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Review

Contamination by hazardous substances in the Gulf of Naples and nearby coastal areas: A review of sources, environmental levels and potential impacts in the MSFD perspective

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HIGHLIGHTS

- We gather data on chemical pollution in the Gulf of Naples and nearby coastal areas.
- Pollution sources and temporal trends are discussed.
- Potential risks to biota and human health are assessed.
- Gaps and future research needs to underpin the MSFD implementation are identified.

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ABSTRACT

During the 7th FW EU Programme, a large group of research institutions with a strong tradition in marine science designed PERSEUS, a policy-oriented, marine research project aimed at identifying human-derived pressures and their impacts in the Southern European Seas. PERSEUS is about gathering and analyzing the data on our marine ecosystems and developing recommendations to assist policy makers in the implementation of the Marine Strategy Framework Directive (MSFD). In its initial phase, the project focuses on the analysis and evaluation of human pressures in selected coastal areas across the Mediterranean and Black Seas. This paper reports on the results about the chemical pollution pressure in the Gulf of Naples, one of the sites selected for the analysis, and surrounding waters of the Southern Tyrrhenian Sea. Based on a systematic up-to-date literature review, the paper brings together for the first time the available information on the presence, severity and distribution of contaminants on the site. In spite of methodological and sampling heterogeneity among studies, this review compiles the data in a harmonized and effective way, so that the current status, knowledge gaps and research priorities can be established. Thus, the review wishes not only to provide a contribution to the scientific community, but also to help to extract recommendations for mitigating pollution sources and risks in the area of concern. A similar process of analysis may be carried out for other areas and pressures in order to facilitate policy making at the European level.

Contents

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1. Introduction

The Marine Strategy Framework Directive (MSFD) represents the crucial element towards a future Maritime Policy for the Union, planned to achieve or maintain “Good Environmental Status” (GES) in Europe's seas by 2020. The European Commission, through the Seventh Framework Programme, has funded a Policy-oriented marine Environmental Research in the Southern EUropean Seas (PERSEUS), aimed at enhancing knowledge of the interacting patterns of natural and human-driven pressures on marine ecosystems and designing innovative tools for meeting the objectives and principles of the MSFD. Through this project, science is given a new significant role in the process of policy making and management. As a first step towards these goals, the project involved the compilation/evaluation of all existing information related to human pressures and their environmental impacts on selected coastal marine areas and the identification of knowledge gaps on the processes underlying changes in the ecosystems. This first activity focused on issues considered as major threats to GES and on areas which exhibit a high level of disturbance, that is, big coastal cities and ports, and coastal areas under the influence of large rivers.

The presence of chemical contaminants has been identified as a major threat to the Mediterranean Sea's biodiversity and ecology (EEA, 1999; UNEP, 1996) and, consequently, marine chemical pollution is a top priority within the recent European Directives. Two of the 11 MSFD qualitative descriptors for determining GES are directly linked with this pressure: Descriptor 8 is formulated as “Concentrations of contaminants are at levels not giving rise to pollution effects”, and Descriptor 9 as “Contaminants in fish and other seafood for human consumption do not exceed levels established by EU legislation or other relevant standards”. Contaminants are defined as “substances (i.e. chemical elements and compounds) or groups of substances that are toxic, persistent and liable to bioaccumulate, and other substances or groups of substances which give rise to an equivalent level of concern”. Pollution effects are defined as “direct and/or indirect adverse impacts of contaminants on the marine environment, such as harm to living resources and marine ecosystems, including loss of biodiversity, hazards to human health, the hindering of marine activities, including fishing, tourism and recreation and other legitimate uses of the sea, impairment of the quality for use of sea water and reduction of amenities or, in general, impairment of the sustainable use of marine goods and services” (Law et al., 2010).

The Gulf of Naples (Southern Tyrrhenian Sea) is subjected to high intensity human uses linked to coastal zone pressures and impacts and is one of the key areas considered in the framework of the PERSEUS project. This paper presents the results of the data compilation from this and adjacent coastal areas with a view to providing an integrated assessment of chemical pollution pressures and state changes. Taking into account the patchy available information on this subject, this review tries to summarize the current state of knowledge in a concise manner and allows extracting relevant data for the proposed achievement of GES. According to the MSFD, the progress to GES will be determined by the ability to keep pollutant levels and their biological effects within acceptable limits, in such way that they don't produce significant impacts on the marine environment. Hence, this work analyzes the gathered data focusing on four key aspects: (1) the extent and sources of priority substances; (2) the biological effects and their impacts on the marine environment; (3) the potential risks for human health; and (4) the gaps which require further research and should be prioritized in the management strategies to achieve and/or maintain GES.

2. The study area

Artale et al. (1994) provided a synthetic description of the Tyrrhenian Sea (Fig. 1) as the deepest basin of the western Mediterranean Sea, connected by the narrow openings of Bonifacio and Messina Straits to the Provencal basin and Ionian Sea, respectively. Its main exchanges occur through the Corsica Channel with Liguro–Provencal Sea and through the opening between Sardinia and Sicily with the Algerian basin. In the Southern Tyrrhenian, the coast of the region of Campania (Fig. 1) extends for approximately 512 km and includes four gulfs: Gaeta, Naples, Salerno, and Policastro. The Gulf of Naples has been described as an approximately rectangular marginal basin of the south-eastern Tyrrhenian Sea (Uttieri et al., 2011). It has an average depth of 170 m and an area of approximately 900 km^2 (Carrada et al., 1980), a complex bottom topography featuring two submarine canyons (Magnaghi and Dohrn) with depths up to 800 m, and a continental shelf with widths ranging from 2.5 to 20 km in the center of the basin. The islands of Ischia, Procida and Capri bond the external part of the gulf; the northern limit is represented by the Campi Flegrei area, whereas the Sorrento peninsula is the southern one. The exchanges between the gulf and the southern Tyrrhenian Sea occur along the Bocca Grande, the main aperture of the gulf between Ischia and Capri. The communications with the neighboring basins of the Gulf of Gaeta and the Gulf of Salerno are respectively guaranteed by the Ischia and Procida channels and by the Bocca Piccola (the passage between Capri and the Sorrento peninsula). Three marginal sub-basins of the Gulf of Naples can be identified: the Bay of Pozzuoli in the northern part, the Bay of Naples in the northeastern sector of the region, and the Gulf of Castellammare in the southeastern part of the basin.

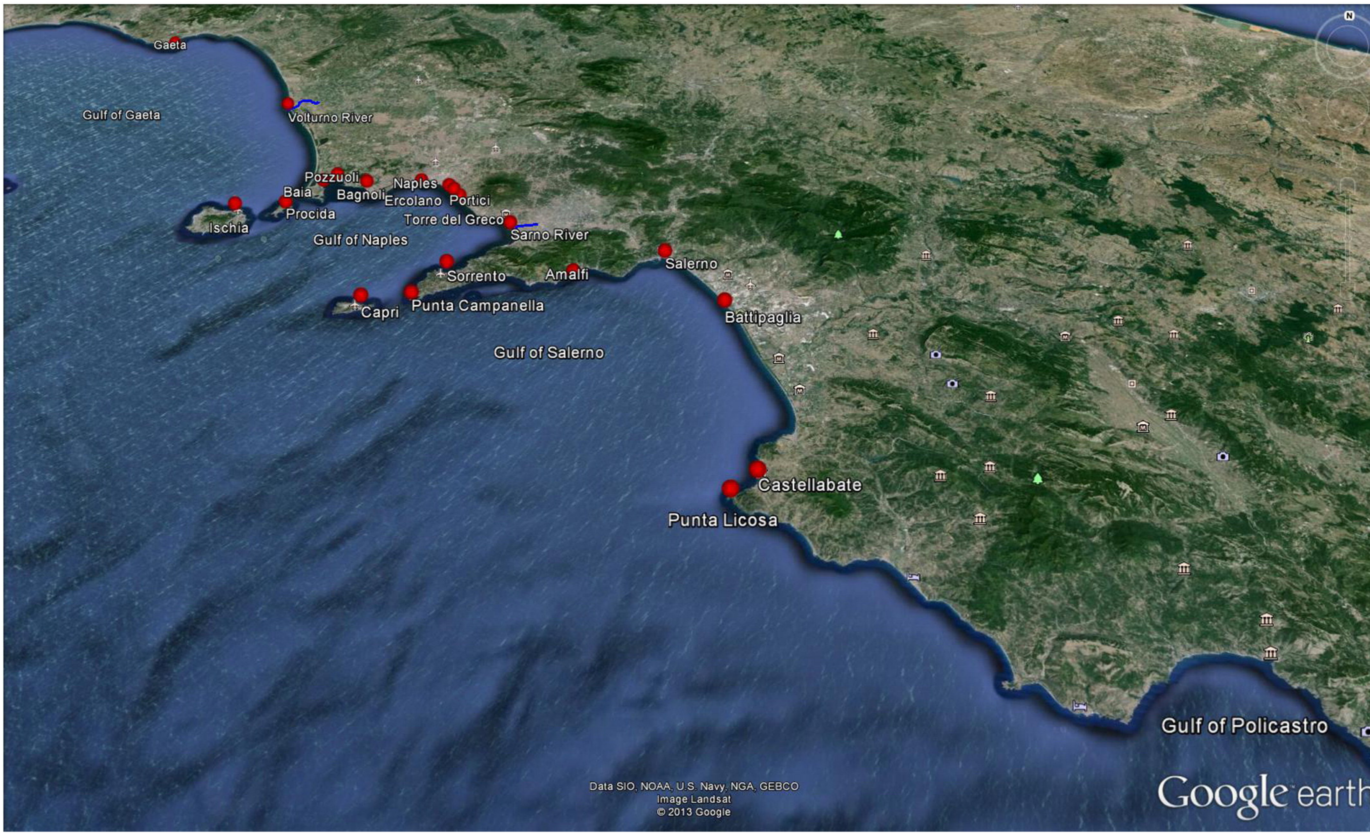

Fig. 1. Location map of the area of study.

The environmental quality of the marine ecosystems in these areas is directly influenced by human activities, and their waters present hydrographic and biological properties reflecting anthropic stress (Ribera d'Alcalà et al., 1989, 2004; Zingone et al., 1990, 2006). Human activities range from dense urban settlements to industrial clusters and intense maritime traffic. According to the Agenzia Regionale per la Protezione Ambientale della Campania (ARPAC), exhaustive discharges of non-purified or without appropriate depuration sewage are still widespread along the region. Industries are mostly concentrated in the northern half of the regional territory, especially next to main cities, and devoted to vegetable preserving processes, textile-apparel, clothes production and leather tannery. Textile industry seems to have a low environmental impact since raw materials are produced and imported from foreign countries. However, inadequate purification systems in the tannery and vegetable preserving activities can lead to significant pollution levels in stream waters and sediments, resulting in a number of health effects on crops, aquatic (both marine and freshwater) and terrestrial biota, and humans (Meriç et al., 2005). As an example, the Sarno River, in the eastern part of the Gulf of Naples, has gained the infamously reputable title of being the most polluted river in Europe after years of continuous supply of untreated effluent of domestic, agricultural and industrial origin (De Pippo et al., 2006). On the other hand, the region is also an internationally renowned touristic location, not only for its historical attractions, but also for swimming and leisure activities along the coastline and the islands, especially in the summer months. Tourism helps to develop local infrastructure and services and represents a major source of income and employment, but can also lead to negative impacts such as increased pollution and discharges into the sea. Consequently, the analysis, maintenance and improvement of the quality of the marine environment in the region are major issues not only for the welfare of the entire ecosystem, but also for social and economic reasons.

3. Levels of major contaminants and their pollution effects

Chemical contaminants are generally separated into three groups: stable trace elements, organic substances, and radionuclides. For the first group, most of the elements considered should be those for which toxicity is known, such as Cu, Zn, Cd and Pb, as well as Hg and their organic forms. The organic contaminants include persistent organic pollutants (POPs) as well as "novel" compounds such as hormones, veterinary medicines and pharmaceuticals. In the Naples area, research has been so far basically devoted to trace elements, organochlorine compounds (OCs), namely polychlorinated biphenyls (PCBs) and the pesticide dichlorodiphenyltrichloroethane (DDT) and its related metabolites (p,p′-DDT, p,p′-DDE, and p,p′-DDD), and polycyclic aromatic hydrocarbons (PAHs). Here we review the main existing data on these compounds in the three core compartments (sediments, water and biota) with the aim of assessing GES in relation to the MSFD descriptor 8.

3.1. Levels in sediments

3.1.1. Trace elements

Table 1 shows the metal concentration data compiled for sea sediments along the coasts of Campania. It can be observed that most data are concentrated in the Bagnoli area, around the Sarno River mouth and in the Naples harbor, with very few measurements in other places of the region. In order to screen sediment contamination in these areas and identify pollutants of concern, the determined levels have been compared to the sediment quality guidelines (SQGs) denoted in Table 1.

