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PCB concentrations in sediments from the Gulf of Nicoya estuary, Pacific coast of Costa Rica

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Abstract: Thirty-one sediment samples collected from 1996-2003 from the Gulf of Nicoya estuary on the northwestern coast of Costa Rica, have been obtained for PCB analyses. This is part of the first study to evaluate the PCB contamination in coastal Costa Rica.Overall, the concentrations are low, especially when compared to sediments from more temperate climates and/or sediments from more heavily industrialized areas. Values average less than 3 ng/g dw sediment, however, a few samples contained up to 7 ng/g dw sediment. Sediments with the highest concentrations were located in the Punta Morales area, where muds were sampled from among mangrove roots. The Puntarenas samples had surprisingly low PCB concentrations, likely due to their sandy lithology. The congener distribution within the majority of the samples showed signs of either recent sources or lack of degradation. However, a few sites, specifically some of the inter-gulf islands and more remote samples had congener distributions indicative of airborne contaminants and/or degradation. Considering the presence of airborne PCBs in the Gulf of Papagayo to the north, the lack of airborne PCBs and more varied congener distribution in the Gulf of Nicoya estuary was surprising.

Key Words: Polychlorinated biphenyls (PCB), organic contamination, Gulf of Nicoya estuary, Costa Rica.

As part of a large project to evaluate the quality of Costa Rican coastal waters, many cores have been obtained from the Gulf of Nicoya area from 1997-2003. These sediment cores have been analyzed for many contaminants, including pesticides, heavy metals and polychlorinated biphenyls (Spongberg and Davis 1999).

From the 1930's through the 1960's the use of PCBs increased widely in many industrial applications, especially in North America. After PCB contamination was recognized (due to their high thermal stability and resistance to both biotic and abiotic degradation) their use was restricted to a limited number of applications and production was banned since 1976. However, their presence is still recognizable in almost all sediment and biological samples from around the world (Rappe 1993). Releases into the environment include improper disposal, leakage, incineration and volatilization. The geochemical properties of the group of PCB congeners include high K_{ow} and low water solubilities, therefore, these pollutants readily adsorb onto organic matter in marine sediments and suspended in the water column. Other transport pathways include atmospheric dry and wet deposition into the marine environment (Broman *et al.* 1992).

This paper provides the detailed analyses of PCB congeners from various locations within the sediments of Gulf of Nicoya estuary on the Pacific coast of Costa Rica. This is the first paper reporting their presence and concentrations in this area. A summary of previous PCB studies in other marine sediments in Costa Rica in included as an accompanying article for comparison (Spongberg 2004).

MATERIALS AND METHODS

Study area: The Gulf of Nicoya is a relatively shallow, sheltered, tidally influenced estuary on the Pacific coast of Costa Rica (Voorhis *et al.* 1983). The gulf is largely fringed with mangrove forests and agricultural lands. However, it harbors the largest ports in the country and a few areas, such as Puntarenas, are heavily populated and serve as potential sources of contaminants to the water and sediments. Also, many rivers which empty into the gulf have more densely populated watersheds. Gulf of Nicoya is the major commercial fishing area in the country. The gulf has a total surface area of ~1 600 km^2, and varies in average depth from less then 20 m in the northern half (roughly north of Puntarenas and Rio Barranca, Figure 1) to more than 200 m where it joins the Pacific ocean (Vargas 1995). Summaries of the geochemical environment of the Gulf can be found in Epifanio *et al.* (1983), Voorhis *et al.* (1983) and Gocke *et al.* (1990), for example.

The areas sampled for this study are shown on Figure 1. Punta Morales (1) is relatively undeveloped and is surrounded by mangroves. The ECMAR Marine Biological Station is located near Playa Blanca. Puntarenas (2) is more densely populated and contains mostly sediments with a coarser grain size than is found elsewhere. Besides the population centers, Puntarenas is surrounded largely by agricultural fields with sugarcane and rice being the main crops. Thirteen sets of sediment samples were taken from the offshore waters (3) near the islands shown in Figure 1. Chira is an island in the northern part of the gulf. Caballo and Bejuco islands are south of Chira and experience more water traffic. The car ferry lane is very close to these islands. Pajaros island is a small biological reserve. The final group of samples (4) are concentrated around rivers entering the gulf near Puntarenas.

Analytical procedures: Details on the collection and analyses of the sediment samples is given in Spongberg (2004). Grab samples were prepared as follows. Estuary and

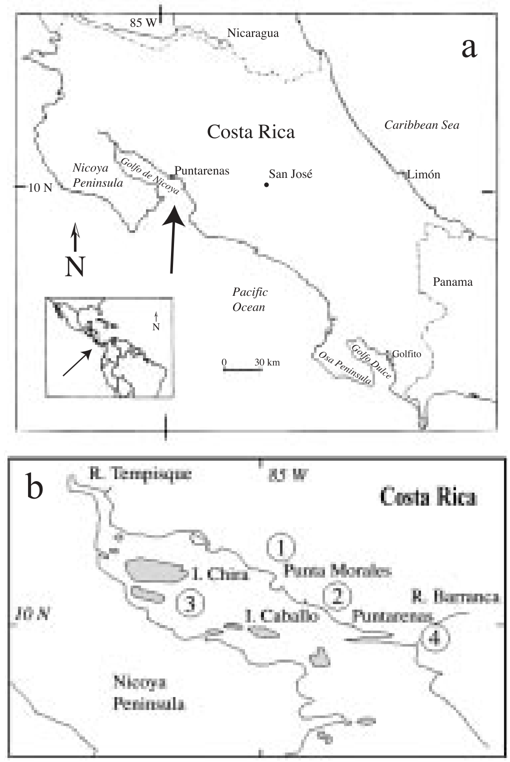


Fig. 1a, b. Location map for samples areas used in the PCB study. 1 = Punta Morales mud flat/mangroves, 2 = Puntarenas populated area, 3 = offshore islands, 4 = rivers entering gulf near Puntarenas.

shallow samples were collected by hand with a clean core barrel and immediately placed in either pre-washed glass jars or plastic bags, depending on the subsequent analyses. Samples were sealed and frozen immediately after collection and transferred to the University of Toledo, Toledo, Ohio still frozen. Samples were dried and re-frozen until analysis.

