

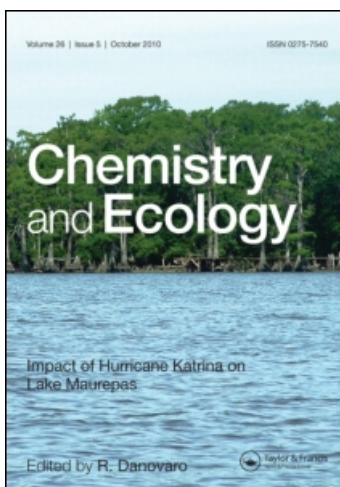
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## Chemistry and Ecology

Publication details, including instructions for authors and subscription information:

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### Chemical contamination and sediment toxicity along the coast of Corsica

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**To cite this Article** Galgani, F. , Chiffolleau, J. F. , Orsoni, V. , Costantini, L. , Boissery, P. , Calendini, S. and Andral, B.(2006) 'Chemical contamination and sediment toxicity along the coast of Corsica', *Chemistry and Ecology*, 22: 4, 299 – 312

**To link to this Article: DOI:** 10.1080/02757540600812156

**URL:** <http://dx.doi.org/10.1080/02757540600812156>

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## Chemical contamination and sediment toxicity along the coast of Corsica

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(Received 29 September 2005; in final form 28 April 2006)

Trace metals (Cd, Pb, Cu, Cr, Ni, Co, Zn, Hg, As, Mn, Al, Fe, and Li) and organic compounds (PCBs, PAHs, lindanes, and DDT and its degradation products) were measured in coastal sediment samples from 27 sites in lagoons and along coastal areas of Corsica. An oyster embryo bioassay evaluated the toxicity of sediments from sites in three coastal lagoons (Urbino, Diane, and Biguglia) and the west coast of Cape Corsica. Despite contamination levels generally lower than those in other Mediterranean coastal areas, contamination is found in specific sites in Corsica and includes natural arsenic contamination on the east coast, insecticide pollution (persistent lindane and DDT) in many areas, both cadmium and lead contamination around Sagone, general contamination of both main harbours (Bastia and Ajaccio) and their surrounding areas, and asbestos mining residues in western Cape Corsica. Monitoring development of *Crassostrea gigas* embryos showed toxic effects at sites near a factory on Cape Corsica, with up to 100% mortality of larvae, and lower levels of toxicity at Sagone (44% mortality) and in the three coastal lagoons (up to 28% mortality). Results of this regional study show the need for further monitoring to understand the environmental issues facing the Corsican coast.

*Keywords:* Chemical contamination; Sediment toxicity; Corsica

### 1. Introduction

Numerous studies interpret contaminant levels in sediments as an indicator of chemical contamination of the environment [1, 2]. Coastal sediments can contain the signature of long-term contamination [3] in deep deposits as well as a more recent history of contaminant loading in the top few centimetres. Long-term monitoring programmes, however, often sample biota, including wild and caged animals, rather than sediments, to assess this contamination. Monitoring in Corsica today is limited to mussels: levels of trace metals and organic compounds in wild mussels have been recorded since 1974 in two coastal lagoons [4] and in caged mussels around

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the island for the past 10 yr [5]. Although sediment from specific sites has been analysed for metal [6–8] and organic [9, 10] contamination, the coastal area as a whole has not been studied. We therefore sampled and analysed sediment from 27 sites around the island to obtain an insight into its chemical concentrations. We also conducted toxicity testing. Our results provide new, original, and valuable information.

The coastline of Corsica is about 1000 km in length and includes productive ecosystems such as coastal lagoons and economically important fishing grounds as well as areas where waste products (e.g. industrial, agricultural, urban, and tourist) are released. In the latter areas, sediments integrate and accumulate measurable quantities of pollutants and toxic waste. To understand the effects of these pollutants, sensitive bioassays can evaluate the spatial extent of their effects and their toxicity to marine organisms. Ghirardini [11] recently reviewed the various sediment indicators associated with toxicity to sea urchin embryos. Elsewhere, she [12] has pointed out the wide use of embryo bioassays and noted the growing interest in using indigenous species and sediment elutriates for bioassays in shallow-water areas, such as coastal lagoons, where contaminated sediment may well be re-suspended. Toxicity bioassays are now used worldwide to help assess sediment quality because only responses of living systems can integrate the various complex effects of contaminants [13]. The oyster embryo bioassay, one of these procedures, has been shown to be reliable, sensitive and ecologically relevant. We chose to use this method for our study of the Corsican coastal region since native oysters live in surrounding waters. Because *C. gigas* is cultivated in the island's largest lagoons, we considered it the most suitable species for toxicity testing. The assay method has been described as a sensitive test for pesticides [14], detergents [15], antifouling paints [16] and heavy metals [17]. It has been also utilized to monitor sediment quality [18] and to measure the toxic effects of urban wastes, dredged materials and immersed cuttings [19–20] on marine organisms.

In this paper we report contaminant concentrations from 27 measuring stations along the Corsican coast and in its lagoons. We also used the *C. gigas* assay to assess sediment toxicity measured by the effects of elutriates in a study focused on Corsica's three principal coastal lagoons and sites along Cape Corsica's west coast. These results provide valuable insight in the chemical contamination of coastal sediments in Corsica. They can also serve as a scientific and technical basis for monitoring sediment quality along the Corsican coastline.

## 2. Materials and methods

### 2.1 Sampling and archiving

During three cruises on the RV *L'Europe COCON* (1999, 10 sites), *RINBIO* (2000, 25 sites), and *Canari* (2001, 10 sites), coastal sediments from the top 10 cm were collected with a Reineck boxcorer (figure 1). Sediments were also collected with a Van Veen Grab from the Biguglia, Diane, and Urbino coastal lagoons (15, 15, and 18 stations, respectively) in June 2003, after maximum river input. Subsamples from the top centimetre were then separated and stored at room temperature (for particle-size determination), at  $-30^{\circ}\text{C}$  (for chemical analysis) or at  $4^{\circ}\text{C}$  in the dark (in sealed bottles until hatchery-conditioned oysters were available).