The Contamination Factor (CF) is obtained by dividing the concentration of each pollutant by the sediment background value (SBVs), i.e. the concentration in uncontaminated sediment. CF < 1 indicates low contamination; 1 < CF < 3 is moderate contamination; 3 < CF < 6 is considerable contamination; and CF > 6 is very high contamination (Hakanson, 1980). According to this, the comparison of metal levels found in Bagnoli coastal sea sediments with SBVs reported for the same area by Damiani et al. (1987) indicates moderate to considerable contamination by Cu, Hg and Pb, while Zn falls in the highly polluted range. Instead, Cr exhibits concentrations close to the natural background. When comparing with the concentration ranges for moderately polluted sediments provided by the US Environmental Protection Agency (USEPA, 1993), the analyzed sediments may be considered as moderately contaminated as regards Cd, Cu and Hg, and heavily polluted as regards As, Pb and Zn, while pollution by Cr is not considered to exist. Furthermore, As, Cd, Hg and Pb exceed in the majority of the cases the intervention limits established by the Italian Law for band sea sediments (D.M. 367/03). Therefore, the coastal area facing the Bagnoli brownfield displays anomalous high concentrations of several trace elements, mainly As, Pb, and Zn, and to a lesser extent Cd, Cu and Hg. This site, formerly the second largest integrated steelworks in Italy, is now a disused industrial area subject to a government remediation project. Despite industrial activities were all closed between 1990 and 2000, the elevated concentrations are suggestive of an active source of contamination (Albanese et al., 2010). Except for As, whose high levels could be attributable to natural hydrothermal processes of the volcanic Campi Flegrei area and not related to anthropogenic contamination, the other metals seem to be correlated to the industrial plant (Romano et al., 2008, 2009).

The CFs of surficial sea sediments around the Sarno River mouth have been calculated using the mean of background values reported by Baldi et al. (1983), Adamo et al. (2005) and Sprovieri et al. (2007). Results indicate moderate contamination by As and Hg and high contamination by all the other studied metals. Comparing to the USEPA benchmarks, the area can be described as moderately contaminated as regards Cd and Hg, and heavily polluted as regards As, Cr, Cu, Pb and Zn. Moreover, Cd and Pb exceed in most cases the Italian intervention limits, while As, Cr and Hg do so essentially only in sediments collected nearer to the river mouth. These findings reflect that the Sarno River estuary is nowadays strongly affected by a number of pollution sources and that the Sarno River should account as one of the main contribution of metal loads into the Gulf of Naples and the Tyrrhenian Sea. Dispersal from this point is dominantly to the southwest (Montuori et al., 2013), which deserves particular attention due to the proximity of the marine protected area (MPA) of Punta Campanella in the Sorrentine Peninsula. Main pollutant sources are related to the massive urban settings and agricultural fields as well as the industrial development of the river basin (Arienzo et al., 2001). In fact, even though the distribution of As in Campania sediments is commonly related to their volcanoclastic nature, the application of inorganic arsenical pesticides and herbicides in this area cannot be disregarded (Albanese et al., 2012). Nevertheless, it is worth mentioning that the administrations are trying to recover this area by means of investment policies aimed to improve the wastewater treatment systems. Thus, despite that Cr levels are still elevated, the decreasing trend of this metal in the period 1978–2008 (Table 1) may be linked to the recent effective treatment of wastewater from the tanning plants along with the tendency to import already tanned raw materials (Albanese et al., 2012). In fact, a similar Cr concentration decrease associated with the gradual decrease of the number of operating tanneries has also been observed in the Elefsis Bay (Greece), which is another key area for the Perseus project (Pantazidou et al., 2007).

The CFs determined for the Naples harbor point out low contamination by As, considerable contamination by Cd, Cr, Cu, Pb and Zn, and very high contamination by Hg. Taken into account the USEPA guidelines, the area may be considered as low polluted with respect to Cd, moderately polluted with respect to Hg and heavily polluted with respect to As, Cr, Cu, Pb and Zn. Furthermore, all elements exceed the proposed Italian intervention limits. It is, therefore, reasonable to assert that most of the metal pollution in the area is anthropogenic and linked to the different industrial and/or commercial activities of the harbor. It seems that Cr levels are mainly associated with shipyard and industrial activities occurring in the Eastern area of the port, while Cu, Hg, Pb and Zn are more related to the commercial area activities, which involve urban and industrial wastewaters, high traffic vehicle emissions and antifouling paints for commercial vessel (Sprovieri et al., 2007). Concentrations of metals tend to diminish as one moves away from these areas, reaching levels close to background near the bay entrance (Baldi et al., 1983; Griggs and Johnson, 1978; SiDiMar, 2005). Nevertheless, Adamo et al. (2005) also found high metal pollution at the margin of the port basin connected to the petroleum refineries east of the city. These results are very useful to recognize potential danger due to remobilization of sediment-held metals and consequently to identify proper management actions for dredging and disposal of harbor sediments (Sprovieri et al., 2007).

In summary, the metal contamination in the region of Campania appears to be mostly restricted to the coastal waters adjacent to industrial areas of Bagnoli and the Naples harbor, whose values are similar to or higher than the highest recorded values for similar marine environments (Cukrov et al., 2011; Tessier et al., 2011). The Sarno River represents the major point source of contaminants entering the eastern part of the Gulf of Naples. In the Bay of Pozzuoli, the coastal zone of Baia also presents high levels of some metals, particularly Cu, Hg and Pb. This area is nowadays included in a MPA, but it was formerly an important commercial harbor. The high levels found here have been associated with the existence for many years of five abandoned sunken vessels on the sea-bottom (Bergamin et al., 2009). On the other hand, the southern shelf of the region (between the gulfs of Salerno and Policastro) displays low metal concentrations close to background levels, indicating this zone has fortunately remained practically unpolluted (SiDiMar, 2005; Sprovieri et al., 2006).

3.1.2. OCs

As early as in the 80s, the concentrations of PCBs in surficial sediments from the vicinity of Naples and the inner bay of Pozzuoli were found to be high and even higher than those yet found in other heavily populated and industrialized Mediterranean cities (Baldi et al., 1983; Damiani et al., 1987; De Simone et al., 1981). A posterior comparison of OC levels in sediments of the different Mediterranean sub-basins showed that the coastal urban area of Naples is especially contaminated and thus should be considered as a hot spot for these pollutants (Albaigés, 2005; Gómez-Gutiérrez et al., 2007). In fact, PCBs in this area occur well above the concentration limits permitted by the Italian Law (D.M. 367/03) (Table 2). The analysis of the distribution and composition of PCBs in the superficial sediments of the Naples harbor has indicated the existence of a single major contamination source, possibly related to the industrial activities (Sprovieri et al., 2007). Another recent study on temporal and spatial distribution patterns of PCBs in this harbor has reported the occurrence of the highest concentrations in the central and easternmost sectors, where the most important industrial and shipping areas are located (Feo et al., 2011). This study also found an unexpected and systematic increase of PCB levels in the upper parts of the sediments compared to the lower ones. Although concentrations show a decline over the period 1980–2004 (Table 2), which is consistent with the banning of production and use of these compounds, the inverse trend with depth appears to evidence present, uncontrolled discharges from nearby land (Feo et al., 2011).

PCBs in sea sediments facing the Bagnoli coastline have been estimated as medium-high and exceeding the reference values for Italian coastal marine areas (D.M. 367/03) (Table 2). PCB levels in this area also increase in the topmost sediment layers and even show an increase for the period 1999–2005 (Table 2). Here, the groundwaters, emanating from the brownfield site to the sea across an artificial structure, have been identified as the main source of contaminants

Table 1
Mean and/or ranges of trace element concentrations (μg/g dry weight) in sediment samples from the Gulf of Naples and adjacent coastal areas. Different sediment quality guidelines are also provided at the bottom of the table for comparison purposes.

Area	Sample	Year	Fraction μm	As	Cd	Cr	Cu	Hg	Pb	Zn	Reference
Gulf of Naples											
Bay of Naples	Surficial sediment	1975	Total			20–80	36–83		44–97		Griggs and Johnson (1978)
Bay of Pozzuoli	Bottom sediment	1975	Total			20–50	20–58		50–221		Griggs and Johnson (1978)
Portici	Bottom sediment	1975	Total			119	128		108		Griggs and Johnson (1978)
Naples harbor	Top 3 cm sediment	1980	Total					0.14–1.70			Baldi et al. (1983)
Bay of Naples	14 cm core sediment	1987–88	Total				1.74–9.46		2.84–62.32	44.85–91.9	Sandulli and De Nicola-Giudici (1990)
Lacco Ameno (Ischia)	Bottom sediment	1993–94	63		0.083		23		134	75	Schlacher-Hoenlinger and Schlacher (1998a)
100–1480 m from Naples	Surficial sediments	2001–04	Total	13.7	0.18	12.6	14.0	0.43	86.9	76.7	SiDiMar (2005)
Portici	Surficial sediments	2001–04	Total	13.0	0.15	17.8	28.2	0.25	20.1	55.4	SiDiMar (2005)
Naples harbor	Surficial sediment	2002	2000	15.7 (8–21)	0.9 (0.2–2.5)	72.5 (10.3–161.8)	131 (40–415)		123 (37–314)	303 (41–1196)	Adamo et al. (2005)
Levante dock (Naples harbor)	Surficial sediment		2000	33.91 (11.1–165.7)	0.72 (0.08–3.07)	247.39 (68.7–838.5)	119.33 (15.4–467.3)	0.47 (0–1.27)	138.96 (34.4–322.4)	264.76 (0.0–1573)	Ferraro et al. (2006)
Granili dock (Naples harbor)	Surficial sediment		2000	22.196 (9.19–45.03)	0.66 (0.06–1.92)	60.104 (5.99–388.6)	48.547 (19.8–150.2)	0.511 (0.0–1.13)	61.015 (22.9–225.3)	177.77 (32.5–578.57)	Ferraro et al. (2006)
Diaz dock (Naples harbor)	Surficial sediment		2000	15.5 (10.1–33.03)	1.075 (0.49–2.0)	52.22 (6.9–165.15)	225.8 (31.2–626)	1.27 (0.02–7.23)	296.65 (34.6–739.2)	595.04 (45.7–1994)	Ferraro et al. (2006)
Naples harbor	Surficial sediment	2004	2000	25.77 (1–39.61)	0.5 (0.01–3.0)	188.46 (7–1798)	198.64 (12–5743)	1.54 (0.01–139)	240 (19–3083)	361.53 (17–7234)	Sprovieri et al. (2007)
Baia	Surficial sediments	2006	Total	53.65[a] (12.9–175.9)	0.17[a] (0.05–0.33)	17.2[a] (10–102.6)	43.3[a] (13.9–286.9)	0.38[a] (0.10–1.37)	119[a] (55–4361)	177[a] (75–421)	Bergamin et al. (2009)
Bagnoli											
Bagnoli	Top 3 cm sediment	1980	Total					1.75			Baldi et al. (1983)
Bagnoli	Surficial sediment		420		0.8 (0.1–4.8)		34 (9–95)	0.2 (0.01–1.0)	275 (83–775)	393 (180–1600)	Sharp and Nardi (1987)
Bagnoli	Beach sediment		Total	50[a] (33–66)	0.27[a] (0.01–0.97)	32[a] (11–66)	79[a] (3–664)	0.18[a] (0.09–0.36)	168[a] (23–443)	213[a] (77–1765)	Romano et al. (2004)
Bagnoli	Surficial sediment		Total	2[a] (0.5–4)	0.57[a] (0.01–3.24)	28[a] (4–54)	27.2[a] (0.5–126.1)	0.7[a] (0.01–9.27)	221[a] (52–896)	602[a] (91–2313)	Romano et al. (2004)
Bagnoli	0–20 cm core sediment	1999	Total	46	0.81	24.37	103.1	0.89	181.54	861.62	Bergamin et al. (2005)
Bagnoli	20–30 cm core sediment	1999	Total	42.51	0.66	20	72.17	0.49	171	720.5	Bergamin et al. (2005)
Bagnoli	30–50 cm core sediment	1999	Total	54.92	1.97	18	141.83	1.16	244	1727.5	Bergamin et al. (2005)
Bagnoli	Surficial sediment	1999, 2002	Total	54.66 (4–90)	0.43 (0.04–1.28)	24.48 (5–40)	41.48 (4–352)	0.35 (0.01–0.89)	187.4 (16–465)	591.81 (52–2313)	Romano et al. (2008)
Bagnoli	Surficial sediment	2004	Total	13 (4–55)	0.71 (0.01–4.7)	15 (4–43)	40 (6–165)	0.58 (0.01–2.9)	260 (21–1288)	539 (111–2525)	Romano et al. (2009)
Bagnoli	0–20 cm core sediment	2004–05	Total	11.7 (2.3–55)	0.76 (0.01–7.4)	16.4 (4–103)	47 (5.88–236)	0.57 (0.01–3.5)	292 (21–1773)	593 (93–2829)	Albanese et al. (2010)
Bagnoli	20–30 cm core sediment	2004–05	Total	9.1 (1.8–26)	1.4 (0.06–9)	14.5 (4.8–61)	59 (5.82–210)	0.72 (0.01–63)	393 (34.7–2220)	827 (90–3200)	Albanese et al. (2010)
Bagnoli	30–50 cm core sediment	2004–05	Total	8.9 (3.3–37)	2.19 (0.05–44)	13 (3.3–142)	56 (5.51–222)	1 (0.01–8.3)	412 (35–3446)	886 (102–5185)	Albanese et al. (2010)

