 10.9 ng/L. In areas affected by rivers and agricultural activities, such as Maliakos Gulf with an extreme bottom value of 9.4 ng/L (excluded after applying the IQR method and not included in **Figure 1**) and Messiniakos Gulf with outlier values of 8.2 and 10 ng/L. In Amvrakikos Gulf, elevated Hg concentrations (4.1–11.8 ng/L) were found, influenced by the rivers Louros and Arachthos. Similarly, in Pagasitikos Gulf, elevated values were recorded, particularly in East Pagasitikos (6.63 ng/L from only two samples in 2013), while the highest concentration was found in Volos (17,15 ng/L -excluded after applying the IQR method), an area impacted by Volos WWTP and various industries, including chemical plants, steel production, and wood-processing facilities.

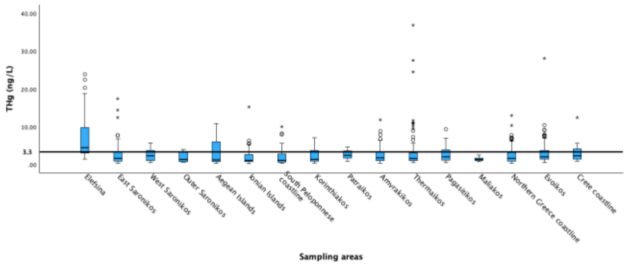


Figure 1. Boxplots of total seawater Hg (ng/L) in the coastal areas of Greece.

Summarizing all of the above it becomes apparent that stations near ports, major cities, motorways, river estuaries and mining /metallurgical activities presented some of the highest values.

Table 2. Mean, median and min-max of Total Hg (ng/L) in the coastal areas of Greece.

	Hg (ng/L)			
Coastal Area	**Mean**	**Median**	**Max**	**Min**
Elefsina Bay	6.86	4.40	23.87	1.36
East Saronikos Gulf	2.64	1.57	17.40	0.29
West Saronikos Gulf	2.44	2.32	5.67	0.47
Outer Saronikos Gulf	1.97	1.35	3.97	0.54
Aegean Islands	2.89	1.11	10.85	0.33
Ionian Sea*	2.11	1.11	15.20	0.23
South Peloponnese coastline	1.92	1.10	9.98	0.24
Korinthiakos Gulf	2.29	1.26	7.05	0.29
Patraikos Gulf	2.59	2.43	4.64	0.85
Amvrakikos Gulf	2.64	1.75	11.80	0.30
Thermaikos Gulf	3.89	1.57	36.90	0.40
Pagasitikos Gulf	2.72	2.00	9.31	0.41
Maliakos Gulf	1.37	1.33	2.49	0.77
Northern Greece coastline	2.70	1.63	12.93	0.33
Evoikos Gulf	3.40	1.97	28.10	0.50
Crete coastline	3.18	2.20	12.40	0.87

**Ionian Sea: stations located in islands and on the Ionian coast of mainland Greece*

In order to determine whether there are significant differences in THg concentrations among the different sampling areas across Greece, the non-parametric Kruskal-Wallis 1-way ANOVA Test was conducted, along with pairwise comparisons. The test reached a statistic of 80.481 with a corresponding asymptotic significance <0.001, suggesting that there are significant differences in THg distribution among the areas.

Based on the above-mentioned facts non-parametric (2 Independent Sample) Mann-Whitney tests were conducted for pairs with significant (sig.) value below the threshold of 0.05.

The results of the comparisons are summarized below:

Elefsina Bay>Evoikos Gulf> Crete=East Saronikos Gulf =Thermaikos Gulf =Pagasitikos Gulf = Amvrakikos Gulf = North Greece> West Saronikos Gulf =Coastal South. Peloponnese= Outer Saronikos Gulf =Aegean islands =Ionian islands=Korinthiakos Gulf =Patraikos Gulf = Maliakos Gulf

In addition to the above, **Figure 2** demonstrates an aggregated mean view of both surface and bottom coastal water samples of Greece, as designed in ODV view. The dataset within this view presents the mean THg levels (measured in ng/L) for each station from 2012 to 2022.