### 2.2 Physical and chemical analyses

After preprocessing according to standardized procedures [1], laser granulometry [21] at each measuring site determined the percentage of silt particles (that is, particles with

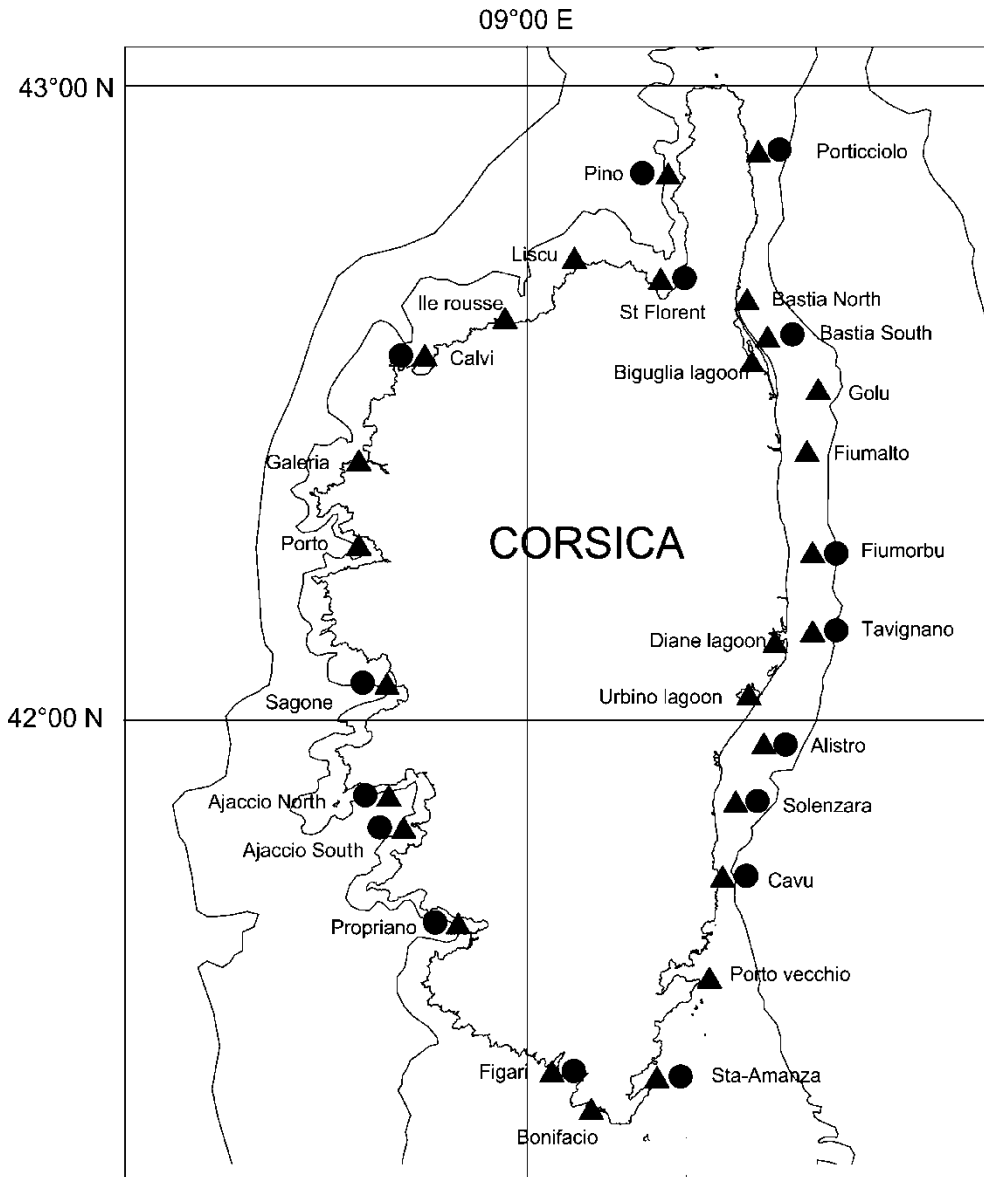


Figure 1. Sample locations for chemical analysis (▲) and oyster embryo bioassay (●) around Corsica.

a diameter less than  $63\ \mu\text{m}$ ) in the sediments sampled at sea and overall particle size distribution for the lagoon samples. After total acid digestion, lead, cadmium, copper, cobalt, chromium, and nickel concentrations were determined by graphite furnace atomic absorption spectrometry, and aluminium, manganese, iron, lithium, and zinc concentrations by flame atomic absorption spectrometry [22]. Arsenic was measured by atomic fluorescence after hydride generation [23], and mercury after direct injection of dry sample in an auto-analyser [24]. Organochlorine pesticides and polychlorobiphenyls (PCBs) were extracted by dichloromethane and measured by gas-phase capillary chromatography combined with

an electron capture detector. Finally, mass spectrometry was used to determine polycyclic aromatic hydrocarbons (PAHs) [25]. Results are expressed in ng or  $\mu\text{g}$  of contaminants per gram of dry mussel flesh.