Bagnoli	100–120 cm core sediment	2004–05	Total	7.3 (2.8–18)	1 (0.1–5.9)	8.6 (1.9–66)	34 (5.4–355)	0.52 (0.01–4.8)	212 (30–1131)	500 (93–1779)	Albanese et al. (2010)
Bagnoli	180–200 cm core sediment	2004–05	Total	8.2 (1.4–73)	1 (0.05–9.4)	7.7 (2.0–38)	36 (2.9–408)	0.29 (0.01–3.4)	282 (25–2061)	570 (10–4229)	Albanese et al. (2010)
Bagnoli	280–300 cm core sediment	2004–05	Total	8.4 (6.3–10.4)	0.2 (0.1–0.4)	7.5 (4.5–11.7)	8.4 (4.9–11.29)	0.02 (0.01–0.07)	208 (89–755)	264 (128–910)	Albanese et al. (2010)
Bagnoli	380–400 cm core sediment	2004–05	Total	9 (6–12)	0.2 (0.1–0.5)	9.6 (4.8–18)	11 (5.7–28)	0.0146 (0.01–0.02)	238 (75–818)	438 (133–1546)	Albanese et al. (2010)
Sarno River											
Sarno River mouth	Surficial sediment	1975	Total			714	76		200		Griggs and Johnson (1978)
200–3000 m from Sarno River mouth	Surficial sediment	2001–04	Total	8.1	0.36	84.4	50.5	0.28	58.2	55.4	SiDiMar (2005)
50 m South from Sarno River mouth	Surficial sediment	2008	Total	69.30	0.89	198.79	469.35	0.56	176.72	802.88	Montuori et al. (2013)
50 m central from Sarno River mouth	Surficial sediment	2008	Total	44.24	2.92	514.4	580.18	1.02	389.88	173.0	Montuori et al. (2013)
50 m North from Sarno River mouth	Surficial sediment	2008	Total	19.92	2.1	310.02	234.0	0.58	434.93	591.89	Montuori et al. (2013)
150 m South from Sarno River mouth	Surficial sediment	2008	Total	11.73	0.71	111.78	119.1	0.31	1147.91	317.16	Montuori et al. (2013)
150 m central from Sarno River mouth	Surficial sediment	2008	Total	30.13	0.39	86.43	204.07	0.24	76.83	349.08	Montuori et al. (2013)
150 m North from Sarno River mouth	Surficial sediment	2008	Total	15.25	1.53	177.32	224.87	0.36	135.23	436.15	Montuori et al. (2013)
500 m South from Sarno River mouth	Surficial sediments	2008	Total	10.96	0.53	58.68	285.84	0.21	81.20	344.5	Montuori et al. (2013)
500 m central from Sarno River mouth	Surficial sediments	2008	Total	6.77	0.60	40.4	141.48	0.23	18.12	347.8	Montuori et al. (2013)
500 m North from Sarno River mouth	Surficial sediments	2008	Total	8.25	0.75	23.77	183.61	0.25	26.94	360	Montuori et al. (2013)
Gulf of Gaeta											
500–3000 m from Volturno River mouth	Surficial sediments	2001–04	Total	5.0	0.2	26.9	13.4	0.24	13.0	33.1	SiDiMar (2005)
Gulf of Salerno											
500–3000 m from Picentino River mouth	Surficial sediments	2001–04	Total	5.8	0.15	14.1	4.6	0.28	6.9	68.6	SiDiMar (2005)
Punta Tresino	Surficial sediments	2001–04	Total	22.9	0.04	5.7	1.3	0.08	4.7	43.8	SiDiMar (2005)
Punta Licosa	Surficial sediments	2001–04	Total	22.0	0.05	5.2	1.8	0.1	4.0	14.6	SiDiMar (2005)
Southern Campania shelf	Surficial sediments	2003	2000	20.85 (6.47–50.77)	0.15 (0.009–2.0)	41.16 (4.46–101.8)	19.6 (1.15–46.44)	0.06 (0.002–0.3)	18 (2.75–46.29)	69.81 (12–124.9)	Sprovieri et al. (2006)
Sediment quality guidelines											
USA	Moderately polluted sediments	1993	Total	3–8	1–6	25–75	25–50	0.3–1	40–60	90–200	USEPA (1993)
Bagnoli	Sediment background levels		Total			30	20	0.25	60	80	Damiani et al. (1987)
Bay of Naples	Sediment background levels		Total					0.1–0.2			Baldi et al. (1983)
Naples harbor	Sediment background levels	2002	2000	15.8	0.2	21.6	21.1		22.7	56.6	Adamo et al. (2005)
Southern Campania shelf	Sediment background levels	2003	2000	21.49	0.16	51.05	24.57	0.07	21.43	80.39	Sprovieri et al. (2006)
Italy	Regulatory guidelines for sea sediments	2003	Total	12	0.3	50		0.3	30		D.M. 367/03
Naples harbor	Sediment background levels	2004	2000	25.77	0.022	43.1	32.7	0.015	46.5	50	Sprovieri et al. (2007)
Freshwater and marine ecosystems in North America	ER-L, effects range low		Total	8.1	1.2	81	34	0.15	46.7	150	Long et al. (1995)
Freshwater and marine ecosystems in North America	ER-M, effects range median		Total	70	9.6	370	270	0.71	218	410	Long et al. (1995)
Freshwater and marine ecosystems in North America	TEL, threshold effect level		Total	7.24	0.68	52.3	18.7	0.13	30.2	124	Macdonald et al. (1996)
Freshwater and marine ecosystems in North America	PEL, probable effect level.		Total	41.6	4.21	160	108	0.7	112	271	Macdonald et al. (1996)

[a] Median instead of mean is provided.

(Albanese et al., 2010). Therefore, PCB contamination in the Gulf of Naples is likely to remain of concern for years to come as seen in other major urban and industrial areas worldwide (Desmet et al., 2012; Diamond et al., 2010).

PCB levels higher than recommended values have also been found around river mouths, particularly the Sarno River, close to the wreck zones of the bay of Baia, in the area of Portici and even in Punta Licosa and Punta Tresino (Table 2). Conversely, in the MPA Punta Campanella, PCB concentrations are low and similar to background levels, so atmospheric deposition rather than nearby human activities must be the primary source of these pollutants (Pozo et al., 2009).

3.1.3. PAHs

The assessment of hydrocarbon pollution in sea sediments from the area of study has mostly focused on the industrial site of Bagnoli. This area exhibits elevated PAH concentrations, both in surface and bottom sediments (Table 2). The highest concentrations are detected in the samples closer to the industrial plant and appear particularly high if compared with some other data reported for other coastal regions of the world (Chen et al., in press; Romano et al., 2004). When looking at Table 2, it would appear that PAH levels in Bagnoli have considerably increased for the period 1999–2005. It is difficult, however, to confirm this because of the differences in analytical and sampling procedures among studies. In fact, the studies that have found the highest concentrations (Albanese et al., 2010; Romano et al., 2009) are also those that have analyzed a higher number of samples coming from the sector closest to the brownfield site, where a large amount of anthropogenic grains mostly made of tar and oil residues are present and so the highest contamination is expected. Moreover, the observed increases in PAH concentrations in the 30–50 cm depth layer with respect to the surface sediments do not point to a present-day release, but rather reflect infiltrations of PAHs from the surface to the groundwater. In any case, based on the pollutant ranges suggested by Baumard et al. (1998): low: 0–0.1 μg/g dw, moderate: 0.1–1 μg/g dw, high: 1–5 μg/g dw, very high: >5 μg/g dw, sediments from Bagnoli fell in the moderate to very high pollution range. Furthermore, PAH levels always exceed the intervention limits established by the Italian Law for sea sediments (D.M. 367/03), and, in most cases, for soils (Parlamento Italiano, 2006) (Table 2). Consequently, the entire area should undergo remediation, being unfeasible the reuse of dredged sediments in residential or industrial areas unless they come from layers deeper than 280 cm (Albanese et al., 2010).

In the Naples harbor, the concentrations of PAHs can be classified as moderate-high and are comparable or higher than those found in other important commercial ports (Sprovieri et al., 2007; Wang and Tam, 2012). Total concentrations decrease progressively with depth, suggesting a more intense anthropic impact in the recent period (Table 2) (Feo et al., 2011). The contamination is more evident in the central and easternmost parts of the harbor, reflecting effects of local inputs from the commercial and industrial activities in nearby lands. PAH contamination has been mainly related to a pyrolitic (incomplete combustion of organic matter) industrial origin with a limited contribution of urban vehicular emissions, while the influence of petroleum unburned sources does not seem significant at all (Feo et al., 2011; Sprovieri et al., 2007).

Data on PAH pollution in the Sarno River and its impact on the Gulf of Naples have been reported for the first time only recently (Montuori and Triassi, 2012). This study found that PAHs in sediments also derive mainly from combustion processes, although here levels fit in the low-moderate range of pollution.

Other analyzed sites of the region of Campania show low contamination by hydrocarbons, with the exception of the Baia coastal zone where median concentration exceed the reference values and so it has been considered of High Environmental Relevance (Bergamin et al., 2009).

3.2. Toxicity of sediments

3.2.1. Trace elements

Although helpful, the previous considerations offer little insight into the environmental impact of contaminants, that is, about whether the sediment in question is toxic or not to aquatic organisms. Thus, the assessment of the potential biological effects related to those highly polluted sediments have been done based on the SQGs established for freshwater and marine ecosystems in North America (Table 1) (Long et al., 1995; MacDonald et al., 1996). ERL (effect range low) and TEL (threshold effect level) represent chemical concentrations towards the low end of the effect ranges, that is, below which adverse biological effects are rarely observed. The ERM (effect range median) and PEL (probable effect levels) represent mid-range above which adverse effects may frequently occur. ERL–ERM and TEL–PEL represent a possible-effects range, within which negative effects would occasionally occur. When contrasting those reference values to the mean levels of trace elements found in surficial sediments (0–20 sampling depth) from the areas of concern (Bagnoli, Naples harbor and Sarno River mouth), it can be seen that most elements fall in the range ERL–ERM and TEL–PEL. Only levels of Hg, Pb and Zn found in Bagnoli, of Hg in the Naples harbor, and of Pb in the Sarno River mouth are higher than both ERM and PEL values. Levels of Cu and Pb in the Naples harbor and Cu and Zn in the Sarno area exceed PEL values, but not ERM values. On this basis, metal-polluted sediments in the three areas pose some potential risks to aquatic biota and the most serious hazards are to be feared in relation to Hg, Pb and Zn.

Despite these alarming findings, little has been done in the area to evaluate the incidence of adverse effects caused by metals in sediments and the limited research has focused primarily on the variation of benthic foraminiferal abundance. Benthic foraminifera are heterotrophic protists that are present in a broad range of marine environments and have been widely used in pollution monitoring since they are very sensitive to environmental changes (Bergamin et al., 2005). In Italy, this kind of studies has been included as experimental research within the environmental characterization of polluted areas listed as National Relevance Sites by the Italian Ministry of Environment (Bergamin et al., 2003, 2005). In this context, the coastal zone of Bagnoli, the Naples harbor, the area of Baia, and several other locations along the Tyrrhenian coast have been investigated. A number of faunal parameters have been correlated with the high metal concentrations found in those areas, such as absence of foraminifera or low faunal abundance and increased presence of pollution-tolerant species and of morphologically abnormal specimens (Bergamin et al., 2005, 2009; Ferraro et al., 2006, 2009; Romano et al., 2008, 2009; Rumolo et al., 2009). However, in a recent work carried out in Bagnoli and Baia, it has been confirmed that sediment grain size is a primary factor controlling the distribution of the most abundant foraminifera species as well as of pollution-tolerant species. Therefore, when assessing the influence of pollution on foraminiferal communities, it is necessary to consider that responses may be a result of sediment changes and not certainly attributable to pollution (Magno et al., 2012).

3.2.2. OCs

As shown in Table 2, ERL and ERM guidelines (Long et al., 1995), as well as TEL and PEL guidelines (MacDonald et al., 1996) have been considered to evaluate the possible toxicological risks of PCBs in the study area. All analyzed sites, with the exception of Punta Campanella, contain levels higher than ERL and TEL values, suggesting that the exposure to PCBs may exert adverse effects on the neighboring benthic organisms. Only the sediments in that MPA as well as those deeper than 280 cm appear substantially free of anthropic contamination. Moreover, PCB concentrations exceed the ERM or PEL values in many samples, which would pose a serious threat to coastal marine life along the region, particularly around the Sarno River and the Portici area. However, these results derive from a single source (SiDiMAr, 2005), so the assumptions about the level of concern should be made with caution.

Table 2
Mean and/or ranges of concentrations (μg/g dry weight) of persistent organic pollutants in marine coastal sediments from the region of Campania. Sediment quality guidelines are also provided at the bottom of the table for comparison purposes.