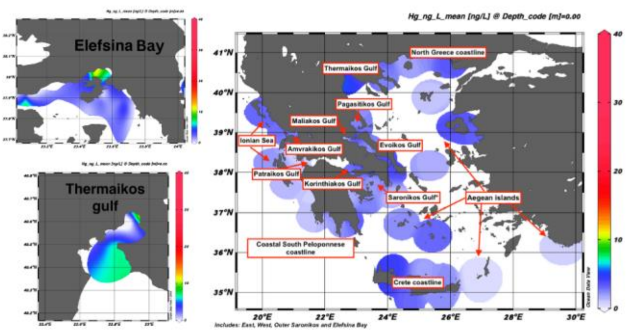


Figure 2. Spatial distribution of THg (ng/L) in coastal waters of Greece.

The dataset was also evaluated for differences with depth and season. No statistical differences were found between the surface and bottom samples, neither for the entire dataset, nor for each of the sub-areas. Regarding the seasonal comparison the data were divided in two groups, winter/spring and summer/autumn because the cold weather samplings usually took place in March or April and the warm weather samplings were conducted between October and November. There were no significant statistical differences ($p>0.05$) between the two seasons in any of the coastal areas. However, in coastal areas of northern Greece there is a slight trend for higher values in the winter/spring period and in southern areas (Saronikos, Crete and coastal South Peloponnese) the opposite trend is observed with higher values in the summer/autumn period. These trends can be attributed to increased winter-spring run-off from the larger rivers in the northern areas and increased atmospheric inputs from fossil fuel combustion for heating needs, whereas in the south of Greece there are smaller rivers and ephemeral streams and the weather is warmer and dryer. The increased THg values in the summer-autumn can be attributed to the heightened tourism activities of this period. Two characteristic cases are presented in **Figure 3**.

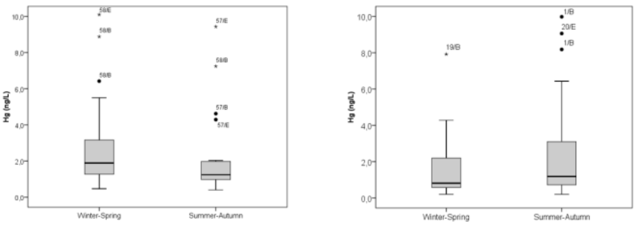


Figure 3. Seasonal variation THg (ng/L) in two areas (a: Thermaikos, b: South Peloponnese)

The winter-spring median and IQR of THg in Thermaikos were 1.9 and 2.4 ng/L while in the summer-autumn period 1.2 and 1.0 ng/L. In South Peloponnese the winter-spring median and IQR of THg were 0.8 and 1.8 ng/L and correspondingly in the summer-autumn samplings 1.2 and 2.4 ng/L.

Regarding temporal trends throughout the ten years of sampling the overall median THg values of 2021 (0.76 ng/L) and 2022 (0.79 ng/L) were found statistically equal to the corresponding values of 2014 and 2015 (1.2 ng/L) and lower than the median values of 2018, 2019 and 2020 (2.5, 2.8 and 1.7 ng/L). These trends may reflect the effects of the COVID shutdown but that cannot be definitively proven.

The levels of THg in the coastal areas of Greece are found similar to case studies from selected European areas. The overall Greek coastal THg median of 1.65 ng/L is lower than mean river water concentrations from Portugal that ranged from 10.3 to 22.2 ng/L but some of the increased concentrations measured in Greece (above 3.3 ng/L and up to 20 ng/L), similarly to the Portuguese rivers can be attributed to industrial and other sources of anthropogenic pollution (Cardoso *et al.* 2023). The majority of THg measurements from the Greek coasts are also lower than concentrations in coastal areas of the Adriatic affected by historical Hg mining pollution (Gulf of Trieste, Marano and Grado lagoons). Specifically, in Horvat *et al.* 1999, reported THg values from the Gulf of Trieste ranging from 0.51-12.7 ng/L with 20 out of 26 values higher than the Greek THg median 1.65 ng/L. In Marano and Grado Lagoons the mean THg concentration was 6.6 ng/L and the range 1.6 to 28.7 ng/L (Bettoso *et al.* 2023). However, some of the THg measurements in the coastal areas of Greece are similar or in most cases higher than values reported for the entire Adriatic Sea by Kotnik *et al.* 2015 (average 0.66 ng/L, range 0.16-1.28 ng/L). This is to be expected because the sampling stations in the study of Kotnik et al, 2015 are located at a greater distance from the shore (more than 15km) while the sampling stations of the present paper are mostly closer to the shoreline (less than 10km). Finally, more than 60% of the Greek data of 2012-2022 fall in the usual nearshore range of Hg levels stated by Horvat *et al.* 1999 (0.5-2 ng/L).