The analysis of PCBs followed a modified version of EPA Methods 8080 and 3620. Approximately 10 to 20 g of dried, sieved sediment was extracted using a Soxtec Organic Extraction Unit, using methylene chloride or acetone:methylene chloride (1:1) as solvents. Separation and clean up were achieved by passing the extract through a florisil-filled glass column with diethylether in hexane (3:1) as the eluant.

Analyses were performed on a Hewlett Packard 6890 gas chromatograph equipped with a SPB-5 fused silica capillary column (30 m length, 0.25 mm ID, 0.25 µm film thickness, Supelco, Inc.) attached to either a ^{63}Ni electron capture detector (HP 5890 Series II) or a mass selective detector (HP 5972).

Quality control included reagent blank determination, matrix spike (0.2 and 1.0 µg/g) recovery, and precision analyses. 2,3,5-trichlorobenzene was used as an internal standard. Calibration was checked routinely. Quantification of individual PCB congeners in samples was made by comparison to standard mixtures and confirmed using the extensive library of mass signatures of individual congeners. Recovery efficiencies varied between 65 and 95%. Detection limits were calculated using the area of the baseline noise over the elution time of each congener using low concentration standards. Limits of detection were three times the standard deviation of the baseline noise, and averaged 0.2 ng/g. Relative standard deviation of data from five consecutive duplicate runs was 3-5%. Data reported are not corrected for blank concentrations or recovery efficiencies.

TABLE 1

PCB IUPAC identification numbers, chlorine substitutions and classes of congeners analyzed in the sediments of Costa Rica

IUPAC number	Chlorine substitutions	Isomer Class
15	4,4’	2 Cl
18*	2,2’,5	3 Cl
31*	2,4’,5	3 Cl
40	2,2’,3,3’	4 Cl
44*	2,2’,3,5’	4 Cl
49*	2,2’,4,5’	4 Cl
52*	2,2’,5,5’	4 Cl
60	2,3,4,4’	4 Cl
87*	2,2’,3,4,5’	5 Cl
101*	2,2’,4,5,5’	5 Cl
110*	2,3,3’,4’,6	5 Cl
118*	2,3’,4,4’,5	5 Cl
121	2,3’,4,5’,6	5 Cl
128	2,2’,3,3’,4,4’	6 Cl
138*	2,2’,3,4,4’,5	6 Cl
151*	2,2’,3,5,5’,6	6 Cl
153*	2,2’,4,4’,5,5’	6 Cl
170*	2,2’,3,3’,4,4’,5	7 Cl
180*	2,2’,3,4,4’,5,5’	7 Cl
183	2,2’,3,4,4’,5’,6	7 Cl
194*	2,2’,3,3’,4,4’,5,5’	8 Cl
195*	2,2’,3,3’,4,4’,5,6	8 Cl
196*	2,2’,3,3’,4,4’,5’,6	8 Cl
199*	2,2’,3,3’,4,5,5’,6’	8 Cl
209*	2,2’,3,3’,4,4’,5,5’,6,6’	10 Cl

* These 19 congeners are used in the calculation of Total PCBs.

RESULTS

The data on the congeners is expressed in two ways. The sum of the congeners identified in this study is presented as $\sum$PCBs. Table 1 lists those congeners. However, because different studies usually identify different congeners and different numbers of congeners, these studies can be difficult to compare. In this study, twenty-five chromatographic peaks could be definitively assigned to PCB congeners. Although the utmost care was taken to assign the correct IUPAC number to that peak, there often unavoidably are other congeners that may co-elute. Due to their geochemical characteristics and mass selective signatures, it is likely that the co-eluting compounds have an equal number of chlorine atoms on the molecule, however, their placement on the biphenyl structure might vary. Therefore, the data are also presented as Total PCBs. As stated in Vanier *et al.* (1996), 19 congeners make up about 50% by weight of all congeners in Arochlor 1242, 1253, 1262, 1254, and 1260 (Table 1). Therefore, the concentrations of these 19 congeners are summed and multiplied by 2 and reported as Total PCBs. This value can, hopefully, be more useful for comparisons in future studies.

Table 2 lists the PCB data for the Gulf of Nicoya sediments. Data are divided by geographic locations and include the $\sum$PCB and Total PCB concentrations, as well as the percentage of the sum attributed to a specific identified congener (given as the IUPAC number).

TABLE 2

PCB data from sediment samples from Golfo de Nicoya, Costa Rica (1997-2003)