Sample	Area	Year	n	PCBs	n	PAHs	Reference
Gulf of Naples							
Top 3 cm sediment	Naples harbor	1980		0.01–3.20			Baldi et al. (1983)
Surficial sediments	Naples	2001–04	6	1.27	17	0.53	SiDiMar (2005)
Surficial sediments	Portici	2001–04	6	1.97	17	0.34	SiDiMar (2005)
Surficial sediments	Naples harbor	2004	38	0.07 (0.001–0.9)	17	3.14 (0.009–31.77)	Sprovieri et al. (2007)
30–50 cm sediment layer	Naples harbor	2004	38	0.049 (0.003–0.19)	13	2.796 (0.007–31.75)	Feo et al. (2011)
100–120 cm sediment layer	Naples harbor	2004	38	0.038 (0.001–0.21)	13	1.596 (0.007–11.51)	Feo et al. (2011)
180–200 cm sediment layer	Naples harbor	2004	38	0.029 (0.002–0.23)	13	1.718 (0.008–18.13)	Feo et al. (2011)
280–300 cm sediment layer	Naples harbor	2004	38	0.027 (0.002–0.14)	13	0.902 (0.026–5.770)	Feo et al. (2011)
Surficial sediments	Baia	2006		0.069[a] (0.002–0.496)		4.02[a] (0.14–23.54)	Bergamin et al. (2009)
Bagnoli							
Beach sediments	Bagnoli			0.027[a] (0.003–0.06)	15	3.11[a] (0.09–12.6)	Romano et al. (2004)
Marine sediments	Bagnoli			0.033[a] (0.004–0.09)	15	0.38[a] (0.004–2.9)	Romano et al. (2004)
0–20 cm sediment layer	Bagnoli	1999		0.052	15	0.70	Bergamin et al. (2005)
20–30 cm sediment layer	Bagnoli	1999		0.027	15	0.66	Bergamin et al. (2005)
30–50 cm sediment layer	Bagnoli	1999		0.038	15	1.48	Bergamin et al. (2005)
Surficial sediments	Bagnoli	1999, 2002		0.058 (0.001–0.36)	15	1.02 (0.01–4.78)	Romano et al. (2008)
Surficial sediments	Bagnoli	2004			15	172.02 (0.14–2947)	Romano et al. (2009)
0–20 cm sediment layer	Bagnoli	2004–05		0.108 (0.008–6.66)		165 (0.1–2947)	Albanese et al. (2010)
20–30 cm sediment layer	Bagnoli	2004–05		0.056 (0.001–0.46)		159 (0.08–1806)	Albanese et al. (2010)
30–50 cm sediment layer	Bagnoli	2004–05		0.055 (0–0.726)		212 (0.05–2265)	Albanese et al. (2010)
100–120 cm sediment layer	Bagnoli	2004–05		0.068 (0–2.19)		105 (0.05–1654)	Albanese et al. (2010)
180–200 cm sediment layer	Bagnoli	2004–05		0.076 (0.0003–1.24)		110 (0.07–2514)	Albanese et al. (2010)
280–300 cm sediment layer	Bagnoli	2004–05		0.0012 (0–0.004)		4 (0.1–8.4)	Albanese et al. (2010)
380–400 cm sediment layer	Bagnoli	2004–05		0.0006 (0–0.001)		3 (0.1–6.4)	Albanese et al. (2010)
Sarno River							
Surficial sediments	Sarno River mouth	2001–04	6	2.95	17	0.11	SiDiMar (2005)
Surficial sediments	Sarno River Mouth at 50 m South	2008			16	0.446	Montuori and Triassi (2012)
Surficial sediments	Sarno River Mouth at 50 m Central	2008			16	0.502	Montuori and Triassi (2012)
Surficial sediments	Sarno River Mouth at 50 m North	2008			16	0.180	Montuori and Triassi (2012)
Surficial sediments	Sarno River Mouth at 150 m South	2008			16	0.651	Montuori and Triassi (2012)
Surficial sediments	Sarno River Mouth at 150 m North	2008			16	0.162	Montuori and Triassi (2012)
Surficial sediments	Sarno River Mouth at 500 m South	2008			16	0.066	Montuori and Triassi (2012)
Surficial sediments	Sarno River Mouth at 500 m Central	2008			16	0.087	Montuori and Triassi (2012)
Surficial sediments	Sarno River Mouth at 500 m North	2008			16	0.040	Montuori and Triassi (2012)
Surficial sediments	Mouth of Volturno River	2001–04	6	0.88	17	0.03	SiDiMar (2005)
Surficial sediments	Mouth of Picentino River	2001–04	6	0.26	17	0.01	SiDiMar (2005)
Gulf of Salerno							
Surficial sediments	Punta Campanella (MPA)	2001	36	0.004			Pozo et al. (2009)
Surficial sediments	Punta Tresino	2001–04	6	0.62	17	0.01	SiDiMar (2005)
Surficial sediments	Punta Licosa	2001–04	6	0.24	17	0.01	SiDiMar (2005)
Surficial sediments	Punta Campanella (MPA)	2002			16	0.045	Perra et al. (2011)
Sediment quality guidelines							
Italian regulatory guidelines for sea sediments				0.004		0.2	D.M. 367/03
Italian regulatory guidelines for soils: residential use						10	Parlamento Italiano (2006)
Italian regulatory guidelines for soils: industrial use						100	Parlamento Italiano (2006)
ER-L, effects range low				0.0227		4.02	Long et al. (1995)
ER-M, effects range median				0.180		44.79	Long et al. (1995)
Threshold effect level (TEL)				0.0215		1.684	MacDonald et al. (1996)
Probable effect level (PEL)				0.189		16.77	MacDonald et al. (1996)

n = Number of PCB congeners or PAH compounds analyzed in each study.
[a] Median instead of mean is provided.

Like for metals, very little research on potential effects of OC pollutants has been conducted in the study area. The recorded PCB concentrations did not seem to affect foraminiferal abundance or produce environmental stress on the foraminiferal population in the Bagnoli industrial area (Bergamin et al., 2005; Romano et al., 2008). Similarly, Ferraro et al. (2009) obtained a non-linear response by the foraminiferal biota to the effects of contamination with the different classes of pollutants in the Naples harbor. On the other hand, Bergamin et al. (2009) observed environmental stress in benthic foraminifera referable to the high PCB levels in the marine area of Baia. Although the experience and knowledge of the use of foraminifera as a tool for pollution monitoring have greatly improved in recent decades, this field is still far from being completely understood or exploited (see Frontalini and Coccioni, 2011 for a review of Italian research).

3.2.3. PAHs

Overall, PAHs in the Bagnoli area exceed PEL and ERM guideline values by several times (Table 2), particularly in the stations located close to the industrial plant, indicating there is a high probability of biological effects. Albanese et al. (2010), in fact, recommended the whole Bagnoli area should be closed to any bathing activity until a recovery of the entire area is completed.

In Baia and the Naples harbor, PAH values are generally between ERL–ERM and PEL–TEL values, so a biological effect will occur occasionally.

Around the Sarno River, PAH levels are well below guideline values regarding the ERL and TEL, so a biological effect may be rare. This is also true for the areas of Portici, Punta Campanella, Punta Licosa and Punta Tresino.

As done for metals and PCBs, the influence of PAH pollution on benthic foraminifera has been also investigated. The most relevant results indicate a correlation of foraminiferal abnormality occurrence with PAHs in the Bagnoli area (Romano et al., 2008). However, any correlation has been found in the other areas, directly suggesting that these pollutants have no direct control on the abundance patterns of the studied benthic species or alternatively indicating specific tolerance of foraminifera to toxic influences of PAHs present in marine sediments (Ferraro et al., 2009).

3.2.4. Joint toxicity

As seen, the co-existence of trace metals, PCBs and PAHs at considerable levels are frequently detected in sea sediments from the area of study. However, most research on potential toxicity has only focused on individual pollutants rather than on combined exposure to multiple chemicals. Therefore, in order to obtain a more accurate assessment of ecological risk due to sediment contamination we have determined the mean probable effect quotients (PEC-Q) for mixtures of chemicals according to the procedure described by the Wisconsin Department of Natural Resources (WDNR, 2003). Firstly, the concentration of each contaminant is divided by its corresponding probable effect concentration (PEC) in order to calculate the individual PEC-Qs. Then, the individual PEC-Qs are summed and divided by the number of PEC-Qs to yield a mean PEC-Q. The result is a single, unitless, effect-based index of the relative degree of contamination that can provide a basis for determining the likelihood that a sediment sample would be toxic to sediment-dwelling organisms (Long et al., 2006). The reliability to predict toxicity has been found to be greatest for total PAHs and total PCBs and the trace elements As, Cd, Cr, Cu, Pb and Zn, so only those chemicals have been considered to analyze the joint toxicity in sediments from the area of study. For this purpose, we have used the data on surficial sediments provided by Sprovieri et al. (2007) and Albanese et al. (2010) for the Naples harbor and the Bagnoli area, respectively. These studies have been selected because they provide concentrations for all the pollutants of interest and are also the most recent.

Table 3 shows the steps to calculate the mean overall PEC-Q for all the considered contaminants. Results are 0.58 for the Naples harbor and 3.79 for the Bagnoli area. These values can be compared with the ranges obtained by Fairey et al. (2001) in toxicity test with marine amphipods from the coasts of the United States. They found that the incidence of toxicity was relatively low in sediments with mean PEC-Q of less than 0.1 and increased to approximately 50% as the quotients increased to 1.0 or greater. The incidence of toxicity peaked at 70–90% with quotients >2.5. According to this, the predicted average incidence of toxicity is low (approximately 30%) in the Naples harbor and very high in Bagnoli (up to 90%). Although the inflection points of transition from primarily nontoxic conditions to impacted conditions often are site-specific, this assessment tool can be predictive of the presence or absence of toxic effects with a quantifiable degree of confidence (Long et al., 2006). Therefore, the presence of adverse effects to sediment dwelling species are highly probable in Bagnoli and further investigation and remedial actions are warranted in this area.

3.3. Levels in water

3.3.1. Trace elements

Table 4 shows the few trace element data available for seawater in the region of Campania. According to Manfra and Accornero (2005), the highest dissolved (<0.45 μm) metal levels are found near river outlets (Garigliano, Volturno and Sarno), and harbors such as Salerno and Naples, testifying that these sites are critical points for inputs of metals into marine coastal waters. More recent data for the Sarno River area (Montuori et al., 2013) show even higher levels of dissolved (<0.7 μm) Cd, Cr and Pb, although this difference might be more related to variations in the analytical methodology between studies than to an increasing trend of these compounds. Nevertheless, Montuori et al. (2013) also found higher concentrations in the suspended particulate matter than in the water dissolved phase, suggesting fresh inputs of metals in the Sarno River and its estuary.

In order to evaluate the ecological significance of the observed levels, they have been compared to the quality values reported by the USEPA (2009). The Criteria Maximum Concentration (CMC) is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable effect. The Criterion Continuous Concentration (CCC) is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect. Thus, As, Cd, Hg, Pb and Zn levels, which are overall below those quality criteria, do not appear to pose any serious risk. Conversely, Cu levels, which surpass CMC values around the Sarno River and the Bay of Pozzuoli and CCC values in the area under the influence of the Volturno River and the Naples harbor, and Cr levels, which are higher than CCC levels in the Sarno estuary, are metals of great concern in the water bodies of the Campanian region.

3.3.2. OCs

To the best of our knowledge, there are no data in the literature documenting OC concentrations in seawater samples from the study area.

3.3.3. PAHs

PAH concentrations in seawater from the area of study have only been reported around the Sarno River plume (Montuori and Triassi, 2012). Mean levels ranged from 163.75 to 1549.25 ng/L in the dissolved phase (<0.7 μm) and from 42 to 630.25 ng/L in the suspended particulate matter, being in general very low in offshore areas (500 m from the river mouth) and very high in the vicinity of the river outflows (50 and 150 m from the river mouth). This study also found that the storm water runoff from the Sarno River is one of the main contribution sources of PAHs to the Tyrrhenian Sea, especially during the rainy season when the river water flow is highest, and that most of PAH inputs move into the sea southward.

3.4. Levels in biota

3.4.1. Trace elements

Table 5 shows the trace element concentrations recorded in biota in the area under study. As seen, data are scattered and limited to

Table 3
Calculation of mean overall PEC-Q for all the considered contaminants in the Naples harbor and the Bagnoli area.

Sediment concentrations (μg/g dry weight)								
As	Cd	Cr	Cu	Pb	Zn	PAHs	PCBs	
25.77	0.5	188.46	198.64	240	361.53	3.142	0.068	Naples harbor (Sprovieri et al., 2007)
11.7	0.76	16.4	47	292	593	165	0.108	Bagnoli (Albanese et al., 2010)
41.6	4.21	160	108	112	271	16.77	0.189	PEC values (MacDonald et al., 1996)
Individual PEC-Q (concentration / PEC)								
0.62	0.12	1.18	1.84	2.14	1.33	0.19	0.36	Naples harbor
0.28	0.18	0.10	0.43	2.61	2.19	9.84	0.57	Bagnoli
Mean PEC-Q for the metals (Σ individual PEC-Qs / number of metals)								
1.20						0.19	0.36	Naples harbor
0.96						9.84	0.57	Bagnoli
Overall mean PEC-Q = (mean PEC-Qmetals + PEC-QPAHs + PEC-QPCBs) / number of classes of chemicals								
0.58								Naples harbor
3.79								Bagnoli

very few species. Filter feeder bivalves, and typically mussels, are the most frequently used indicators of metal bioavailability in coastal and estuarine regions worldwide (Hung et al., 2001). Concentrations in common mussels (*Mytilus galloprovincialis*) from the Gulf of Naples and adjacent areas are overall low and within the range of the mean values reported in other Mediterranean sites (Amodio-Cocchieri et al., 2003; Fernández et al., 2012). As expected, the areas relatively free from industrial activities, such as the Gulf of Gaeta, Punta Licosa and Punta Tresino, although not completely uncontaminated, are of least concern. Conversely, the areas close to the river mouths present high values of some metals, particularly Cd and Zn. It is interesting to outline the general reduction of Pb levels over the period 1986–2004 (Giordano et al, 1991; SiDiMar, 2005), probably due to the rapid removal of this element in the North-western Mediterranean atmosphere after its prohibition as an additive in gasoline (Migon et al., 2008). Furthermore, a recent analysis of Cd, Pb and metallothionein contents in mussels from aquaculture stations located in the Gulfs of Naples and Salerno has also revealed low heavy metal toxicity in the farmed specimens (Trinchella et al., 2013). Only Hg values seem to be relatively high in the Gulf of Naples and even higher than those shown in the early 90s, when many industrial developments were located in the area (Amodio-Cocchieri et al., 2003; Giordano et al., 1991; Ministero dell'Ambiente, 2001). These findings are in line with those of the MYTILOS project, a large scale study of trace metal contamination by means of caged mussels undertaken along the Western Mediterranean Sea during 2004–2006. They reported a comparatively moderate to low contamination by Cd, Pb and Ni in the Tyrrhenian coast, while the highest Hg concentrations were found in this sub-basin (Andral et al., 2011; Benedicto et al., 2011). The Tyrrhenian Sea is subject to Hg enrichment due to the natural weathering of cinnabar ores in central Italy and the related extraction activities carried out there for many centuries (Bacci, 1989). Enhancement of Hg in the Tyrrhenian Sea compared to other areas has also been reported for cephalopods, fish and dolphins (André et al., 1991; Bernhard, 1988).