4. Conclusions

This paper provides a preliminary attempt to present Hg levels in selected coastal marine areas of Greece. Since 2012, mercury (Hg) concentrations in the coastal waters of Greece have remained consistently below the European Environmental Quality Standard (EQS) threshold of 70 ng/L. However, the bioaccumulation and biomagnification concerns regarding Hg is marine species and the possibility for human health risk reported in the Mediterranean region (Kousteni 2006, Cinnirella *et al.* 2019, Capodifero *et al.* 2022) warrant further investigation in Greek waters where knowledge around Hg is still relatively scarce.

Further investigation should include a detailed assessment of the full Greek Hg dataset, under the monitoring frameworks of WFD for coastal seawater (2012-2023) and transitional water bodies (2018-2023) along with offshore seawater Hg measurements (MSFD 2018-2023), which was recently finalized. There should be a statistical estimation of Hg background levels in the Greek marine waters as well as a more exhaustive examination on spatial and temporal trends and finally a comprehensive comparison with Hg seawater levels in other EU countries.

Furthermore, it is important to establish correlations between Hg concentrations in Greek marine waters, with Hg levels in fish and seafood harvested there along with assessments of potential human health risks associated with seafood consumption. A comprehensive approach that examines Hg contamination in both seawater and edible marine organisms will facilitate the proposal of an appropriate and safe Good Environmental Status (GES) threshold for this hazardous element.

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Supplementary material

Table S1. WFD Sampling stations in Greek coastal areas (2012-2022).

Area	Station	Depth(surface-bottom)	Latitude	Longitude
Coastal South. Peloponesse	Kyparissiakos	2m-30m	37.32279097	21.69524138
	Gytheio	2m-17m	36.76682187	22.5693483
	Vourlias (Argolikos)	2m-190m	37.50111667	22.87326667
	Messiniakos	2m-50m	37.00195	22.02493333
	Argolikos	2m-16m	37.55977139	22.78498238
	Dokos	2m-72m	37.33573599	23.36406064
	Pylos	2m-67m	36.9005	21.67691
	Pylos South	2m-60m	36.90046	21.67836