Golfo de Nicoya	Internal ID	Sum (ng/g dw *1000)	Total*	IUPAC No., Percentage of Sum 15/17	18	31	40	44	49	52	60	87	101	110	118	121	138	151	153	170	180	183	194	195	196	199	209	Figure
Punta Morales Biological Station, ECMAR, tidal flat, high tide 2 m	13C	4732	6488	3.29	3.95	4.51	6.92	3.79	± 4.75	5.53	8.42	† **10.26**	7.98	4.75	7.17	5.96	4.51	3.95	4.91	1.85	0.81	2.09	1.61	1.05	1.93	0.00	0.00	2
Punta Morales- Playa Blanca, west side of mangrove	4F	4717	6949	2.11	7.59	5.29	4.27	4.59	± 7.77	8.75	5.94	**7.79**	5.92	7.47	3.98	1.45	1.64	2.45	4.85	3.61	4.38	5.09	3.07	1.06	0.64	0.26	0.00	2
Punta Morales, Playa Blanca, east side of mangrove	3F	2893	4057	2.22	7.20	5.82	8.61	± 3.95	4.13	12.05	**8.69**	1.02	9.67	6.48	5.37	1.62	1.72	0.78	6.52	5.02	1.65	2.26	1.80	1.13	2.15	0.16	0.00	2
Punta Morales, next to Cortezas inlet	PMA	1497	2154	0.00	6.10	1.22	13.41	± 6.10	1.22	0.00	2.44	7.32	**14.63**	8.54	9.76	3.66	12.20	0.00	7.32	6.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2
Punta Morales, Mangroves	PMA-X	1234	1701	0.00	**± 54.15**	3.61	28.88	3.61	0.90	0.72	0.54	1.08	1.44	0.36	0.00	1.26	0.18	0.72	1.44	0.72	0.36	0.00	0.00	0.00	0.00	0.00	0.00	2
Punta Morales, Mangroves	PMA-X	518	682	12.38	8.66	± 9.90	3.71	2.48	9.41	**3.96**	3.84	6.31	7.55	12.38	7.43	1.86	2.48	0.00	2.97	3.47	1.24	0.00	0.00	0.00	0.00	0.00	0.00	2
Puntarenas	PMC	2888	4836	0.00	11.63	5.81	± 9.30	2.33	8.14	11.63	0.00	**2.33**	3.49	2.33	9.30	4.65	10.47	5.81	6.98	4.65	0.00	0.00	1.16	0.00	0.00	0.00	0.00	3
Puntarenas, north tip, sand/mud flats, sugarcane and rice fields	19C	1311	1935	4.58	6.73	8.67	± 5.93	1.03	6.96	8.10	2.85	**7.76**	4.68	3.99	5.59	8.55	5.59	6.05	6.73	2.97	1.14	0.29	1.83	0.00	0.00	0.00	0.00	3
Puntarenas mud flats close to shore	20C	1293	2032	3.60	8.91	6.42	3.41	± 7.99	7.07	7.73	2.10	**6.68**	5.37	4.19	6.68	6.02	6.81	2.10	2.23	2.49	3.14	2.10	3.01	1.18	0.79	0.00	0.00	3
Puntarenas, Angostura	PMC-XWC	818	1135	0.00	4.00	6.67	± 14.67	5.33	6.67	8.00	**6.67**	5.33	2.67	4.00	14.67	5.33	9.33	0.00	5.33	1.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3
Puntarenas, western tip, very sandy, 6m	21C	705	1208	2.97	11.28	5.64	4.51	± 2.26	7.90	13.54	0.00	**3.38**	3.38	2.26	9.03	4.51	10.15	5.64	7.90	4.51	0.00	0.00	1.13	0.00	0.00	0.00	0.00	3
Mid-gulf, 9 m	8C	2428	3578	6.30	8.10	6.13	± 8.21	1.85	9.83	5.32	2.31	**2.08**	4.05	2.31	8.10	5.32	6.48	9.49	1.85	4.74	3.01	1.85	2.66	0.00	0.00	0.00	0.00	5
Car ferry lane, 17 m	10C	3730	5491	4.30	6.89	4.96	5.37	1.62	± 4.96	2.84	2.33	6.69	3.09	2.56	5.77	6.89	8.81	5.98	6.99	7.90	2.53	4.96	2.13	1.52	0.91	0.00	0.00	5
Mid-gulf, just south of entrance to Biological Station, 19 m	22C	3200	4749	4.75	7.13	8.34	± 9.43	5.56	11.12	1.57	**3.14**	1.69	5.08	1.57	4.11	6.17	3.02	8.22	5.80	8.58	1.33	0.73	1.09	1.08	0.48	0.00	0.00	5
North of Chira Island, off easternmost point, 10 m	2C	1496	2170	4.49	7.62	5.49	5.94	‡ 1.79	5.49	3.14	2.58	1.46	0.45	1.35	6.39	**7.62**	9.75	6.61	7.73	8.74	2.80	5.49	2.35	1.68	1.01	0.00	0.00	4
Chira Island, mouth of bay, 2.5 m	1C	555	799	5.19	5.17	4.29	4.91	4.21	± 4.03	7.80	4.12	4.99	**6.05**	3.68	5.96	7.36	6.92	5.61	7.19	4.29	0.18	2.80	1.05	3.68	0.53	0.00	0.00	4
Caballo Island, eastern tip, 17 m	11C	949	1280	9.45	12.18	± 6.79	3.59	5.69	4.59	2.80	**6.09**	4.57	6.49	4.19	3.10	4.99	7.19	4.79	1.60	4.39	1.00	4.19	2.30	0.00	0.00	0.00	0.00	4
Caballo Island	PMB	621	468	**± 53.16**	8.31	4.98	1.66	0.83	3.32	8.31	1.66	2.16	3.32	4.98	2.66	0.83	1.83	0.50	0.00	0.66	0.33	0.00	0.17	0.33	0.00	0.00	0.00	4
Caballo Island	PMB	350	362	20.00	± 5.88	7.06	4.71	3.53	2.35	**9.41**	4.71	2.35	4.71	8.24	2.35	1.18	5.88	0.00	3.53	0.00	4.71	9.41	0.00	0.00	0.00	0.00	0.00	4
Interchannel between mainland and Caballo and Bejuco Islands, high tide 12 m	9C	1507	2215	3.40	4.76	2.62	8.69	2.43	± 6.45	5.89	2.43	4.39	5.51	**5.79**	7.75	4.48	8.69	5.51	4.30	6.07	2.43	1.68	3.36	1.87	1.49	0.00	0.00	5
Bejuco, western tip	6C	463	691	4.70	6.12	4.90	4.29	4.90	± 7.75	4.39	7.86	3.37	**7.14**	4.18	8.26	4.29	7.45	5.10	7.14	4.08	1.02	0.00	1.02	2.04	0.00	0.00	0.00	5
Bejuco	5C	420	662	4.23	8.42	5.26	4.21	± 3.16	7.37	4.21	6.31	3.16	**7.37**	2.10	7.37	4.21	11.58	5.26	7.37	4.21	1.05	0.00	1.05	2.10	0.00	0.00	0.00	5
Bejuco, north of western tip	4C	297	457	8.91	10.84	± 7.59	6.51	4.34	7.59	**13.01**	1.08	3.25	3.25	2.17	6.51	4.34	5.42	5.42	4.34	4.34	0.00	0.00	1.08	0.00	0.00	0.00	0.00	5
Berrugate Pt., 10 m	3C	503	807	4.82	9.17	4.59	3.44	2.29	± 8.03	8.03	2.29	3.44	**4.59**	2.29	8.03	6.88	10.32	4.59	9.17	4.59	1.15	0.00	1.15	1.15	0.00	0.00	0.00	5
Pajaros Island, south of Biol. Reserve	7C	945	1413	4.24	9.40	4.80	4.20	± 4.80	6.10	4.30	5.80	3.20	**7.00**	4.10	6.10	6.90	3.80	5.00	8.80	4.00	3.40	0.00	2.10	2.00	0.00	0.00	0.00	5

continued…

TABLE 2 (…*continued*)