Marine macroalgae have also been used extensively for the biomonitoring of metal contamination of seawater (Brown and Depledge, 1998), although in Campania this issue has received little attention. The analyses of some brown, red and green algal species from the Gulf of Gaeta, the Gulf of Naples and the Ischia Island shoreline have highlighted the bioconcentration of metals in these sessile organisms, being levels in Naples significantly higher than those of the other areas (Conti and Cecchetti, 2003; Papa et al., 2008). Particularly, Cu levels in *Enteromorpha* and *Corallina* spp. from Naples correspond to those reported for strongly contaminated sites (Papa et al., 2008).

The seagrass *Posidonia oceanica* accumulates trace metals in its tissues from seawater and, therefore, has also been proposed as a sensitive bioindicator for monitoring the environmental quality of Mediterranean coastal waters (Luy et al., 2012). Seagrass beds rank among the most endangered marine ecosystems, primarily due to direct mechanical destruction (trawling, anchoring, etc.), but also to the toxic effects of anthropogenic chemical pollutants. Despite this, few contaminant data have been reported for this species in the Gulf of Naples (Table 5). Direct comparisons between studies must be made with caution since metal accumulation may depend on the examined tissue. In seagrass leaves, Cd and Pb concentrations have been reported to be within the range of low heavy metal-polluted coastal areas, while those of Cu and Zn are typical of highly contaminated regions (Schlacher-Hoenlinger and Schlacher, 1998a). Warnau et al. (1995) described the Ischia meadows as significantly contaminated with Cu and Hg, but not with Zn, Pb, Cd and Cr. Ancora et al. (2004), on the other hand, suggested that the Gulf of Naples is overall subject to low levels of heavy metal pollution. In general, metal levels area higher in localities characterized by higher anthropogenic activities (Costantini et al., 1991), although high values have been also found in a relatively low-impacted area like Ischia, possibly related to the wind-driven current circulation in the Gulf of Naples (Ancora et al., 2004).

Trace metal levels can be memorized through the belowground tissues (dead sheaths and rhizomes) of *P. oceanica*, which enables retroactive dating (lepidochronology) that can be used to investigate past-changes in the near-shore environment (Pergent-Martini, 1998). Trace elements in the Gulf of Naples over the period 1989–1999, as assessed by lepidochronology, have showed an overall increasing trend for Cd, Cu and Hg, and a decreasing trend for Pb, and Zn (Ancora et al., 2004). However, Pergent-Martini (1998) reported an opposite trend for Hg in *P. oceanica* from the Ischia Island over the period 1969–1992, which is in conjunction with the drastic decline in cinnabar mining activity that occurred in Italy after the 1970s (Hylander and Meili, 2003).

Data on other biota species are much scarcer (Table 5). Some researchers have investigated the use of the gastropod mollusks *Monodonta turbinata* and *Patella cerulean* as bioindicators for trace metal pollution, such as Camoni et al. (1980) in the Bay of Naples and Conti and Cecchetti (2003) and Conti and Finoia (2010) in the Gulf of Gaeta. These areas showed significant basal contamination levels, although did not reach those of clearly contaminated areas. Warnau et al. (1995) found that Hg and Pb concentrations in the equinoid *Paracentrotus lividus* from Ischia showed significant departures from background contamination, whereas this species is practically free from pollution in the marine park of Castellabate, about 100 km south of Naples (Sheppard and Bellamy, 1974). Trace metal concentrations in the polychaete *Sabella spallanzanii* collected at different points around the Gulf of Naples were found to be typical for unpolluted environments and considerably lower as compared to organisms from contaminated areas receiving treatment plant effluents, sewage outfall, mining, and industrial wastes (Bocchetti et al., 2004). In loggerhead turtles (*Caretta caretta*) from the South Tyrrhenian Sea, overall metal concentrations were found to be comparable or even lower than those determined in the same species from other areas. The only

Table 4
Mean and ranges of trace element concentrations (μg/L) in seawater samples from the Gulf of Naples and adjacent coastal areas. Water quality criteria values are also provided at the bottom of the table for comparison purposes.

Area	Sample	Year	As	Cd	Cr	Cu	Hg	Pb	Zn	Reference
Gulf of Gaeta	Total (soluble + particulate)	2000		0.26 (0.21–0.30)	0.44 (0.39–0.51)	2.72 (2.12–3.21)		2.5 (2.0–3.15)	9.3 (7.5–10.4)	Conti and Cecchetti (2003)
Gulf of Gaeta	Dissolved	2000		0.130 (0.11–0.14)	0.32 (0.28–0.37)	1.23 (0.79–1.67)		1.68 (1.05–2.83)	5.7 (4.75–7.21)	Conti and Cecchetti (2003)
River Garigliano	Dissolved			0.16		2.28		0.38	34.78	Manfra and Accornero (2005)
River Volturno	Dissolved			0.11		3.42		0.28	4.18	Manfra and Accornero (2005)
Pozzuoli	Dissolved			0.02		4.99		0.15	3.18	Manfra and Accornero (2005)
Naples	Dissolved			0.04		3.81		0.23	9.27	Manfra and Accornero (2005)
Portici	Dissolved			0.04		1.98		0.24	8.83	Manfra and Accornero (2005)
River Sarno	Dissolved			0.13		3.46		0.51	3.23	Manfra and Accornero (2005)
Sarno	Dissolved			0.10		4.45		0.15	7.71	Manfra and Accornero (2005)
Punta Campanella	Dissolved			0.05		0.93		0.21	2.24	Manfra and Accornero (2005)
Salerno	Dissolved			0.21		0.60		0.39	11.13	Manfra and Accornero (2005)
Punta Tresino	Dissolved			0.10		1.15		0.14	3.93	Manfra and Accornero (2005)
Licosa	Dissolved			0.16		2.20		0.30	6.50	Manfra and Accornero (2005)
50 m South from Sarno River mouth	Dissolved	2008	16.21	0.36	620.36	6.29	0.33	5.33	2.06	Montuori et al. (2013)
50 m central from Sarno River mouth	Dissolved	2008	19.86	0.23	281.0	3.15	0.53	5.69	1.63	Montuori et al. (2013)
50 m North from Sarno River mouth	Dissolved	2008	16.54	0.14	275.3	3.00	0.23	3.15	2.52	Montuori et al. (2013)
150 m South from Sarno River mouth	Dissolved	2008	16.70	0.33	139.0	2.87	0.12	2.96	1.61	Montuori et al. (2013)
150 m central from Sarno River mouth	Dissolved	2008	10.17	0.38	278.31	2.10	0.14	1.62	1.28	Montuori et al. (2013)
150 m North from Sarno River mouth	Dissolved	2008	9.37	0.16	120.73	1.66	0.11	1.75	1.51	Montuori et al. (2013)
500 m South from Sarno River mouth	Dissolved	2008	5.54	0.09	722.44	1.29	0.14	0.97	1.50	Montuori et al. (2013)
500 m central from Sarno River mouth	Dissolved	2008	4.27	0.08	221.34	1.46	0.16	0.86	0.90	Montuori et al. (2013)
500 m North from Sarno River mouth	Dissolved	2008	4.94	0.07	123.62	1.10	0.24	1.13	2.40	Montuori et al. (2013)
50 m South from Sarno River mouth	Particulate	2008	65.67	0.17	239	468.5	42.30	590.25	1796.5	Montuori et al. (2013)
50 m central from Sarno River mouth	Particulate	2008	46.77	0.40	711.75	602.75	20.19	574.5	220	Montuori et al. (2013)
50 m North from Sarno River mouth	Particulate	2008	52.8	0.27	59.25	308.5	25.40	674.5	576.75	Montuori et al. (2013)
150 m South from Sarno River mouth	Particulate	2008	30.75	0.13	390.5	120	23.92	2707.25	320	Montuori et al. (2013)
150 m central from Sarno River mouth	Particulate	2008	36.95	0.30	458.5	350.5	23.92	2779	415.25	Montuori et al. (2013)
150 m North from Sarno River mouth	Particulate	2008	20.52	0.13	134.25	368.5	10.03	350	555.5	Montuori et al. (2013)
500 m South from Sarno River mouth	Particulate	2008	6.72	0.24	155	396.25	7.68	340.25	357.5	Montuori et al. (2013)
500 m central from Sarno River mouth	Particulate	2008	12.87	0.12	296.75	160.75	7.52	64.25	659.5	Montuori et al. (2013)
500 m North from Sarno River mouth	Particulate	2008	10.85	0.05	53.25	212.5	9.94	88.75	319.5	Montuori et al. (2013)
Water quality criteria										
USA	Criteria Maximum Concentration (CMC)		69	40	1100	4.8	1.8	210	90	USEPA (2009)
USA	Criterion Continuous Concentration (CCC)		36	8.8	50	3.1	0.94	8.1	81	USEPA (2009)

exception was Cd, which accumulated in the kidney to relatively high concentrations compared to those reported for other marine vertebrates. However, since turtles integrate metal concentrations over the whole range of the habitats frequented during any life stage, it cannot be said with certainty if the concentrations are a result from foraging on prey in Campanian waters (Maffucci et al., 2005). It is noteworthy that Hg concentrations in all turtle specimens remained very low for an area supposed to have natural Hg enrichment, possibly the result of low trophic level in sea turtles. Conversely, stripped dolphins (*Stenella corelualba*) from the same areas showed very high Hg levels since dolphins accumulate this element through the food chain (Monaci et al., 1998).

3.4.2. OCs

Although several anthropogenic releases of OCs can be expected, very few studies have analyzed the accumulation of those pollutants in marine species from the area of study. First data were acquired in the liver of several bird species from coastal areas along the Campania region (Naso et al., 2003). This study showed elevated mean PCB and DDE levels in resident avian species living close to human settlements, which is consistent with the intense urbanization and industrial development of this area. In fact, those levels were considerably higher than those observed in fish-eating birds from other areas in southern Italy and other Mediterranean regions. Even though concentrations of OCs were generally lower than the threshold values known to affect reproduction, species such as the yellow-legged herring gull (*Larus cachinnans*) and the blackheaded gull (*Larus ridibundus*) contained PCBs at levels much higher than those known to elicit immunosuppressive effects and possibly increase susceptibility to parasites (Table 6) (Naso et al., 2003). Significant PCB levels were also later reported in edible fish and mollusk species from the Gulf of Naples (Table 6). Naso et al. (2005) found that contamination by PCBs was most evident in the strictly resident species inhabiting shallow coastal waters, such as the sea bass (*Dicentrarchus labrax*) and the grey mullet (*Mugil cephalus*), which pointed to local agricultural, industrial, and municipal sources of these compounds along the Campania region. In contrast, the content of PCBs is rather low in seafood samples obtained within 80 km from the Naples coast, which appears to indicate that concentrations drop rapidly beyond the zone of influence of these discharges (Table 6) (Garritano et al., 2006). More recently, the MYTILOS project has identified the Gulf of Naples as a hot spot of PCB and DDT contamination (Andral et al., 2011). Mussels transplanted to this location presented maximum levels of some PCB congeners in the Western Mediterranean as well as the highest DDT concentrations recorded in Italy, mainly because of the Sarno River basin contributions (Scarpato et al., 2010). Similarly, high DDT levels have also been found in Campania freshwaters, suggesting a recent, although not extensive, use of the banned pesticides (Ferrante et al., 2010). Although it is difficult to support this hypothesis and instead it is likely to consider other indirect contamination routes, e.g. re-mobilization from surrounding sediments or from runoff of fluvial sediments DDT-ladened (Scarpato et al., 2010), a more efficient management of the existing regulations regarding the use and stocking of these obsolete pesticides should be promoted in the region. On the other hand, farmed mussels along the region of Campania show generally low PCB concentrations, testifying a low anthropogenic influence (Table 6) (Serpe et al., 2010a).