	Evrotas	2m-15m	36.80005117	22.70003973
Korinthiakos gulf	Itea	2m-20m	38.4239274	22.42233871
	Korinthos	2m-85m	37.96900278	22.83478889
	Aigio	2m-400m	38.26276667	22.0855
	Antikyra	2m-68m	38.35129436	22.66043648
	Xylokastro	2m-70m	38.08358889	22.618125
	Domvraina	2m-52m	38.19682583	22.9916147
Patraikos gulf	Patra	2m-88m	38.22125	21.70076667
	S. Patraikos	2m-58m	38.18148517	21.5711748
	W. Patraikos	2m-85m	38.20958333	21.4885
Ionian islands	Laganas	2m-32m	37.69968374	20.90399201
	Argostoli	2m-17m	38.24186808	20.45180903
	Igoumenitsa	2m-20m	39.50011314	20.22811466
	Killini	2m-130m	37.94645987	21.14359626
	Echinades	2m-20m	38.45930168	21.08131696
	Kerkyraiki	2m-38m	39.65589299	19.92931721
Evoikos gulf	Diavlos Oreon	2m-61m	38.91268283	22.9534857
	Asopos	2m-13m	38.33928543	23.7447309
	Larymna	2m-25m	38.57194583	23.30076988
	Skouries	2m	38.57785722	23.37502596
	Rafina	2m-58m	37.95167017	24.03564224
Maliakos gulf	Maliakos	2m-20m	38.88335652	22.61802713
Aegean islands	Santorini	2m-355m	36.42575587	25.41254534
	Moudros	2m-10m	39.88258639	25.38337384
	Adamantas	2m-30m	36.71732567	24.45177971
	Kolpos Geras	2m-15m	39.07950256	26.48940603
	Kalloni	2m-10m	39.15414937	26.20510676
	Kastelorizo	2m	36.13766776	29.59932512
	Kalogeroi	2m-80m	38.16484852	25.31872852
	Koufonisia	2m-36m	36.91398507	25.62094798
	Oinousses	2m	38.51290763	26.27259771
	Kasos	2m	35.36684	26.93646
Crete	IG2-Irakleio	2m-75m	35.34716786	25.10072149
	Agios Nikolaos	2m-22m	35.20395003	25.72039859
	Souda	2m-25m	35.46394064	24.19166896
	Messara	2m-25m	35.06385084	24.73386682
Pagasitikos gulf	Volos	2m-40m	39.33340745	22.9667019
	Volos port	2m-40m	39.34987	22.945229
	Trikeri	2m-78m	39.10304668	23.00138867
	C. Pagasitikos	2m-46m	39.1835628	23.00001952
	W. Pagasitikos	2m-57m	39.23344302	22.90002362
	E. Pagasitikos	2m-96m	39.25018195	23.05002663
Amvrakikos gulf	South Amvrakikos	2m-50mr	38.92166964	21.09445694
	Louros estuary	2m-17m	39.03033289	20.80473722
	Arachthos estuary	2m-19m	39.03932696	21.09424881
Thermaikos gulf	TP32-Katerini	2m-38m	40.36681239	22.71817955
	TP16 Mihaniona	2m-26m	40.46943711	22.71754452
	TP10 Thessaloniki gulf	2m-16m	40.53583638	22.95139419
	Gallikos	2m-18m	40.606834	22.904011
	NM1-Thermaikos	2m-10m	40.49600000	22.81100000
	TP8-Thermaikos	2m-20m	40.54830000	22.83830000
	TP2-Thermaikos	2m-10m	40.61430000	22.92760000
North Greece	Gulf of Kavala	2m-10m	40.95372911	24.53023164
	Evros	2m-7m	40.83284285	25.93349494
	Porto Lagos	2m-7m	40.98318088	25.09993044
	Strymonikos	2m-52m	40.74996004	23.88333455
	Ierisos gulf-Stratoni	2m-43m	40.48341754	23.83310539
	Diavlos Thasou	2m-25m	40.83331638	24.71669797
	Afytos	2m-45m	40.06682031	23.47247051

	Vourvourou	2m-46m	40.10381665	23.98440274
Saronikos gulf				
Elefsis bay	S2	2m-30m	38.00768	23.45903
	S1	2m-23m	38.0183116	23.55759872
	S3	2m-29m	37.9507	23.58422
East Saronikos	EL7	2m-32m	38.01193333	23.4889556
	OS1	3m-49m	37.92345	23.54012
	OS2	3m-53m	37.92242	23.63137
	OS5	3m-69m	37.84700	23.67100
	S11	2m-72m	37.87662341	23.64175852
	S13	2m-85m	37.84095	23.45487
	OS7	3m-90m	37.84293	23.59390
	S7 (Psitalia)	2m-75m	37.92838363	23.5958076
	OS6	3m-34m	37.85797	23.71625
	S16	2m-85m	37.78717	23.70067
	S8	2m-88m	37.88345053	23.53345747
	E8	2m-42m	37.70028293	23.91410388
West Saronikos	Faneromeni	2m-13m	37.97137014	23.43099635
	S25/UN11	2m-400m	37.64722675	23.25540091
	MOT13A	2m-50m	37.91003	23.05307
	MOT16	2m-85m	37.90298	23.08853
	MOT16A	2m-100m	37.89992	23.05133
	UN4	2m-79m	37.95095	23.33885
	UN5	2m-140m	37.89098	23.07322
	UN6	2m-193m	37.89092	23.18095
Outer Saronikos	UN12A	2m-189m	37.61483889	23.54503333
	N2	2m-190m	37.73065	23.63987
	S22	2m-190m	37.58523056	24.01073056
	UN13	2m-189m	37.6645	23.79583056