PCB data from sediment samples from Golfo de Nicoya, Costa Rica (1997-2003)

Golfo de Nicoya	Internal ID	Sum (ng/g dw *1000)	Total*	IUPAC No., Percentage of Sum 15/17	18	31	40	44	49	52	60	87	101	110	118	121	138	151	153	170	180	183	194	195	196	199	209	Figure
Barranca River - bridge just upstream	5F	3892	5793	0.32	3.09	3.60	1.79	1.81	0.89	3.99	4.61	‡ 6.57	3.63	7.14	6.72	**6.55**	12.84	7.71	7.19	4.63	2.56	5.17	3.97	1.57	2.35	1.31	0.00	6
Estero Pitahaya Vieja, mangrove near bay west of stream mouth	17C	2693	3372	7.27	6.13	9.41	‡ 10.29	6.13	2.96	5.04	**2.85**	1.64	4.16	4.60	5.25	10.07	5.25	5.04	7.88	1.75	0.55	2.30	0.99	0.44	0.00	0.00	0.00	6
Estero Puerto Alto, mid-stream north of Coast Guard	18C	2403	3869	3.23	9.97	5.25	6.40	‡ 5.04	7.24	11.02	1.57	**6.51**	3.67	2.94	5.14	5.25	5.04	7.87	7.98	3.04	1.47	0.10	1.26	0.00	0.00	0.00	0.00	6
Lagarto River	23C	1049	1534	7.28	13.18	‡ 7.94	6.95	7.94	3.26	**7.23**	3.69	6.10	1.84	6.95	7.51	1.70	0.85	5.95	4.39	2.98	1.13	0.28	1.98	0.85	0.00	0.00	0.00	6
Estero Pitahaya Nueva mouth, agricultural, housing, sandy, 4 m	14C	960	1500	5.62	6.62	9.15	‡ 3.97	5.18	7.83	**11.80**	4.74	3.31	3.86	4.19	6.84	3.42	5.51	7.72	4.74	4.41	0.00	0.00	1.10	0.00	0.00	0.00	0.00	6
Punta Morales mud flat, 2.5 m	12C	783	1180	3.90	5.56	2.95	6.35	‡ 9.76	5.22	8.51	6.58	**1.82**	10.44	6.35	6.47	1.47	4.77	4.42	6.13	7.15	1.02	0.00	0.79	0.34	0.00	0.00	0.00	6

* See text for calculation of Total PCBs.
† represents congener at 50% cumulative total.
‡ underscored figures represent congener at 25% cumulative total.

The congener in **bold type** represents the IUPAC number where half of the total sample lies below (fewer Cl) and half is heavier (more Cl atoms). The underscored congener percentage represents the 25% cumulative value. Also included is the reference to the figure number where the sample is illustrated.

DISCUSSION

Of primary importance is the observation that no samples were found that contained high concentrations of PCBs, especially compared with studies from temperate climates or more developed countries where concentrations can be an order of magnitude higher than the values reported here. The average sum and total PCB concentrations were 1.67 (S.D. 1.32) and 2.44 (S.D. 1.93) ng/g dw, respectively, with an overall range of 4.44 and 6.59 ng/g dw, respectively. The highest concentration ($\sum$PCB) found was 4.73 ng/g dw in one of the Punta Morales samples. In fact, many of the samples from Punta Morales had the highest values found in this study, with an overall average sum of 2.60 ng/g dw (S.D. 1.82). These particular sediments were obtained from mud flats among the mangrove roots. There was little human activity at the time of collection, however, nearby were several small communities and unwanted items were haphazardly discarded in some areas. Of interest, also, is the sample with high PCB concentration (3.89 ng/g dw) from the Barranca River where gold mining exists upstream. In the mid-gulf, the concentrations are usually low, especially around the Chira and Caballo Islands. However, the sample directly in the car ferry lane had an average concentration of 3.89 ng/g dw. The islands tended to have the lowest overall concentration of PCBs.

The Puntarenas area had some of the lowest concentrations of PCBs, although this area was expected to have the highest concentrations due to its development. However, these sediments tend to be coarser grained than the other sampled areas. And, despite the fact that the samples were sieved to remove the larger grain sizes the Puntarenas area was still found to be low in PCB concentrations. Many of these samples were located on the far western tip of the peninsula and perhaps do not represent areas where chemicals would be expected to enter the gulf. The river samples are located just north of Puntarenas and have similar values.

When the distribution of congeners is examined, the uniformity of the samples throughout the Gulf of Nicoya becomes more apparent. Figures 2-6 are line plots of the distribution of congeners detected in this study. The top plots in each figure show the IUPAC identification of the congener on the x-axis, representing an increase in the number of chlorines on the biphenyl structure from left to right. The y-axis is the cumulative percent of congeners at or below the x-value. The bottom plot is the same data illustrated as percent of the sum of PCBs with a particular number of chlorine atoms on the biphenyl structure. Plots are divided by area and are identified in Table 2 as to the plot where the samples are portrayed.

Figure 2 shows the data for the Punta Morales area. These data show a distribution skewed towards the heavier chlorinated congeners. This usually indicates either a recent source of PCB contamination or deposition within sediments that do not favor their dechlorination. Four of the six samples from Punta Morales show this congener distribution. Two of the samples, both labeled PMA-X show a distribution skewed towards the lighter, less chlorinated congeners. This normally indicates either degradation or dechlorination, or an airborne source for the PCBs.