3.4.3. PAHs

Along the Southern Italian Mediterranean coast, the Gulf of Naples is especially involved in oil-related activities. Already in 1990, PAH levels were reported to be high in shellfish and fish from the area, thus enlightening the need of careful future monitoring of these compounds (Amodio-Cocchieri et al., 1990). However, the literature about hydrocarbon pollution in biota from the region is still scarce (Table 6). Amodio-Cocchieri et al. (2003) reported PAH levels in mussels from the Gulf of Naples similar to those of mollusks living in areas considered moderately polluted. They also found that concentrations had remained mainly stable during the period of 1988–2001. A few years later, in 2004, a slight decrease of the PAH content was observed and related to the environmental protection actions engaged in the Gulf of Naples with the dismantling of the industrial plant of Bagnoli (Perugini et al., 2007a). Nevertheless, the ambient air PAH levels in major cities of western European countries have been found to significantly decrease in past decades (Menichini et al., 2006; Shen et al., 2011; Valerio et al., 2009), so the decline observed in the Gulf of Naples might be linked to this global trend and not reflect a local improvement. Whatever the reason, despite this decrease, the reported PAH levels were still particularly high if compared with other Mediterranean areas. In fact, within the context of the MYTILOS project, the Naples area has been described as a hot spot of PAH pollution in the Western basin of the Mediterranean Sea. Here, most individual PAHs have been found at significant levels, with Bagnoli presenting the highest levels of fluoranthene, which is considered as the best representative of PAHs (Andral et al., 2011). This project points to petrogenic sources, such as ballasting or deballasting operations of tankers, discharges of oily bilge water, tank washing, refinery effluents, municipal waste, discarded lubricant oils, and natural seepages as the most probable sources of PAH in the Naples area (Galgani et al., 2011). The situation, nevertheless, appears to have improved to a certain extent lately since the concentrations found in fresh and farmed mussels all along the Campania coast in two recent studies (Cirillo et al., 2009; Serpe et al., 2010a) are lower than those previously reported (Table 6). Furthermore, far from strongly urbanized and industrial areas, mussels present generally relatively low PAH levels (SiDiMar, 2005) (Table 6).

Other biota species, such as the anchovy (*Engraulis enchrasicholus*) and the common sole (*Solea vulgaris*) were also found to display very high PAH concentrations (Amodio-Cocchieri et al., 1990) (Table 6). Unfortunately, more recent data on these species are not available, so it is not possible to assess any temporal trend. However, we can anticipate a probable reduction in PAH levels over the period 1988–2001, as it has been reported for other fish species like the bogue (*Boops boops*), the pandora (*Pagellus erythrinus*), the rainbow wrass (*Coris julis*), the rock goby (*Gobius paganellus*), the scorpion fish (*Scorpaena scrofa*), and the spotted weever (*Trachinus araneus*) (Amodio-Cocchieri et al., 2003). On the other hand, and contrarily to what has been noticed for mussels, the concentrations in the European hake (*Merluccius merluccius*) were found to be extremely higher in specimens collected in 2008–09 (Marrone et al., 2011) than in those collected in 2004 (Perugini et al., 2007a). This may be indicative of an increase in PAH inputs with time or perhaps reflect differences in sampling and analytical procedures between studies. Marrone et al. (2011) also found very elevated PAH levels in the scaldfish (*Arnoglossus laterna*), the chub mackerel (*Scomber japonicus*), and the musky octopus (*Eledone moschata*) (Table 6), so further analyses would be necessary to gauge the current extent of PAH contamination in the area of study.

4. Risks for human health

Fish and seafood ingestion is one of the main sources of human exposure to a variety of chemical contaminants. Unfortunately, there is very little information on public health implications through food consumption in the Campania region. We analyze here the available data on this issue according to the MSFD requirements of Descriptor 9.

4.1. Trace elements

Reported values for *M. galloprovincialis* (Table 5) do not exceed either the safety levels for human consumption regulated in the European legislation (European Communities, 2006) or the highest international standards gathered by the Food and Agricultural Organization (FAO) of the United Nations (FAO/WHO, 2007). Likewise, levels always

Table 5
Mean and/or ranges of trace element concentrations (μg/g dry weight) in biota samples from the Gulf of Naples and adjacent coastal areas.

Sample	Area	Year	As	Cd	Cr	Cu	Hg	Pb	Zn	Reference
Algae										
Corallina sp.	Naples	2005		14.82		23.08		44.76		Papa et al. (2008)
Corallina sp.	Ischia	2005		0.02		0.98		2.05		Papa et al. (2008)
Codium tomentosum	Naples	1986		0.13			<DL	14.81		Costantini et al. (1991)
Codium tomentosum	Salerno	1986		0.11			0.13	8.21		Costantini et al. (1991)
Enteromorpha sp.	Naples	2005		1.8–17.6		10–158		98–118		Papa et al. (2008)
Padina pavonica	Ischia	1993–94		0.16		5.83		5.125	31.66	Schlacher-Hoenlinger and Schlacher (1998b)
Padina pavonica	Gulf of Gaeta	2000		0.5	3.45	12.28		3.98	50.8	Conti and Cecchetti (2003)
Ulva lactuca	Gulf of Gaeta	2000		0.18	1.63	5.76		1.94	45.2	Conti and Cecchetti (2003)
Seagrass										
Posidonia oceanica (leaves)	Naples	1986		3.31			0.09	4.67		Costantini et al. (1991)
Posidonia oceanica (leaves)	Capri	1986		1.95			0.03	2.63		Costantini et al. (1991)
Posidonia oceanica (leaves)	Salerno	1986		4.63			0.05	4.14		Costantini et al. (1991)
Posidonia oceanica (leaves)	Ischia	1986		3.55			0.02	4.24		Costantini et al. (1991)
Posidonia oceanica (leaf-epiphyte complex)	Ischia	1991–92		2.1	1.67	16.2		8.35	144	Warnau et al. (1995)
Posidonia oceanica (rhizomes)	Ischia	1991–92		0.72	2.85	12.4		14.5	103	Warnau et al. (1995)
Posidonia oceanica (roots)	Ischia	1991–92		1.36	1.76	22		10.5	107	Warnau et al. (1995)
Posidonia oceanica	Ischia	1993					0.034			Pergent-Martini (1998)
Posidonia oceanica	Ischia	1993					0.039			Pergent-Martini (1998)
Posidonia oceanica	Ischia	1993					0.025			Pergent-Martini (1998)
Posidonia oceanica	Ischia	1993					0.048			Pergent-Martini (1998)
Posidonia oceanica (leaves)	Ischia	1993–94		1		14.1		3.4	168	Schlacher-Hoenlinger and Schlacher (1998a)
Posidonia oceanica (*scales*)	Bay of Naples	1999		0.74		10.1	0.06	4.5		Ancora et al. (2004)
Posidonia oceanica (*rizhomes*)	Bay of Naples	1999		1.16		52.5	0.08	0.65		Ancora et al. (2004)
Molluscs										
Monodonta turbinata	Gulf of Gaeta	2000		1.12	0.42	62.22		0.58	98.32	Conti and Cecchetti (2003)
Murex trunculus	Ischia	1986–87		2.37			0.15	0.57		Giordano et al. (1991)
Murex trunculus	Naples	1986–87		3.30			0.27	2.02		Giordano et al. (1991)
Murex trunculus	Salerno	1986–87		4.97			0.13	0.72		Giordano et al. (1991)
Mytilus galloprovincialis	Bay of Naples	1973				8		56.7	227	Sheppard and Bellamy (1974)
Mytilus galloprovincialis	Naples	1986–87		0.90			0.19	8.07		Giordano et al. (1991)
Mytilus galloprovincialis	Naples	2001–04	19.2	0.8	5.3	9.6	0.24	4.6	201.4	SiDiMar (2005)
Mytilus galloprovincialis	Ischia	1986–87		0.44			0.03	1.34		Giordano et al. (1991)
Mytilus galloprovincialis	Bay of Pozzuoli	1998–99		0.35[a,b] (0.006–0.7)	0.96[a,b] (0.02–1.37)		1.41[a,b] (0.29–3.6)	1.34[a,b] (0.029–1.8)		Amodio-Cocchieri et al. (2003)
Mytilus galloprovincialis	Bay of Pozzuoli	2000–01		0.19[a,b] (0.006–0.6)	0.87[a,b] (0.02–1.22)		1.18[a,b] (0.03–2.12)	1.22[a,b] (0.03–1.58)		Amodio-Cocchieri et al. (2003)

Mytilus galloprovincialis	Portici	2001–04	15.1	0.69	7.8	9	0.3	3.5	132.2	SiDiMar (2005)
Mytilus galloprovincialis	Mouth of Sarno River	2001–04	8.4	1.28	8.4	9.6	0.28	3.6	228.4	SiDiMar (2005)
Mytilus galloprovincialis	Salerno	1986–87		1.04			0.16	4.63		Giordano et al. (1991)
Mytilus galloprovincialis	Punta Tresino	2001–04	14.5	1.13	2.7	5.4	0.09	1.5	171.1	SiDiMar (2005)
Mytilus galloprovincialis	Punta Licosa	2001–04	14.8	1.16	2.9	5.9	0.11	1.4	164.7	SiDiMar (2005)
Mytilus galloprovincialis	Gulf of Gaeta	2000		0.38	0.91	8.73		2.07	157.3	Conti and Cecchetti (2003)
Mytilus galloprovincialis	Mouth of Volturno River	2001–04	11.8	0.74	10.1	7.6	0.24	2.5	212	SiDiMar (2005)
Mytilus galloprovincialis	Mouth of Picentino River	2001–04	11.1	1.37	4.2	4.7	0.26	2.4	261.4	SiDiMar (2005)
Mytilus galloprovincialis	Sea farms along Campania	2007–09		0.45[a] (DL-1.13)	1.72[a] (0.18–4.8)		DL	2.43[a] (0.28–6.98)		Serpe et al. (2010a)
Patella cerulea	Bay of Naples			1.65[c]				3.78[c]		Camoni et al. (1980)
Patella cerulea	Castellabate marine park			1.06[c]				4.31[c]		Camoni et al. (1980)
Patella cerulea	Gulf of Gaeta	2000		3.54	0.85	14.3		0.95	100.8	Conti and Cecchetti (2003)
Urchins										
Arbacia lixula (gut and gonads)	Bay of Naples	1973				16.6		58.6	120	Sheppard and Bellamy (1974)
Arbacia lixula (gut and gonads)	Castellabate marine park	1973				7		21	76	Sheppard and Bellamy (1974)
Paracentrotus lividus (gut and gonads)	Bay of Naples	1973				13.8		42.3	122	Sheppard and Bellamy (1974)
Paracentrotus lividus (gut and gonads)	Castellabate marine park	1973				7.6		20	55.6	Sheppard and Bellamy (1974)
Paracentrotus lividus (digestive wall and gonads)	Ischia	1991–92		5.81	2.82	24.95	0.68	3.95	205	Warnau et al. (1995)
Fish										
Serranus cabrilla	Ischia	1986–87		<DL			0.53	<DL		Giordano et al. (1991)
Serranus cabrilla	Naples	1986–87		<DL			0.43	0.23		Giordano et al. (1991)
Serranus scriba	Ischia	1986–87		<DL			0.85	<DL		Giordano et al. (1991)
Serranus scriba	Capri	1986–87		<DL			0.50	<DL		Giordano et al. (1991)
Sea turtles										
Caretta caretta (liver)	South Tyrrhenian coast	2000–01		19.3			1.10		66	Maffucci et al. (2005)

DL = Detection limit.
[a] Wet w/dry w conversion factor: 5.8 (Ricciardi and Bourget, 1998).
[b] Median instead of mean is provided.
[c] Wet wt/dry w conversion factor: 2.66 (Conti and Cecchetti, 2003).

Table 6
Mean and/or ranges of concentrations (ng/g wet weight.) of persistent organic pollutants in marine coastal organisms from the region of Campania.