### 2.3 Embryo toxicity experiments

Conditioned adult oysters (*C. gigas*) were induced to spawn by thermal stimulation [14] and addition of ripe gametes. These experiments used filtered natural sea water, sampled offshore. Eggs and sperm were suspended in sterile beakers and stirred for fertilization. After 15 min, fertilized eggs were counted and placed in microplate wells (IWAKI, five replicates per treatment) containing 100  $\mu\text{l}$  of elutriates or 100  $\mu\text{l}$  of whole sediment solution. Elutriates were made by adding 100 mg of sediment to 240 ml of water, agitating the mixture for 8 h, letting it settle for 8 h, and decanting it. Sediment solutions consisted of either 1 or 5 g  $\text{l}^{-1}$  of freeze-dried sediment in 0.2  $\mu\text{m}$  filtered natural sea water. Final volumes of sediment solutions were adjusted to 300  $\mu\text{l}$  with natural sea water, added by micropipette. Embryos were incubated at  $24 \pm 1$  °C for 24 h; 50  $\mu\text{l}$  of 40% buffered formalin was then added to each vial. The percentages of abnormalities were determined, according to the criteria from previous studies [13, 18] by direct observation of 100 randomly selected individuals per vial under an inverted microscope. Results for each site and for comparisons within samples are expressed as the net percentage of abnormalities (NPA [26]), where:

$$\text{NPA} = \% \text{ abnormal larvae} - \% \text{ abnormal larvae in control.}$$

Using NPA prevents bias by the normal rate of abnormalities in the absence of sediment toxicity. Where NPA = 0, no abnormalities related to sediment toxicity were found, whereas an NPA of 100 indicates a highly toxic sediment.

Data from coastal lagoons were mapped with the kriging algorithm (50  $\times$  50 grid) from SURFER VI (Golden Software, Golden, CO).

## 3. Results

### 3.1 Sediments

Table 1 presents a general description of the sediment samples, listing its aluminium, manganese, iron, lithium, total organic carbon (TOC) and carbonate content as well the granulometry (percentage of silt). It shows substantial variability between the different sample sites: only 12 of 27 contained at least 30% silt. The highest value was observed at Cavu (57.4%) and the lowest at Liscu (2.3%). TOC also varied between measuring stations: many samples had TOC levels less than 2%. These levels were highest at Sagone, Galeria and especially Bastia (up to 5.1%), and lowest at Liscu, Porto and Tavignano (0.2%). In all, 14 stations had more than 50% carbonates. The maximum was 90% at Portocciolo. Very few stations had less than 20% carbonates, and values were lowest at Propriano. Aluminium, lithium, iron and manganese were also heterogeneously distributed with relatively low concentrations at many stations (including Ile Rouse and Bonifacio).

Table 1. Description of the physicochemical characteristics of sediments collected around Corsica including the percentage of silt particles (% particles < 63  $\mu\text{m}$ ), total organic carbon (TOC), carbonates ( $\text{CaCO}_3$ ), and metals commonly used as grain-size indicators.

Station	Latitude	Longitude	Slit (< 63 $\mu\text{m}$ ) (%)	Mn ( $\mu\text{g g}^{-1}$ )	Al ( $\mu\text{g g}^{-1}$ )	Fe ( $\mu\text{g g}^{-1}$ )	Li ( $\mu\text{g g}^{-1}$ )	TOC (%)	$\text{CaCO}_3$ (%)
Pino	42°53.1	09°17.7	49.7	278	1.15	1.29	157	1.7	50.0
St Florent	42°42.5	09°17.2	46.0	279	3.98	1.84	53	2.4	30.0
Liscu	42°45.1	09°10.4	2.3	120	3.54	0.52	27	0.2	40.0
Ile Rousse	42°39.2	08°58.3	6.0	53	0.97	0.26	100	0.6	88.0
Calvi	42°34.5	08°46.5	14.1	106	5.70	0.83	45	0.4	11.0
Galeria	42°26.1	08°38.6	16.8	121	4.01	0.84	51	4	36.0
Porto	42°17.4	08°39.8	3.7	196	5.64	1.06	54	0.2	14.0
Sagone	42°04.3	08°42.5	23.4	299	4.30	1.25	48	2.9	39.0
Ajaccio north	41°54.2	08°41.7	25.0	196	2.01	0.70	43	2.1	64.0
Ajaccio south	41°52.6	08°45.9	35.7	185	2.34	0.82	111	1.8	65.0
Propriano	41°41.5	08°52.1	26.2	547	8.36	3.05	68	1.1	2.0
Figari	41°26.8	09°02.8	13.9	108	1.99	0.33	41	0.9	73.0
Bonifaccio	41°23.6	09°07.2	6.7	60	0.86	0.14	87	0.5	79.0
Sta-Amanza	41°26.7	09°16.5	45.4	158	1.64	0.79	117	1.4	68.0
Porto Aecchio	41°36.3	09°23.5	49.5	224	2.89	1.26	138	0.5	55.0
Cavu	41°43.9	09°24.9	57.4	330	4.23	1.90	54	1.6	38.0
Solenzara	41°52.6	09°26.3	39.5	271	3.06	1.77	88	0.8	52.0
Alistro	42°15.8	09°35.4	17.0	186	3.88	1.13	140	0.9	66.0
Tavignano	42°07.6	09°35.1	14.4	243	4.83	1.53	116	0.2	19.0
Fiumorbu	41°57.3	09°29.4	49.1	257	1.19	0.99	179	0.3	27.0
Fiumalto	42°28.0	09°35.4	35.8	350	1.39	1.18	69	0.6	78.0
Golo	42°32.6	09°37.1	39.9	217	1.11	0.76	52	0.4	81.0
Bastia south	42°38.7	09°30.1	24.9	317	4.05	2.48	113	0.8	35.0
Bastia north	42°41.4	09°27.6	33.4	496	4.95	3.43	65	5.1	10.0
Porticciolo	42°55.0	09°29.9	25.9	138	0.47	0.56	128	1	90.0