In fact, the majority of samples from the Gulf of Nicoya sediments show quite a uniform distribution of congeners. Specifically, the samples from Puntarenas are remarkably similar (Figure 3). Fortunately, these samples were run with several other chemically different samples, therefore, we have confidence that this distribution is not due to analytical error or laboratory contamination. The Puntarenas samples are similar to sediments with recent PCB contaminant sources. The author is unaware of potential sources in the Puntarenas area, however.

Samples from the offshore islands, particularly Caballo Island, show samples indicative of degradation or airborne contamination (Figure 4). These samples are similar to samples analyzed from the Gulf of Papagayo, further north along the Costa Rican coastline. The data are skewed towards the congeners with fewer chlorines on the biphenyl structures. These lighter congeners have relatively lower sorption affinities to the sediments or organic matter, greater solubilities and volatilities and are more easily transported. In contract to these samples, many of the other deeper samples, specifically those from the car ferry lanes and one sample from the mouth of the bay at Chira Island have samples skewed towards the higher chlorinated congeners, as found elsewhere in Gulf of Nicoya (Figure 5). Figure 6 shows the data from the various rivers in the area and again shows data similar to the other Gulf of Nicoya samples. Of note is the sample from Río Barranca that is the most highly skewed towards the heavier chlorinated congeners than any other sample tested in this study.

All of the sediment samples had fairly low organic matter concentrations, with the exception of some of the sediments from the mangrove swamps. There was no apparent correlation between OM and PCB concentration. Often a correlation is found, reflecting the capacity of organic matter to sorb the organic contaminants. Another reason why the values of Total and $\sum$PCBs are low might be the warm temperatures in this tropical area. Degradation reactions tend to increase as temperature increases. Therefore, if PCBs were present they may be degrading in this favorably warm climate. Nevertheless, PCBs tend to need anaerobic conditions for dechlorination to take place and the shallow, oxygenated waters in the gulf prevent those conditions from existing for any significant length of time. The pattern of congeners does reflect a recent source to the waters of Gulf of Nicoya

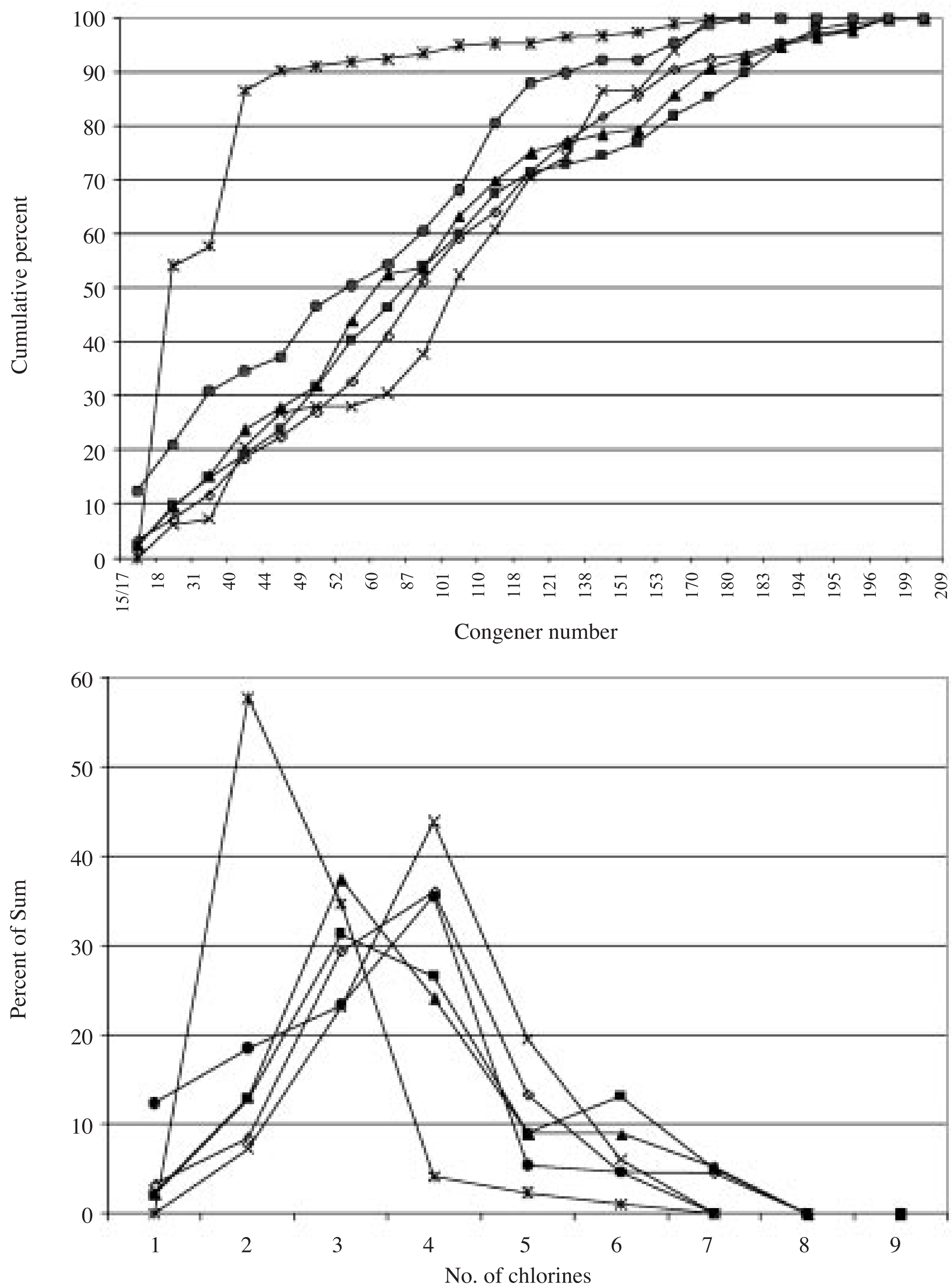


Fig. 2. PCB congener distribution for the Punta Morales area, Golfo de Nicoya, Costa Rica (1997-2003). Top plot is the cumulative data for all analyzed congeners (see Table 1). Bottom plot shows the percent of sum by number of chlorine atoms on the biphenyl molecule.