Sample	Area	Year	n	DDTs	n	PCBs	n	PAHs	BaP	Reference
Mollusks										
Amigdala decussata	Bay of Pozzuoli	1988					16	208	6	Amodio-Cocchieri et al. (1990)
Cardium edule	Bay of Pozzuoli	1988					16	198	21	Amodio-Cocchieri et al. (1990)
Ensis siliqua	Bay of Pozzuoli	1988					16	199	5	Amodio-Cocchieri et al. (1990)
Eledone moschata	Gulf of Naples	2003	3	0.56 (<DL-1.04)	20	5.25 (1.68–9.37)				Naso et al. (2005)
Eledone moschata	Gulf of Naples	2008–09					13	191.32	6.59	Marrone et al. (2011)
Loligo vulgaris	Within 80 km S–W from Naples port	2004			7	15.5				Garritano et al. (2006)
Mytilus edulis	Bay of Pozzuoli	1988					16	295	5	Amodio-Cocchieri et al. (1990)
Mytilus galloprovincialis	Naples	2001–04					17	30.15[a]		SiDiMar (2005)
Mytilus galloprovincialis	Gulf of Naples	2003	3	1.77 (0.32–3.1)	20	19.28 (7.9–26.79)				Naso et al. (2005)
Mitylus galloprovincialis	Naples	2005		2.57[a]		15.32[a]				Andral et al. (2011)
Mitylus galloprovincialis	Naples	2005					16	13.47[a]		Galgani et al. (2011)
Mytilus galloprovincialis	Sea farms from Naples	2007–09					11	22.63	2.52	Serpe et al. (2010b)
Mytilus galloprovincialis	Sea farms from Bacoli	2007–09					11	21.24	2.49	Serpe et al. (2010b)
Mytilus galloprovincialis	Bay of Pozzuoli	1998–99					16	334[b] (105–831)		Amodio-Cocchieri et al. (2003)
Mytilus galloprovincialis	Bay of Pozzuoli	2000–01					16	241[b] (16–627)		Amodio-Cocchieri et al. (2003)
Mytilus galloprovincialis	Sea farms from the Bay of Pozzuoli	2003–04	3	0.86 (<DL-2.78)	7	12.33 (3.38–28.11)				Ferrante et al. (2007)
Mytilus galloprovincialis	Sea farms from the Bay of Pozzuoli	2004					11	126.34 (44.7–207.1)	6.61	Perugini et al. (2007a)
Mytilus galloprovincialis	Sea farms from the Bay of Pozzuoli	2007–09					11	27.26	2.23	Serpe et al. (2010b)
Mytilus galloprovincialis	Mouth of Volturno River	2001–04					17	51.93[a]		SiDiMar (2005)
Mytilus galloprovincialis	Portici	2001–04					17	28.47[a]		SiDiMar (2005)
Mytilus galloprovincialis	Mouth of Sarno River	2001–04					17	31.82[a]		SiDiMar (2005)
Mytilus galloprovincialis	Mouth of Picentino River	2001–04					17	13.4[a]		SiDiMar (2005)
Mytilus galloprovincialis	Punta Tresino	2001–04					17	23.45[a]		SiDiMar (2005)
Mytilus galloprovincialis	Punta Licosa	2001–04					17	18.42[a]		SiDiMar (2005)
Mytilus galloprovincialis	Sea farms from Ercolano	2007–09					11	4.1	0.5	Serpe et al. (2010b)
Mytilus galloprovincialis	Sea farms from the Torre del Greco	2007–09					11	19.9	1.52	Serpe et al. (2010b)
Mytilus galloprovincialis	Sea farms from Battipaglia (Gulf of Salerno)	2007–09					11	29.7	1.9	Serpe et al. (2010b)
Mytilus galloprovincialis	Fresh mussels from markets in Campania	2007			7	5.81[b]	16	12.80[b]		Cirillo et al. (2009)
Mytilus galloprovincialis	Farmed mussels from markets in Campania	2007			7	10.1[b]	16	42.5[b]		Cirillo et al. (2009)
Mytilus galloprovincialis	Sea farms along Campania	2007–09			18	8.8 (1–21.6)	11	13 (<DL–41.6)	1.7 (<DL–5)	Serpe et al. (2010a)
Octopus vulgaris	Gulf of Naples	2003	3	0.15 (<DL–0.58)	20	24.97 (5.86–47.69)				Naso et al. (2005)
Octopus vulgaris	Within 80 km S–W from Naples port	2004			7	9.25				Garritano et al. (2006)
Sepia officinalis	Gulf of Naples	2003	3	0.1 (<DL–0.55)	20	51.78 (3.55–95.97)				Naso et al. (2005)
Sepia officinalis	Within 80 km S–W from Naples port	2004			7	6				Garritano et al. (2006)
Todarodes sagittatus	Gulf of Naples	2003–04	3	1.29 (<DL–4.65)	7	15.45 (1.54–29.79)				Ferrante et al. (2007)
Todarodes sagittatus	Gulf of Naples	2004					11	43.81	<DL	Perugini et al. (2007a)
Venus verrucosa	Bay of Pozzuoli	1988					16	185	<DL	Amodio-Cocchieri et al. (1990)

Fish										
Arnoglossus laterna	Gulf of Naples	2008–09					13	336.96	22.33	Marrone et al. (2011)
Boops boops	Bay of Pozzuoli	1988					16	1281	12	Amodio-Cocchieri et al. (1990)
Coris julis	Bay of Pozzuoli	1988					16	184	7	Amodio-Cocchieri et al. (1990)
Dicentrarchus labrax	Gulf of Naples	2003	3	13.79 (66.64–17.86)	20	316.47 (42.9–649.44)				Naso et al. (2005)
Dicentrarchus labrax	Fresh fish from markets in Campania	2007			7	5.48[b]	16	9.27[b]		Cirillo et al. (2009)
Engraulis enchrasicholus	Bay of Pozzuoli	1988					16	1930	43	Amodio-Cocchieri et al. (1990)
Engraulis enchrasicholus	Gulf of Naples	2003	3	2.80 (1.69–3.89)	20	45.83 (19.81–98.84)				Naso et al. (2005)
Gobius paganellus	Bay of Pozzuoli	1988					16	210	<DL	Amodio-Cocchieri et al. (1990)
Labrus bimaculatus	Bay of Pozzuoli	1988					16	94	<DL	Amodio-Cocchieri et al. (1990)
Merluccius merluccius	Gulf of Naples	2003	3	3.35 (0.98–9.2)	20	28.97 (6.72–101.35)				Naso et al. (2005)
Merluccius merluccius	Gulf of Naples	2003–04	3	3.01 (<DL-5.31)	7	16.8 (4.09–46.28)				Ferrante et al. (2007)
Merluccius merluccius	Gulf of Naples	2004					11	6.06	<DL	Perugini et al. (2007a)
Merluccius merluccius	Gulf of Naples	2008–09					13	551.83	12.33	Marrone et al. (2011)
Micromesistius poutassou	Gulf of Naples	2003–04	3	1.38 (<DL-3.02)	7	12.42 (1.55–26.6)				Ferrante et al. (2007)
Micromesistius poutassou	Within 80 km S–W from Naples port	2004			7	52				Garritano et al. (2006)
Micromesistius poutassou	Gulf of Naples	2004					11	18.44	<DL	Perugini et al. (2007a)
Mugil cephalus	Gulf of Naples	2003	3	9.14 (<DL-27.24)	20	214.7 (40.75–622.8)				Naso et al. (2005)
Mugil cephalus	Within 80 km S–W from Naples port	2004				9				Garritano et al. (2006)
Mullus barbatus	Gulf of Naples	2003	3	4.32 (3–6.23)	20	27.85 (20.07–44.50)				Naso et al. (2005)
Mullus barbatus	Gulf of Naples	2003–04	3	3.01 (<DL-8.80)	7	30.11 (4.31–44.77)				Ferrante et al. (2007)
Mullus barbatus	Within 80 km S–W from Naples port	2004			7	13.67				Garritano et al. (2006)
Mullus surmeletus	Gulf of Naples	2004					11	16.15	<DL	Perugini et al. (2007a)
Pagellus erythrinus	Bay of Pozzuoli	1988					16	106	3	Amodio-Cocchieri et al. (1990)
Scomber japonicus	Gulf of Naples	2008–09					13	349.15	6.32	Marrone et al. (2011)
Scomber scombrus	Gulf of Naples	2003	3	8.09 (<DL-23.79)	20	56.06 (2.54–237.78)				Naso et al. (2005)
Scomber scombrus	Gulf of Naples	2003–04	3	0.18 (<DL-1.67)	7	23.22 (1.26–56.38)				Ferrante et al. (2007)
Scomber scombrus	Within 80 km S–W from Naples port	2004			7	23				Garritano et al. (2006)
Scomber scombrus	Gulf of Naples	2004					11	15.70	<DL	Perugini et al. (2007a)
Scophthalmus rhombus	Bay of Pozzuoli	1988					16	109	8	Amodio-Cocchieri et al. (1990)
Scorpaena scrofa	Bay of Pozzuoli	1988					16	119	7	Amodio-Cocchieri et al. (1990)
Serranus cabrilla	Bay of Pozzuoli	1988					16	336	13	Amodio-Cocchieri et al. (1990)
Solea vulgaris	Bay of Pozzuoli	1988					16	760	<DL	Amodio-Cocchieri et al. (1990)
Sparus aurata	Within 80 km S–W from Naples port	2004			7	30				Garritano et al. (2006)
Sparus aurata	Fresh fish from markets in Campania	2007			7	5.16[b]	16	9.86[b]		Cirillo et al. (2009)
Trachinus araneus	Bay of Pozzuoli	1988					16	219	21	Amodio-Cocchieri et al. (1990)
Trachurus trachurus	Bay of Pozzuoli	1988					16	122	3	Amodio-Cocchieri et al. (1990)
Trigla lyra	Bay of Pozzuoli	1988					16	283	<DL	Amodio-Cocchieri et al. (1990)
Xyrichthys novacula	Bay of Pozzuoli	1988					16	164	44	Amodio-Cocchieri et al. (1990)
Birds										
Larus cachinnans	Coast of Campania	1998–2002			7	3340 (120–8431)				Naso et al. (2003)
Larus ridibundus	Coast of Campania	1998–2002			7	2079 (494–5520)				Naso et al. (2003)

n = Number of PCB congeners or PAH compounds analyzed in each study. BaP = benzo(a)pyrene. DL = Detection limit.

[a] Wet w/dry w conversion factor: 5.97 (Andral et al., 2011).

[b] Median instead of mean is provided.

below the maximum advisory limits were also found in mussels collected from classified sea farms along Campania during 2007–2009 (Serpe et al., 2010a). What is more, even in the areas under the influence of the heavily polluted Sarno River, which paradoxically present an extraordinary richness of benthic, planktonic and nektonic organisms, there is no evidence of metal pollution that can preclude the eatability or modify the organoleptic properties of those important fishing resources (Zupo and Buia, 2000). Despite these results, further investigations of the potential health risks through fish consumption should be conducted in the region, because some works in nearby waters have revealed Hg levels of concern, i.e. in canned and fresh bluefin tuna and in swordfish from the Tyrrhenian Sea (Focardi, 2012; Storelli et al., 2010). Indeed, a survey carried out in the city of Naples found that concentration of Hg in hair of adult subjects with no occupational exposure is mainly dependent on dietary intake and that fish consumption is the main factor that contributes to total Hg levels (Díez et al., 2008).

4.2. OCs

Since 1999, the European Union establishes a maximum value of 200 ng/g lipid weight for the sum of seven main PCB congeners (IUPAC 28, 52, 101, 118, 138, 153, 180) and of 1000 ng/g lipid weight for DDTs in some foods of animal origin, although no limits are available for fish and shellfish (EU Directive 1999/788/CE). Based on these limits, organochlorine pesticides in marine species caught in the Gulf of Naples are unlikely to cause any significant health hazard (Ferrante et al., 2007; Naso et al., 2005). Conversely, concentrations of PCBs far exceeding those regulatory values have been found in several commercial marine species from the Gulf of Naples, including the common mussel, the grey mullet, the European sea bass, the anchovy, the European hake, the musky octopus, the Atlantic mackerel (*Scomber scombrus*), the red mullet (*Mullus barbatus*), the common octopus (*Octopus vulgaris*), the cuttlefish (*Sepia officinalis*), the European flying squid (*Todarodes sagittatus*), and the blue whiting (*Micromesistius poutassou*), indicating that they are likely to be a significant risk for human health (Ferrante et al., 2007; Naso et al., 2005). On the other hand, the PCB concentrations measured in all the species sampled in Campania (Table 6) always fell below the fish advisory level (2000 ng/g wet weight) considered dangerous by the U.S. Food and Drug Administration (FDA, 2001). These limits, however, are not based on health effects. Instead, the USEPA provides monthly fish consumption advisories taking into account both carcinogenic and chronic systemic health endpoints. This approach considers significant the appearance of one new case of cancer every 100,000 individuals for consuming fish contaminated with PCBs (Table 7) (USEPA, 2000). Accordingly, it is only recommended to eat an unrestricted amount of fish when the PCB concentration ranges from 0 to 1.5 ng/g wet weight, while no fish should be eaten if the PCB concentration is greater than 94 ng/g wet weight (Table 7). Therefore, all the analyzed species in the Gulf of Naples present levels of concern (Table 6), being particularly alarming the mean concentrations found in the European sea bass and the grey mullet, which fit in the “no consumption” recommendation due to the increased risk of cancer. For the Atlantic mackerel, 3 and 0.5 meals a month correspond to a potential chronic effect and an increase in the risk of carcinogenesis, respectively. Regarding the European hake, the red mullet or the anchovy, 4 meals a month can determine chronic effects, while only 1 meal a month is enough to reach the carcinogenic risk. These findings indicate that most fish caught in the Gulf of Naples can be unsafe for humans, which represents a serious socio-economic problem bearing in mind the great importance of fish as source of food and income in this area. Risks seem to decrease moving away from the Naples coast, although the levels found in species such as the blue whiting and the gilt-head seabream (*Sparus aurata*) still indicate these fish should be consumed with caution to avoid toxicity (Table 6) (Garritano et al., 2006). This study, in fact, could not find any significant correlation between the PCB content and the estrogenic activity in specimens collected within 80 km S–W from the Naples port. Conversely, Pinto et al. (2008) found such a correlation in farmed sea bass from the Tyrrhenian Sea, suggesting that commercial feed is an important source of PCB pollutants. PCB concentrations in farmed marine fish marketed in Campania have been found to be higher than those of their wild counterparts, although levels were always below risk for health concerns (Cirillo et al., 2009). Farmed sea bass safe for human consumption have also been found in a recent study along the Italy's coasts (Trocino et al., 2012).