### 3.2 Chemical contamination

Table 2 reports contaminant concentrations. Cadmium concentrations were low; the lowest levels were  $0.02 \mu\text{g g}^{-1}$  at Calvi 3, Tavignano, and Fiumor'bu, and highest at Pino, St Florent, Sagone, and southern Bastia ( $0.14 \mu\text{g g}^{-1}$  for southern Bastia). Similarly, copper concentrations were low, except at Pino, St Florent, Cavu, and, especially, southern Bastia ( $31 \mu\text{g g}^{-1}$ ). Lead concentrations were highest (greater than  $20 \mu\text{g g}^{-1}$ ) in sediments from Sagone, south and north of Ajaccio, and especially Bastia, where it reached  $53.8 \mu\text{g g}^{-1}$ . Significant mercury levels were measured only in northern Ajaccio ( $0.054 \mu\text{g g}^{-1}$ ) and southern Bastia ( $0.27 \mu\text{g g}^{-1}$ ). We did not observe elevated zinc concentrations anywhere. Nickel and chromium concentrations were highest in Pino ( $221 \mu\text{g g}^{-1}$  and  $357 \mu\text{g g}^{-1}$ , respectively) and St Florent, while arsenic was distributed homogeneously throughout the measuring stations except in southeastern samples (up to  $29 \mu\text{g g}^{-1}$  at Fiumalto).

Of the PCB congeners assayed, CB138 and CB157 were most common, with concentrations well above detection limits in all samples. The highest CB138 levels were found in the southern part of the island (Figari, Bonifaccio, Santa Amanza, Porto Vecchio, and Cavu). They ranged from  $1.2$  to  $1.6 \text{ ng g}^{-1}$  in Pino and northern Bastia (table 3), where DDT concentrations ranged from  $1$  to  $4 \text{ ng g}^{-1}$ . Northern Bastia is also where the highest concentrations of DDD and DDE, and DDT degradation products, were found ( $2.8 \text{ ng g}^{-1}$  and  $1.9 \text{ ng g}^{-1}$ , respectively). The distribution of  $\gamma\text{HCH}$  (hexachlorocyclohexane) was similar to that of DDT, except in Ajaccio, where concentrations were significantly above the detection limit ( $0.1 \text{ ng g}^{-1}$ ).

Table 2. Trace-metal concentrations in sediments collected around Corsica.

Station	Cd ( $\mu\text{g g}^{-1}$ )	Pb ( $\mu\text{g g}^{-1}$ )	Cu ( $\mu\text{g g}^{-1}$ )	Cr ( $\mu\text{g g}^{-1}$ )	Ni ( $\mu\text{g g}^{-1}$ )	Co ( $\mu\text{g g}^{-1}$ )	Zn ( $\mu\text{g g}^{-1}$ )	Hg ( $\mu\text{g g}^{-1}$ )	As ( $\mu\text{g g}^{-1}$ )
Pino	0.09	18.4	10.4	357	221.5	16.3	39	0.026	6.8
St Florent	0.07	19.9	10.3	252	88.1	7.5	44	0.029	12.0
Liscu	0.04	12.5	1.4	9	2.9	1.8	16	0.001	1.0
Ile rousse	0.04	9.9	1.4	9	3.4	1.8	12	0.006	3.6
Calvi	0.02	17.9	2.2	12	4.7	1.8	25	0.005	2.3
Galeria	0.06	16.2	3.6	10	4.1	1.7	32	0.011	7.2
Porto	0.04	15.0	4.6	29	9.5	3.2	37	0.001	3.4
Sagone	0.11	23.8	5.4	11	6.0	3.4	49	0.026	4.1
Ajaccio north	0.06	20.5	5.3	10	5.5	2.6	33	0.054	4.2
Ajaccio south	0.05	24.6	5.3	10	6.0	2.4	37	0.039	7.2
Propriano	0.05	19.7	3.5	13	6.5	7.3	69	0.010	6.7
Figari	0.03	8.0	1.2	7	2.7	1.0	12	0.008	1.8
Bonifaccio	0.04	6.0	0.8	6	2.2	0.6	6	0.009	1.0
Sta-Amanza	0.04	14.2	4.4	28	19.8	2.7	26	0.026	10.4
Porto vecchio	0.03	17.1	3.6	36	19.4	3.6	30	0.016	20.9
Cavu	0.05	21.2	8.6	69	42.8	6.1	48	0.043	16.0
Solenzara	0.03	12.4	4.2	61	30.5	4.9	35	0.017	28.0
Alistro	0.02	13.0	3.1	36	18.9	3.9	19	0.011	25.5
Tavignano	0.02	13.0	3.0	57	26.9	4.6	31	0.007	18.4
Fiumorbu	0.03	12.2	4.3	43	24.0	4.1	27	0.019	20.6
Fiumalto	0.04	14.1	5.3	41	24.8	6.0	28	0.047	29.0
Golo	0.04	10.9	3.7	23	15.7	3.3	21	0.021	15.1
Bastia south	0.04	15.5	5.3	77	45.9	7.3	57	0.031	16.7
Bastia north	0.14	53.8	31.1	302	162.9	15.4	84	0.269	17.1
Porticciolo	0.04	8.6	2.3	28	17.0	2.4	15	0.019	12.2

We analysed six PAHs, including benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, benzo(ghi)perylene, indeno(1,2,3-cd)pyrene, and fluoranthene (table 4). All samples from every site showed similar PAH patterns. Fluoranthene and benzopyrene levels were high in two stations near Ajaccio (200 and 486  $\text{ng g}^{-1}$ , respectively) and in northern Bastia (800 and 1360  $\text{ng g}^{-1}$ , respectively).

### 3.3 Ecotoxicology

Toxicological tests performed with the oyster embryo bioassay and whole sediment samples (table 5) showed that toxicity was not high at most of the 15 stations around the island, except in Sagone, where the NPA value was 45%, and, to a lesser extent, in southern Bastia, where NPA values were 12% after 24 h.