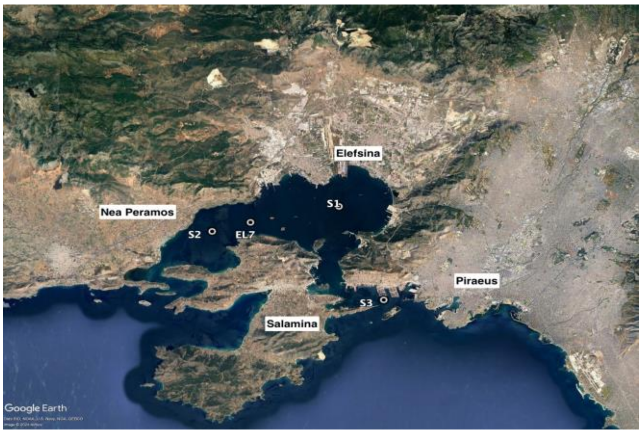

Figure S1: Sampling points in Elefsina Bay.

Figure S2: Sampling points in East Saronikos Gulf.

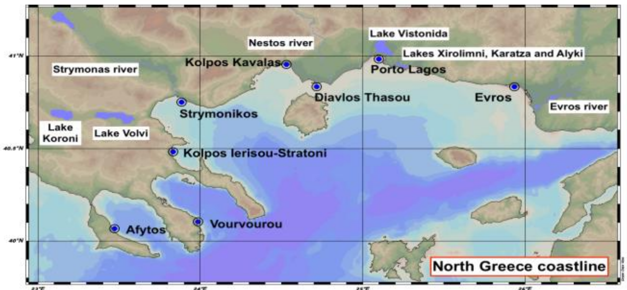

Figure S3: North Greece coastline sampling points (incl. rivers and lakes).

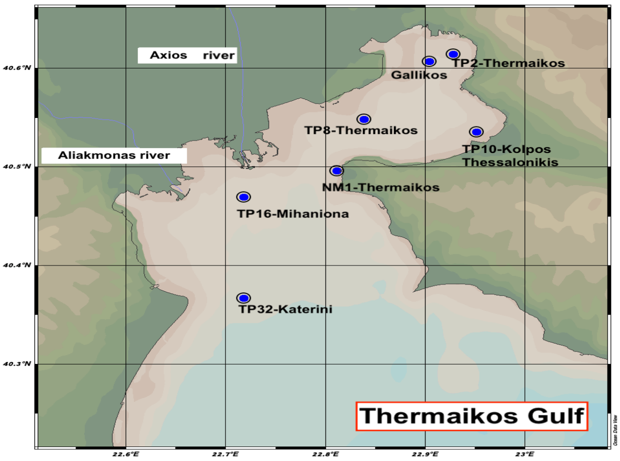

Figure S4: Thermaikos Gulf sampling points (incl. rivers and lakes).

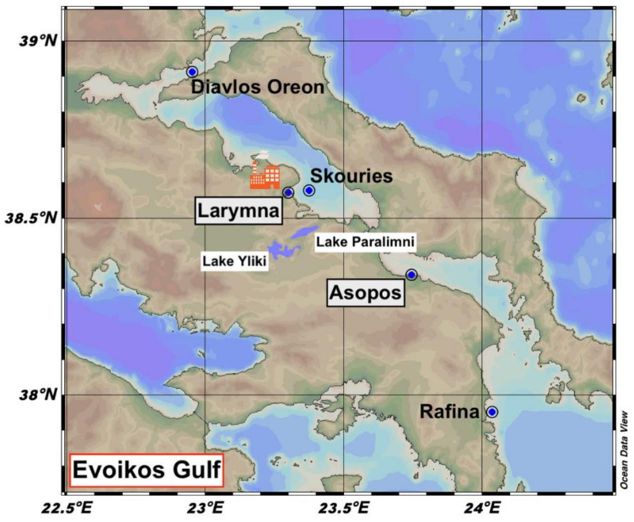

Figure S5: Evoikos Gulf sampling points (incl. rivers and lakes).