4.3. PAHs

Different approaches have been proposed for the estimation of human health risks of the PAHs mixture in food. The most widely applied is the use of benzo(a)pyrene (BaP) as an indicator for the occurrence and effect of carcinogenic PAH. The EU Scientific Committee on Food fixes maximum admissible concentrations for this compound of 2 ng/g w.w.in fish muscular tissue, 5 ng/g w.w.in cephalopods–crustacean and 10 ng/g w.w. in bivalve mollusks (European Communities, 2006). As it can be seen in Table 6, BaP is present at detectable levels in most of analyzed organisms. Several fish species and the edible cockle (*Cardium edule*) surpassed the proposed limits in samples collected more than 20 years ago (Amodio-Cocchieri et al., 1990), but evidently we cannot envisage current risks from such old data. However, recent measurements have determined levels well over safety limits in other fish and seafood species, indicating this issue should be seriously considered (Marrone et al., 2011) (Table 6). Moreover, although the mean BaP level obtained in *M. galloprovincialis* by Perugini et al. (2007a) is below the regulatory level, 71.43% of mussels they collected in winter exceeded this value. Higher accumulation of higher weight compounds rather than the lower in winter compared to summer has also been observed by Marrone et al. (2011) and related to the hydrodynamics in the Gulf of Naples (Perugini et al., 2007a). Nevertheless, annual cyclic variation in the PAH content of fish has been found in other areas like the Adriatic Sea (Perugini et al., 2007b) and the Atlantic Ocean (Ramalhosa et al., 2012), and associated with seasonal differences of biotic and abiotic factors regulating metabolic mechanisms and PAHs bioaccumulation. Whatever the reason, this information may be useful for public health surveillance helping to select the less PAHs-contaminated species to be consumed in the different seasons. On the other hand, mussels originating from Campania shellfish farms and markets were compliant for the BaP in any period of the year (Cirillo et al., 2009; Serpe et al., 2010a, 2010b), but, as levels were higher than those found in the Adriatic and Ionian coasts of Italy, greater control of PAHs in the areas where mussels are harvested has been suggested (Serpe et al., 2010b).

Instead of using only BaP as a marker of PAH contamination in food, the European Food Safety Authority (EFSA) Panel on Con taminants in the Food Chain (CONTAM Panel) has recently concluded that eight PAHs (PAH8; BaP, benz(a)anthracene (BaA), benzo(b)fluoranthene (BbF), benzo(k)fluoranthene (BkFA), benzo(g,h,i)perylene (BghiP),

Table 7
Monthly fish consumption limits for carcinogenic and non-carcinogenic effects of PCBs based on an adult body weight of 70 kg (USEPA, 2000).

Risk based consumption limit[a]	Non-cancer health endpoints	Cancer health endpoints
Fish meals/month	Fish tissue concentrations (ng/g wet weight)	Fish tissue concentrations (ng/g wet weight)
Unrestricted (>16)	0–5.9	0–1.5
16	>5.9–12	>1.5–2.9
12	>12–16	>2.9–3.9
8	>16–23	>3.9–5.9
4	>23–47	>5.9–12
3	>47–63	>12–16
2	>63–94	>16–23
1	>94–190	>23–47
0.5	>190–380	>47–94
None (<0.5)	>380	>94

[a] The assumed meal size is 227 g.

chrysene (CHR), dibenz(a,h)anthracene (DBahA), and indeno(1,2,3-cd) pyrene) (IP), and a subgroup of four PAHs (PAH4; the sum of BaP, CHR, BaA, and BbF) are currently the best possible indicators of the carcinogenic potency of PAHs in food, with PAH8 not providing much added value compared to PAH4 (EFSA, 2008). Therefore, risk assessment regulation has been amended to incorporate a new maximum level for the PAH4 in bivalve mollusks (30 ng/g w.w.) while maintaining a separate one for BaP (European Union, 2011). This regulation has also specified that maintaining a maximum level in fresh fish is no longer appropriate since PAH are quickly metabolized and do not accumulate in the fresh fish muscle meat. The mean PAH4s calculated from data of Perugini et al. (2007a) for farmed mussels from Pozzuoli are 53.31 and 17.33 in winter and summer, respectively. Therefore, mussels collected in winter might represent a serious risk for human health since PAH4 at that season is well above the maximum advisable level. Conversely, according to the data provided by Serpe et al. (2010b), farmed mussels from different sites of the region of Campania, including Pozzuoli, present concentrations of PAH4 always below that limit, indicating they are safe for human consumption.

5. Other contaminants

Research on other contaminants in the region of Campania is much more limited and, in many cases, lacking. In the beginning of 90s, high concentrations of tributyltin (TBT) and other organotoxins were reported in marina and harbor waters of the Gulf of Naples, particularly in spring and summer periods of most intensive boating activity (Amodio-Cocchieri et al., 1993). These authors found organotin concentrations exceeding those considered toxic for certain sensitive marine species even in the relatively uncontaminated areas, confirming the extent and severity of the contamination. Later, very high levels of imposex (superimposition of male characters on female gonochorist gastropods) were observed in *Hexaplex trunculus* in areas like Portici, Bacoli, the Naples harbor and Ischia, indicating the existence of diffuse TBT pollution along the coasts of the Gulf of Naples (Terlizzi et al., 1998). Imposex has also been seen in *H. trunculus* populations from the relatively pristine areas of several Italian marine protected areas, including Punta Campanella (Terlizzi et al., 2004). These findings demonstrate there are certain threats to marine systems against which MPAs fail to provide any direct protection.

Yet there is substantial evidence that TBT contamination has decreased following the introduction of legislation prohibiting the use of TBT-based paints on vessels less than 25 m in length, antifouling paints are still of concern in marinas, harbors and, particularly, in sites adjacent to vessel repair facilities (Albaigés, 2005). In fact, organotin levels found in some farmed fish and shellfish from markets of Naples province (Amodio-Cocchieri et al., 2000) and in sediments from the port of Baia (ICRAM, 2006) were still higher than those considered acceptable for the marine environment. The previous data on TBT pollution in the region, although scarce, may be useful for further monitoring to test the effectiveness of the regulations restricting the use and sale of antifouling paints containing organotin compounds.

After the ban of TBT, paint manufacturers have developed new tin-free antifouling formulations, which are generally made of a main active component, usually a copper compound, and an additional biocide (booster), which should perform effective action against algal species having a marked tolerance to copper. In order to assess the potential risks to the marine ecosystem posed by those antifouling booster biocides, Di Landa et al. (2009) analyzed the concentrations of irgarol 1051, diuron and dichlofluanid in different seawater samples from marinas and harbors inside the Gulf of Naples. Higher levels of biocides were associated with large yacht marinas housing recreational water craft and/or fishing boats more than with commercial ports, and peak values were found during the summer season. Nevertheless, the ecological risk was judged to be low in the study area, so no serious damages to the local marine ecosystem induced by those biocides were expected.

Regarding to radionuclides, information is very scarce in the southern Mediterranean coasts. In the period 1972–1991, several sea sediment cores were collected in four Mediterranean areas, including the Gulf of Gaeta, for plutonium determination (Delfanti et al., 1995). The mean concentration in that area was about twice as high as that in other locations, probably as a result of the Garigliano and Volturno Rivers flowing into the gulf, although no significant contamination by nuclear plants was found. In 2002, the International Mediterranean Commission (CIESM) implemented the "Mediterranean Mussel Watch Program", a large-scale survey of radioactive contaminants in the Mediterranean and Black Seas using *M. galloprovincialis* as a biomonitor species. A number of locations have been investigated using a single, standardized common methodology in order to produce a distribution map of intercomparable ^{137}Cs levels in mussels. Within the context of this program, concentrations in mussels from the Naples and Bagnoli areas were found to be very low (<0.05 Bq kg^{-1} wet wt) (Thébault et al., 2008).

6. Conclusions, gaps and needs

Despite the growing attention in the last decades to the risk linked to the emission of potentially hazardous substances into the marine environment, with the concurrent monitoring activities it is still very hard to provide an exhaustive assessment even for relevant areas and sites like Naples, certainly one of the most important cities in the Mediterranean Sea. While it is premature to draw a general rule, two aspects came out clearly during our effort: i) while monitoring activities are likely conducted at a regular pace, much of the generated information is, at least in Italy, hard to access, not systematically analyzed, and, very seldom, the object of re-analysis to produce a synthetic view; and ii) the relevant information is still derived from contributions in the scientific literature. The latter shows the commendable effort made by individual researchers or groups to convey important messages to the society but, because of the first aspect, also the scientific contributions are generally linked with episodic and isolated efforts.

What can be learnt from this experience is that, at least in Italy, some energy should be invested in filling the gap between the scientific community and the structures devoted to environmental monitoring and protection to make regularly possible a fertile and mutual flux of information. In view of strategic choices for the implementation of the MSFD, devising how to fill this gap is equally important than improving the observational strategies and the quality of the data.

The research on the occurrence and distribution of pollutants in the different biotic and abiotic compartments of the Naples area, conducted so far, is limited for metals and persistent organic compounds, and almost missing for other contaminants of more recent concern. And, if it is not missing, it is not easily accessible. In general, existing data originate from local or "hot spot" studies, like those conducted in the industrial area of Bagnoli, as the result of research campaigns rather than of monitoring networks, so significant geographical and temporal data gaps exist. This deficiency of data, along with the heterogeneity in sampling and analytical methodologies, somehow hampers the accurate interpretation of the status of contamination in the studied area. Despite this, the data compilation presented here gives at least an overview over the most important results in a way that allows meaningful comparisons among studies and analysis of trends over time.

This review has shown that current releases from anthropogenic sources of chemical contaminants are still significant in the region of Campania. Contamination is higher in heavily urbanized and industrialized sites and at the river's mouths, and tends to drop rapidly far from the zone of influence of the discharges. Special concerns appear to be related to Hg, Pb, Zn, PAHs, and PCBs in Bagnoli, to Hg and PCBs and to a lesser extent to Cu in the Naples harbor, and to Cu, Cr and Pb around the Sarno River mouth. Levels of As are also worrying all along the study area, although they do not appear to be linked to human activities but derive from natural sources. In numerous cases, the measured contaminants are at concentrations above legislation limits and environmental quality standards, indicating a situation of serious potential danger for the coastal ecosystems and their living resources. However, a much better understanding of how these chemicals behave in the environment and exert their impacts on marine organisms as well as the possible risks for consumer health is still necessary in the region.

To a certain extent Naples and surrounding areas can be considered as a good example of the possible impacts of a large city, which went through a process of deindustrialization though with many anthropogenic activities that cause pressures and impacts on the marine environment. It can be expected, and this review may stimulate similar compilations, that similar patterns will be observed in the vicinities of all the large Mediterranean cities.

On the positive side, there is that the literature review has revealed some variations in the contaminant loads positively connected with the protection measures taken by the administrations, such as the reduction of Cr in the Sarno basin after the improvement of the wastewater treatment systems and the diminution of PAHs levels in farmed mussels after the dismantling of the industrial plant of Bagnoli.

Nevertheless, the sediments from the latter area have shown a recent and considerable enrichment in PCBs and PAHs. As suggested by Albanese et al. (2010), these sediments should be removed and undergo remediation and the leak of pollutants from the brownfield into the groundwaters must be completely stopped. Even though bathing is still banned, the area is crowded by bathers and beach users in the summertime, so besides cleaning, authorities should also implement efficient risk communication practices to prevent further damages to the population.

Although temporal trends cannot be certainly established from the available data, which connects to what was discussed above, other variations have been suggested that are worth of exploration. Further regulatory control is especially required to ascertain whether (and why) the levels of Hg are increasing in the Gulf of Naples and whether the high DDT residues detected around the Sarno River are a result of past or recent illegal use. Moreover, it is also necessary to assess the true significance of the supposedly raised hydrocarbon pollution seen in commercial fish species from the Gulf of Naples. If these results represent an actual site, public health could be seriously compromised and a thorough observation of the compliance with safety protection standards becomes urgent.

Overall this paper summarizes the up-to-date information on chemical pollution issues in coastal areas of the region of Campania, providing, despite the uncertainties, key insights into the major patterns of contaminants and their associated risks. From here, and in order to progress further towards Good Environmental Status, additional actions are needed, particularly:

1) Development of standardized methodologies of sampling and analysis for a regular monitoring of contaminants in the region, including pollutants of emerging concern. In addition to chemical measurements in sediments, water and biota, biochemical studies should also be performed in order to determine the level of pollutant that is available to the organisms.
2) Design of experiments to evaluate the causal relationships and mechanistic processes between the environmental contaminant levels and their adverse effects on biota. The results should be good for the derivation of specific numerical guidelines values at reference sites.
3) Determination of appropriate geochemical backgrounds of pollutants at the local scale to better identify anthropogenic forcing.
4) Rigorous controls on food products, mostly for carcinogenic and endocrine disruptor compounds. The evaluation of fish and seafood consumption patterns in the region and the use of the "Margin of Exposure" (MOE) approach, as indicated by the EFSA, are strongly recommended.
5) Effective communication of the collected data to the governmental institutions in order to implement adequate sediment management policies and remedial strategies for identified pollution sources.

All the above should be carefully considered during the implementation phase of the MSFD if the complex and, to some extent abstract, concept of GES has to gain a real effectiveness.

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