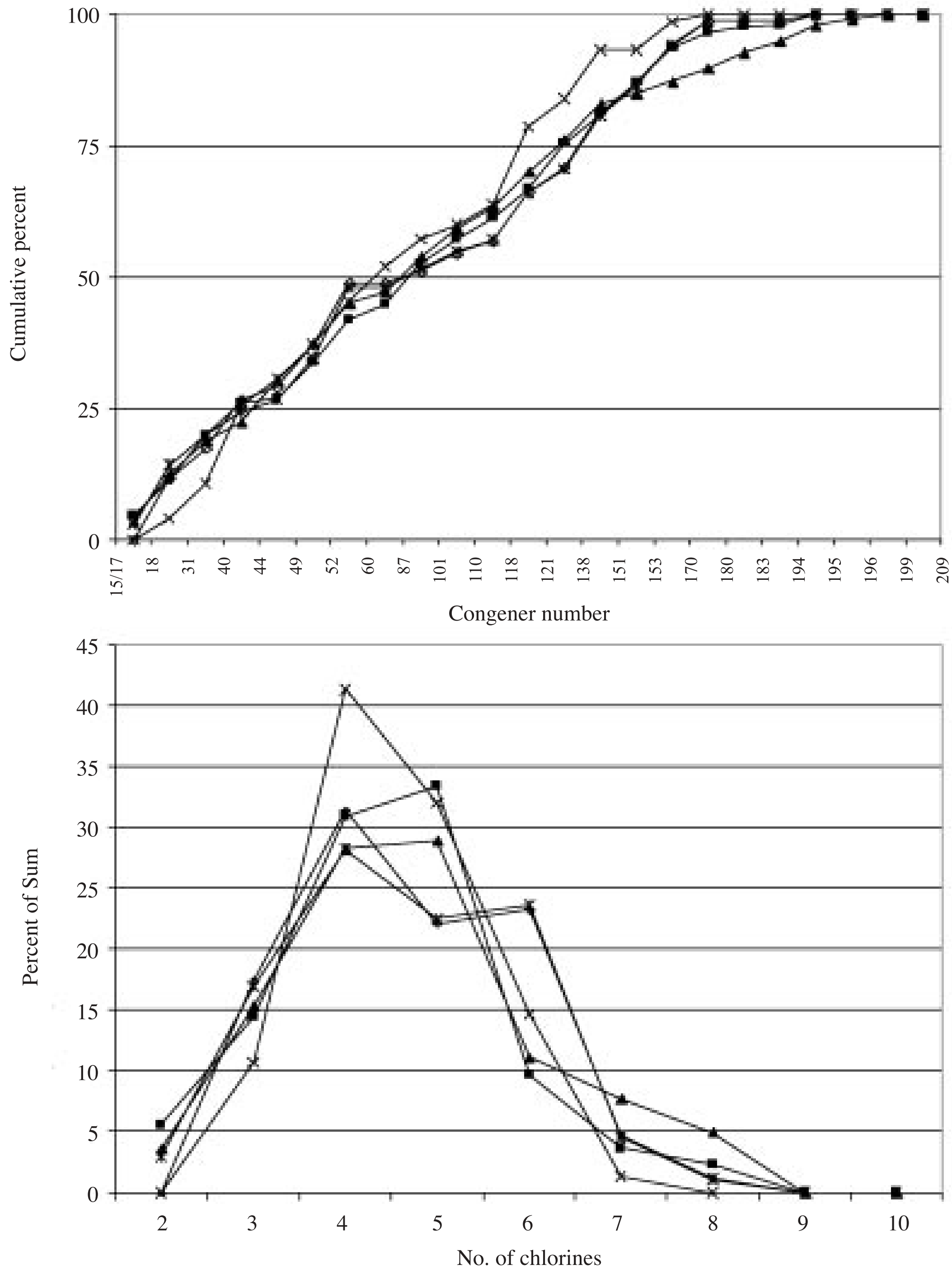


Fig. 3. PCB congener distribution for the Puntarenas area, Golfo de Nicoya, Costa Rica (1997-2003). Top plot is the cumulative data for all analyzed congeners (see Table 1). Bottom plot shows the percent of sum by number of chlorine atoms on the biphenyl molecule.