Elutriates from sediments collected on the western side of Cape Corsica during two cruises were used to measure the effects of past asbestos mining on larval development (figure 2). Samples taken in 1999 from a station located adjacent to a factory in Canari produced 100% mortality. This was confirmed in 2001 when samples from the sites near its effluent outlet were found to have 100% mortality. Toxicity was lower farther from the Canari mining area; to the north and to the south.

We also mapped toxicity and the percentage of silt particles in the three principal coastal lagoons of Corsica, Urbino, Diane, and Biguglia, where samples were taken from 18, 15, and 15 stations, respectively (figure 3). Overall results indicate that their sediments are not highly toxic, with abnormal larvae values ranging from less than 10% to 28% (Diane Lagoon) (figure 3). Toxicity was lowest in Biguglia, where it was less than 10% in all sites, and highest in the western areas of the Urbino and Diane lagoons. There was no evidence of any

Table 3. PCB concentrations in sediments collected around Corsica (results are expressed in  $\text{ng g}^{-1}$  for each PCB congener, CB xxx).

Station	CB 28 ( $\text{ng g}^{-1}$ )	CB 31 ( $\text{ng g}^{-1}$ )	CB 52 ( $\text{ng g}^{-1}$ )	CB 101 ( $\text{ng g}^{-1}$ )	CB 105 ( $\text{ng g}^{-1}$ )	CB 118 ( $\text{ng g}^{-1}$ )	CB 138 ( $\text{ng g}^{-1}$ )	CB 153 ( $\text{ng g}^{-1}$ )	CB 156 ( $\text{ng g}^{-1}$ )	CB 180 ( $\text{ng g}^{-1}$ )
Pino	2.210	1.660	1.280	2.310	0.910	2.050	1.550	1.310	0.210	0.360
St Florent	0.070	0.020	0.370	0.310	0.070	0.320	0.260	0.220	0.040	0.060
Liscu	0.360	0.250	0.090	0.090	0.010	0.070	0.050	0.050	0.010	0.010
Ile rousse	0.100	0.070	0.120	0.150	0.010	0.110	0.080	0.080	0.010	0.020
Calvi	0.020	0.020	0.170	0.170	0.030	0.150	0.130	0.110	0.010	0.030
Galeria	0.370	0.300	0.680	0.910	0.030	0.550	0.410	0.380	0.010	0.090
Porto	0.100	0.080	0.120	0.190	0.010	0.130	0.080	0.070	0.010	0.010
Sagone	0.090	0.060	0.160	0.340	0.020	0.270	0.450	0.500	0.010	0.150
Ajaccio north	0.060	0.050	0.220	0.470	0.030	0.400	0.480	0.500	0.020	0.180
Ajaccio south	0.060	0.060	0.220	0.280	0.040	0.250	0.260	0.250	0.010	0.020
Propriano	0.040	0.030	0.140	0.100	0.030	0.130	0.120	0.120	0.010	0.050
Figari	4.120	3.250	3.260	4.220	0.770	1.920	1.210	1.370	0.150	0.290
Bonifaccio	3.920	3.070	3.180	5.080	0.980	2.280	1.700	2.330	0.170	0.420
Sta-Amanza	4.300	3.290	3.420	4.660	0.880	2.030	1.500	1.770	0.040	0.400
Porto vecchio	4.210	3.480	3.180	4.220	0.890	2.170	1.410	1.690	0.150	0.390
Cavu	5.120	4.110	3.640	3.880	0.790	1.940	1.300	1.420	0.030	0.330
Solenzara	0.040	0.050	0.170	0.150	0.010	0.110	0.080	0.080	0.005	0.010
Alistro	0.070	0.060	0.230	0.360	0.070	0.330	0.300	0.240	0.030	0.040
Tavignano	0.030	0.030	0.180	0.210	0.020	0.150	0.130	0.110	0.010	0.020
Fiumorbu	0.030	0.020	0.120	0.130	0.020	0.050	0.080	0.080	0.020	0.020
Fiumalto	2.190	1.680	1.200	1.570	0.270	1.130	0.690	0.660	0.030	0.190
Golo	0.050	0.040	0.150	0.160	0.030	0.110	0.140	0.130	0.010	0.080
Bastia south	1.750	1.360	1.000	1.260	0.560	1.930	0.870	0.830	0.120	0.300
Bastia north	3.050	2.450	1.710	2.460	0.440	2.200	1.730	1.820	1.170	0.580
Porticciolo	1.640	1.240	0.820	1.200	0.460	0.910	0.710	0.620	0.010	0.200



Table 4. Polyaromatic hydrocarbons (PAHs) and organochlorine insecticides in sediments collected around Corsica.