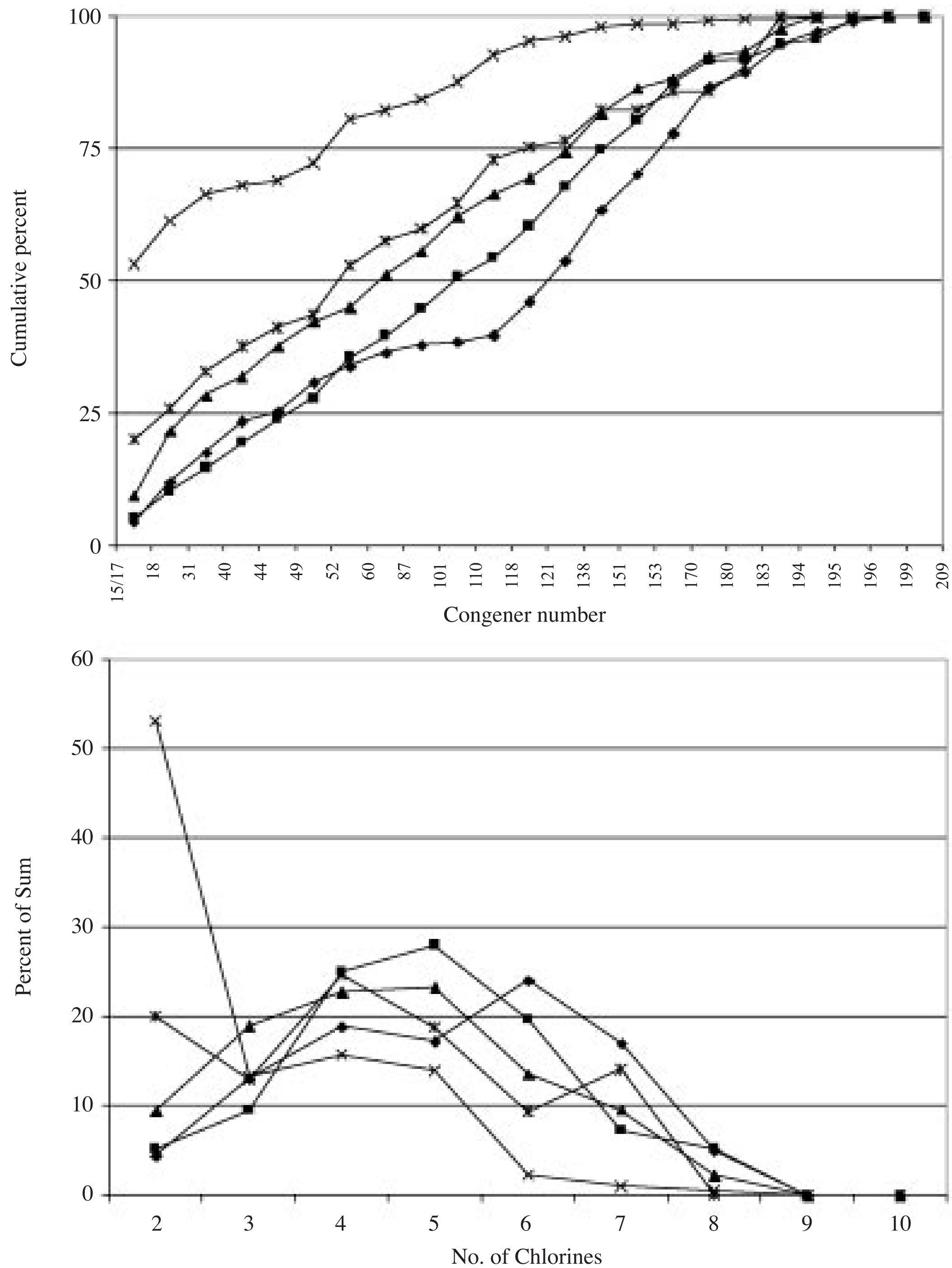
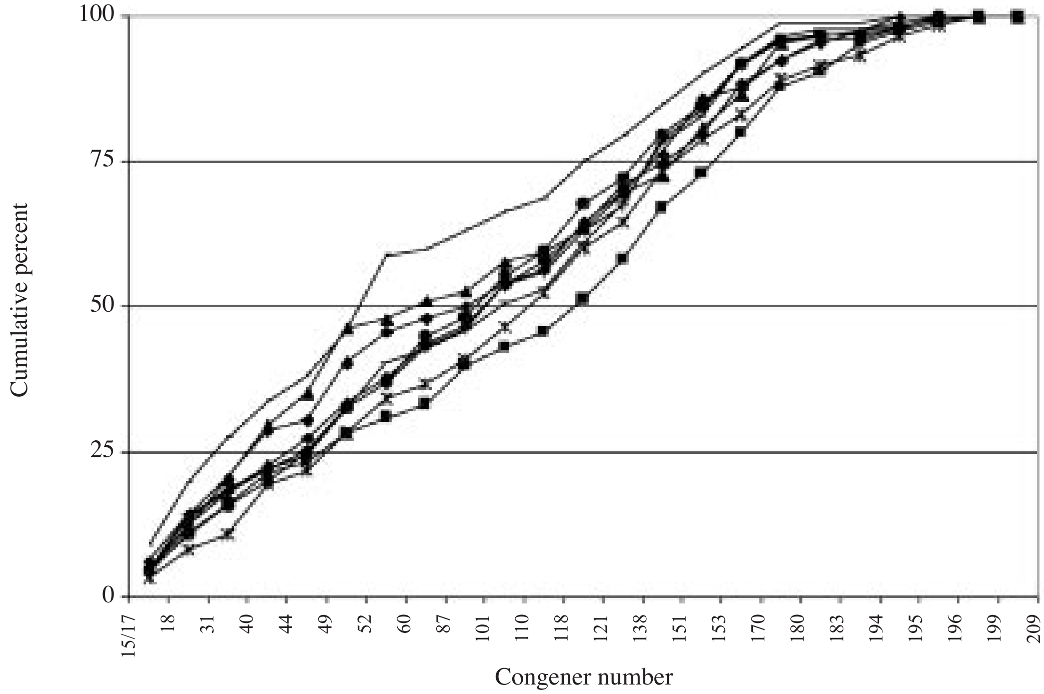


Fig. 4. PCB congener distribution for the sediments from Chira and Caballo Islands, Golfo de Nicoya, Costa Rica (1997-2003). Top plot is the cumulative data for all analyzed congeners (see Table 1). Bottom plot shows the percent of sum by number of chlorine atoms on the biphenyl molecule.