Station	Fluo (ng g <sup>-1</sup> )	BenKflu (ng g <sup>-1</sup> )	BenBflu (ng g <sup>-1</sup> )	BenApyr (ng g <sup>-1</sup> )	Ind123 (ng g <sup>-1</sup> )	Benperyl (ng g <sup>-1</sup> )	AHCH (ng g <sup>-1</sup> )	BHCH (ng g <sup>-1</sup> )	GHCH (ng g <sup>-1</sup> )	DHCH (ng g <sup>-1</sup> )	DDE (ng g <sup>-1</sup> )	DDD (ng g <sup>-1</sup> )	DDT (ng g <sup>-1</sup> )	ΣDDT (ng g <sup>-1</sup> )
Pino	187	0.5	6	0.5	18	0.5	0.4	0.005	1.85	0.005	0.79	0.005	1.21	2.005
St Florent	133	34	31	30	20	28	0.0	0.0	0.22	0.0	0.18	0.0	0.03	0.215
Liscu	18	0.50	0.50	0.50	0.50	0.50	0.05	0.005	0.15	0.005	0.005	0.23	0.01	0.24
Ile rousse	67	1	2	1	1	1	0.02	0.0	0.12	0.02	0.03	0.0	0.29	0.325
Calvi	14	0.50	0.50	0.50	0.50	0.50	0.005	0.005	0.12	0.005	0.005	0.005	0.01	0.015
Galeria	91	17	8	0.50	0.50	0.50	0.005	0.005	0.47	0.005	0.005	0.13	0.01	0.14
Porto	30	0.50	0.50	0.50	0.50	0.50	0.005	0.005	0.27	0.005	0.005	0.10	0.01	0.11
Sagone	0.50	11	10	0.50	0.50	0.50	0.0	0.0	0.04	0.0	0.0	0.04	0.09	0.135
Ajaccio north	1104	172	246	486	181	201	0.0	0.17	0.16	0.05	0.57	1.13	3.82	5.52
Ajaccio south	89	9	32	34	13	22	0.005	0.005	0.005	0.005	0.30	0.005	3.89	4.195
Propriano	50	0.50	0.50	0.50	0.50	0.50	0.01	0.005	0.02	0.005	0.01	0.03	0.02	0.06
Figari	14	0.50	0.50	0.50	0.50	0.50	0.23	0.10	1.97	0.005	0.60	1.16	1.14	2.9
Bonifaccio	33	6	18	11	15	16	0.005	0.005	1.68	0.005	1.03	1.15	4.04	6.22
Sta-Amanza	20	0.50	0.50	0.50	0.50	0.50	0.29	0.005	2.4	0.005	0.99	1.31	3.32	5.62
Porto Vecchio	72	0.50	6	0.50	0.50	0.50	0.30	0.07	2.16	0.04	0.8	1.31	3.17	5.28
Cavu	41	3	5	0.50	0.50	0.50	0.38	0.005	2.74	0.005	0.79	1.70	2.26	4.75
Solenzara	58	0.50	7	0.50	0.50	0.50	0.005	0.005	0.12	0.005	0.005	0.005	0.50	0.51
Alistro	48	1	1	1	1	1	0.0	0.05	0.10	0.02	0.04	0.03	0.32	0.39
Tavignano	63	1	1	1	1	1	0.005	0.005	0.12	0.005	0.005	0.005	0.01	0.015
Fiumorbu	133	6	19	38	1	15	0.005	0.05	0.09	0.005	0.005	0.03	0.01	0.04
Fiumalto	44	1	1	1	1	1	0.27	0.06	1.30	0.005	0.005	0.005	2.02	2.03
Golo	35	1	1	1	1	1	0.005	0.07	0.04	0.05	0.04	0.005	0.13	0.175
Bastia south	207	0.5	0.5	0.5	0.5	0.5	0.005	0.005	1.08	0.005	0.005	0.03	0.66	0.695
Bastia north	2973	505	874	1361	768	787	0.005	0.005	1.73	0.005	1.88	2.77	0.31	4.96
Porticciolo	143	0.5	11	0.5	0.5	0.5	0.29	0.005	1.34	0.005	0.09	0.04	2.11	2.24

Table 5. Net percentage of abnormalities (NPA) after 24 h of larval development of *Crassostrea gigas* in sediment collected around Corsica<sup>1</sup>.

Station	Latitude (N)	Longitude (E)	0.1 g l <sup>-1</sup>	0.5 g l <sup>-1</sup>	1 g l <sup>-1</sup>	2.5 g l <sup>-1</sup>	5 g l <sup>-1</sup>
Pino	42°53.1	09°17.7	5.60	4.00	3.00	3.60	2.40
St florent	42°42.6	09°17.2	0.80	0.80	0.80	2.60	7.60
Calvi	42°35.1	08°45.2	6.00	0.80	4.80	5.80	2.40
Sagone	42°04.3	08°42.5	13.20	0.80	4.40	32.00	44.00
Ajaccio north	41°54.2	08°41.7	13.20	0.00	1.40	0.00	0.60
Ajaccio south	41°52.6	08°45.9	13.20	0.00	1.40	0.00	0.60
Propriano	41°41.5	08°52.1	12.80	0.00	0.60	4.60	5.00
Figari	41°26.8	09°02.8	12.80	0.00	2.80	2.00	2.30
Sta-Amanza	41°26.7	09°16.5	8.80	1.00	2.20	2.40	0.20
Cavu	41°43.9	09°24.9	8.80	1.20	0.00	2.40	6.20
Solenzara	41°52.6	09°26.4	12.60	0.80	0.00	4.00	2.00
Fiumorbu	41°57.3	09°29.4	12.60	3.00	3.00	8.40	3.60
Bastia sud	42°38.6	09°30.1	16.80	5.60	7.20	10.40	12.00
Porticciolo	42°55.0	09°29.9	5.60	4.40	2.80	2.40	3.60

<sup>1</sup>Toxicological tests used sediment elutriate exposure procedures at various concentrations ranging from 0.1 to 5 g l<sup>-1</sup> (see section 2).

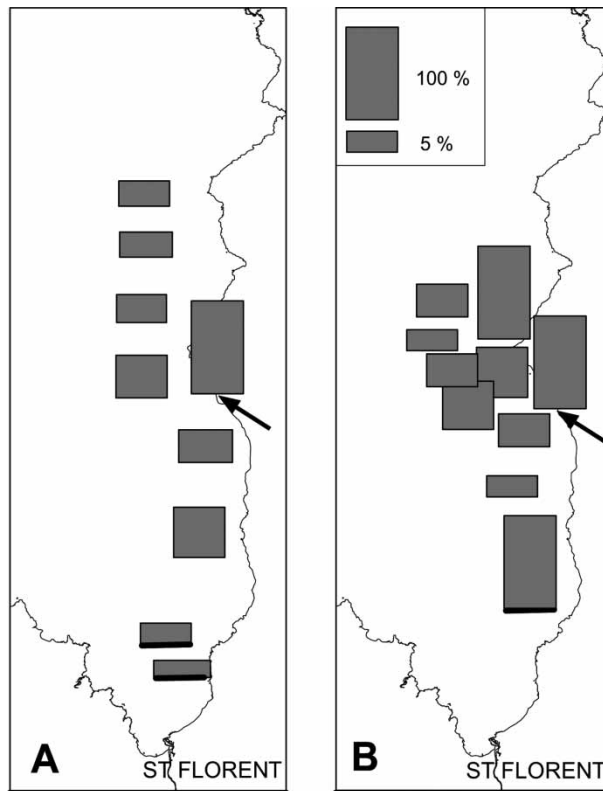


Figure 2. Toxicity of sediment elutriates determined from the oyster embryo bioassay in western Cape Corsica. Sediments were collected during cruises in 1999 (A) and 2001 (B). The arrow indicates where mechanically treated sediments from an asbestos factory were dumped at sea.

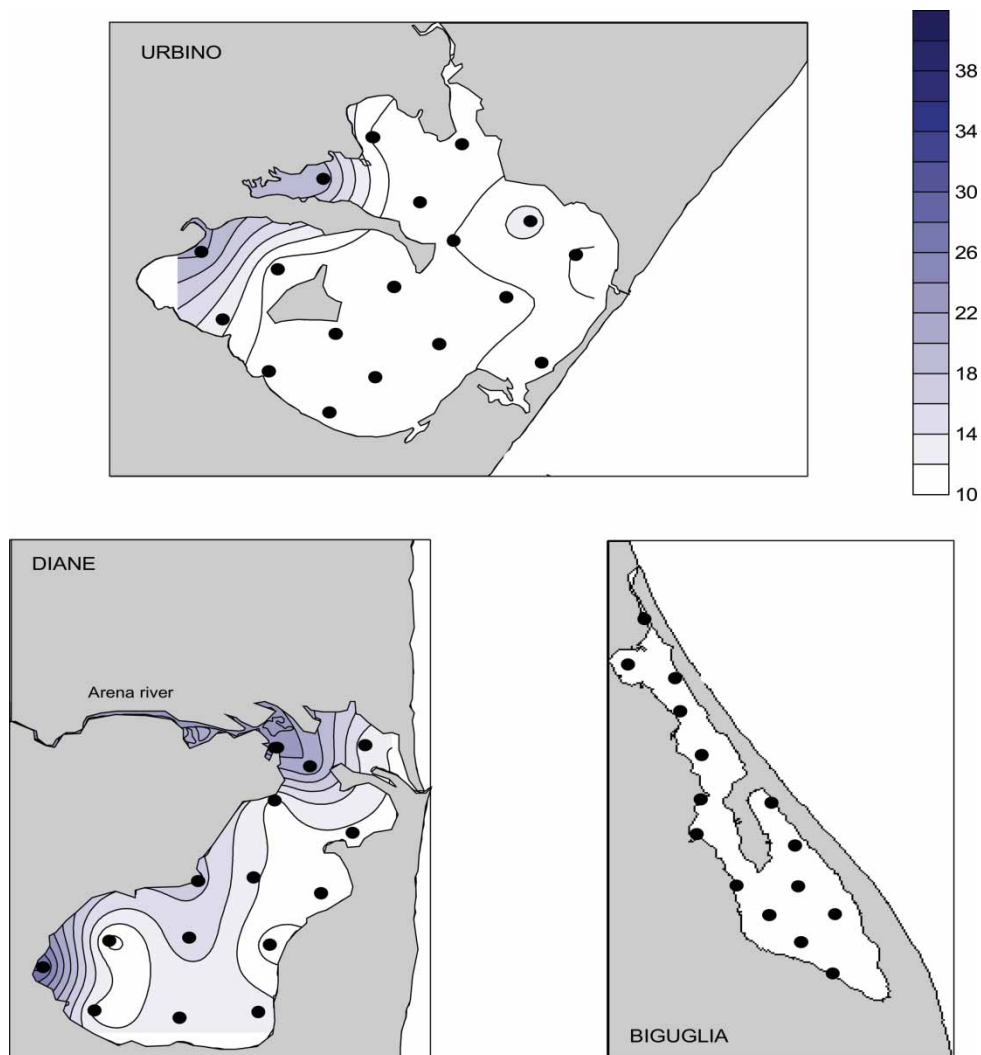


Figure 3. Toxicity of elutriates from sediments collected in Urbino (scale 1/65 000), Diane (scale 1/250 000) and Biguglia (scale 1/35 000) lagoons. Data from the coastal lagoon areas with toxicity (NPA) > 10% were mapped with the kriging algorithm using Surfer VI software. (●): sampling locations.

relation between the percentage of silt and toxicity in sediments from any of the three coastal lagoons.

#### 4. Discussion

Sediments collected around Corsica vary in nature and origin. Recently, De Lazzari *et al.* [27] emphasized the importance of various factors in the distribution of individual elements or compounds in surface sediments. These include such general hydrodynamic factors as surface and deep circulation, particle size, which determines transport and dissemination through the water, mineralogical and geochemical factors, and the contribution of inorganic and organic waste. The most important characteristics affecting the behaviour of contaminants in surface

sediments are their clay and clay silt fractions and concentrations of detrital minerals rich in organic matter, such as quartz, calcite, and dolomite. Our data do not permit such an analysis. We none the less examined explanations for the heterogeneity in the sediments around Corsica by looking for links between contamination and the physicochemical characteristics of sediments that affect their binding to, and absorption of, contaminants. Sediments that are fine-grained or rich in organic matter can absorb more contaminant than coarse-grained or sandy sediment. Coarse sediments, which we defined as those containing less than 30% silt, would tend to have much less affinity for contaminants than sediments containing higher percentages of finer material. Fine-grained sediments also contain more surface binding sites to immobilize particle-reactive contaminants [27] and tend to be found together with higher concentrations of organic carbon, which can absorb more contaminants, especially organic contaminants. Carbonate sediments, on the other hand, formed by the detritus of calcium-fixating benthic and planktonic organisms, generally contain lower contaminant concentrations and tend to have a diluting effect on them [28].

In our study, statistical tests of the correlation between physical parameters and contaminant levels did not demonstrate robust linear relations with either TOC or carbonates. Moreover, we could not express contaminant levels in relation to aluminium, lithium, iron, or manganese because of the high variability of these cofactors. Accordingly, we interpret this chemical contamination more as a consequence of input rather than as natural concentrations or strong effects from local physical characteristics. We therefore compared the results to known sediment contaminant concentrations described in national [1] and international [29] monitoring programmes.

Overall, contaminant levels are low in Corsica compared with those measured in the north-western basin of the Mediterranean. This is the case for cadmium and lead, except in southern Ajaccio, southern Bastia and Sagone. It is also the case for mercury, except in southern Bastia, and for PCBs, except for some high levels along the southern coast. Significant levels of PAHs were found in Sagone and Bastia, and sediments from the southwestern coast and Bastia contained organochlorine insecticides. Sediments from around Bastia and, to a lesser extent, Ajaccio contain notable levels of both metal and organic contaminants. These results cannot be explained only by the industrial activity in and around these two towns, the largest in Corsica. The high contaminant levels are more likely associated with harbour activities, including dredging and shipping, both essential activities that link the island to the continent. High TBT measurements previously reported in Corsican harbours attest to the importance of shipping and boating as a source of some of the contamination in the two harbours [10]. Widespread dredging [16] may account for most of the contamination.

Arsenic was homogeneously distributed along the eastern coast and was likely due to natural leaching of terrestrial soils and sediments [30]. Arsenic concentration increased, however, when the overall sediment content changed, as in Alistro, Solenzara, and Fiumalto, where samples had a low organic carbon and high  $\text{CaCO}_3$  content.

Along the southern coast, the CB138 and CB153 congeners were distributed in similar patterns. Since the measurement sites there had low levels of  $\text{CaCO}_3$  and relatively high concentrations of organic matter, they—especially Bonifacio—may be considered to have been polluted by PCBs. The prevalence of CB138 and CB153 at all sites demonstrated the urban origin of the initial PCBs [31], although their production has been banned for decades, and a wastewater treatment plant has been in operation since 1987. The similarity of the CB138/CB153 ratio in all samples indicated the absence of specific transformation or metabolism in sediment. It also confirms the environmental persistence PCBs.

Even though lindane and DDT use stopped 30 yr ago, after local eradication of malaria, these contaminants are still present, being persistent and toxic. Contamination by organochlorine insecticide (and their degradation products) is still a problem, especially in Bastia and along

the southern and southwest coasts, where it was found at levels significantly above the limit detection. Insecticide contamination in Corsican sediment was first described in 1994 [3], and our results indicate that more careful monitoring should continue in years to come. The mere presence of DDTs does not indicate that they are toxic; toxicity tests are needed to make that determination. Measurement of DDT and related products is none the less useful for tracing chemical contamination and its long-term evolution.

Toxicity experiments clearly showed that sediments from the west coast of Cape Corsica, Sagone, and, to a lesser extent, the western parts of the Urbino and Diane lagoons had strongly toxic effects. In Biguglia, on the other hand, the sediments tested were not toxic. The two other lagoons, Urbino and Diane, receive runoff waters from agricultural areas and local river discharge (from the Arena River in the north of the Diane Lagoon). For other lagoons, the low toxicity may be explained by the lack of industry and low contaminant inputs except for the leaching of natural minerals such as arsenic. Moreover, these low toxicity levels do not increase locally when the percentage of silt in lagoons rises. We conclude from the low toxicity levels that these inputs do not have important ecological consequences.

At the Sagone stations, sediment toxicity may be related to the presence of lead and cadmium. Results in the western part of Cape Corsica and at Pino and St Florent are, however, more clearly related to the high concentration of contaminants such as chromium and nickel found in these sediments. Previous measurements found extremely high concentrations of nickel and chromium (950 and 1600  $\mu\text{g g}^{-1}$ , respectively; Chiffolleau *et al.*, in preparation) in sediments collected around the dumping site from an old asbestos factory located on the coast near Canari. Between 1948 and 1970, 11 million tonnes of mechanically treated rocks and sediments were dumped at sea there. Sediment toxicity is restricted to the area around the dumping site and is related to the presence of natural components of asbestos-rich sediments such as chromium and nickel, although the organisms may also be affected by cobalt and manganese [32].

Despite the low contaminant levels compared with French [1], Spanish [33], and Italian [34] Mediterranean coastal areas as well as other islands in the northwest basin of the Mediterranean, such as the Balearic islands [33] and Sardinia [35], various specific sites are becoming contaminated in Corsica. Specific contamination includes natural arsenic on the east coast, persistent insecticides, cadmium and lead in the Sagone area, general contamination of the areas surrounding the two principal harbours, and finally the residues related to asbestos mining. Additional studies will enable us to quantify these pollutants and examine their environmental effects, geographical extent, and evolution over time. The results of this first broad study provide a valuable baseline for further monitoring of sediment contamination in the coastal zone of Corsica.

## Acknowledgements

This work was partly supported by l'agence de l'eau RMC and the Office of Environment from Corsica, both of which we thank sincerely. We also thank the captain and crew of the RV *L'Europe* for logistic support, Jo Ann Cahn for editing, and those who assisted with sampling and analysis, especially C. Ravel, G. Herve, and E. His.

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