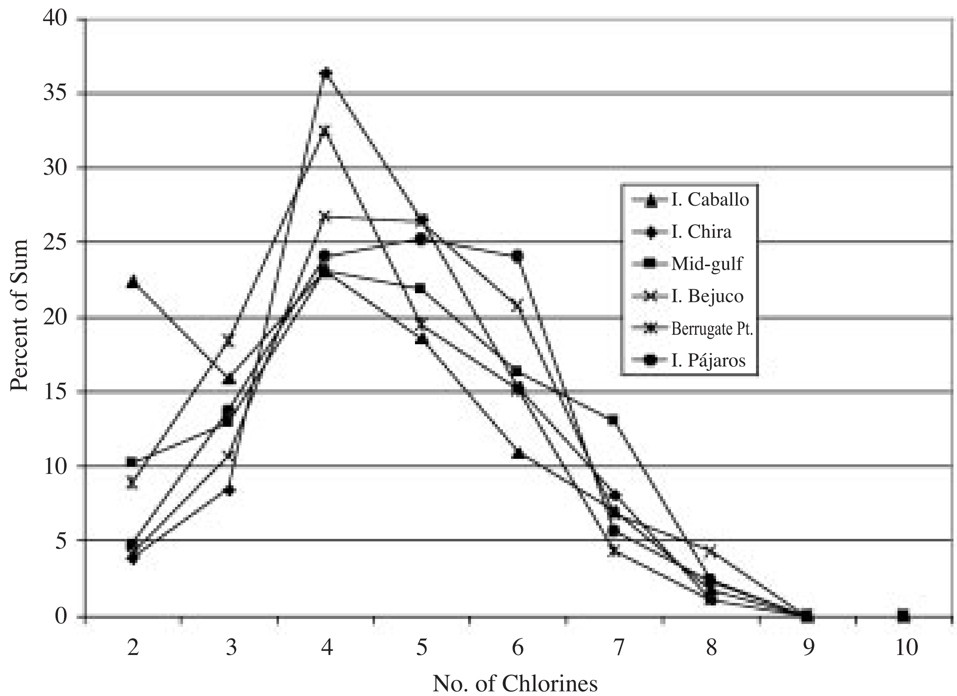


Fig. 5. PCB congener distribution in sediments from the deeper waters and islands in Golfo de Nicoya, Costa Rica (1997-2003). Top plot is the cumulative data for all analyzed congeners (see Table 1). Bottom plot shows the percent of sum by number of chlorine atoms on the biphenyl molecule.

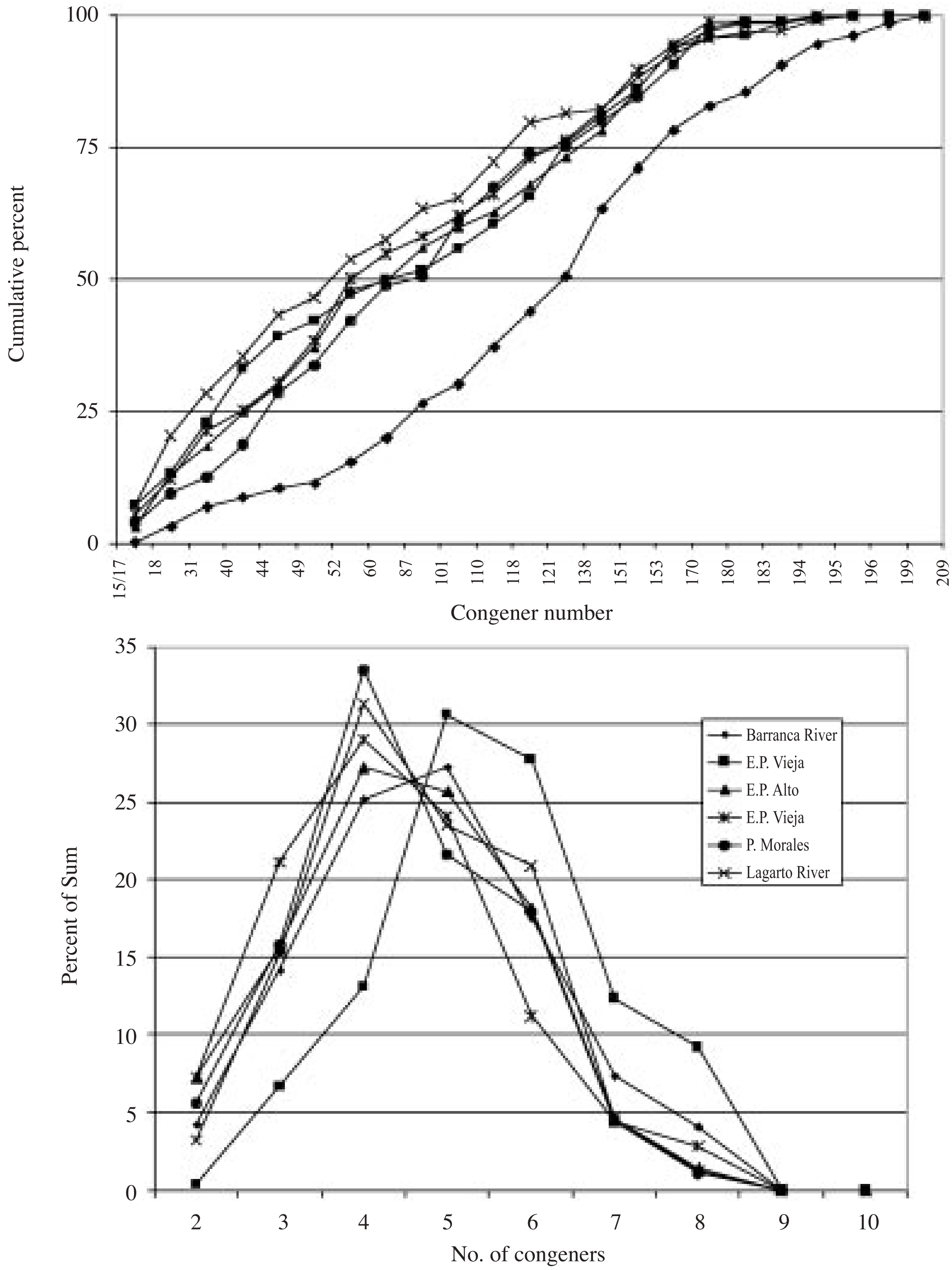


Fig. 6. PCB congener distribution for the sediments from the various rivers near the port of Puntarenas, Golfo de Nicoya, Costa Rica (1997-2003). Top plot is the cumulative data for all analyzed congeners (see Table 1). Bottom plot shows the percent of sum by number of chlorine atoms on the biphenyl molecule.

and not conditions of degradation. Perhaps the circulation patterns favor the removal of the PCBs from the gulf entirely and their subsequent redistribution either within the Pacific Ocean or at a down current point of deposition. However, the possibility that these areas just do not have much PCB contamination should also be considered a reasonable explanation. Many of the sampling locations are remote and would not be expected to have high contamination or significant human impact.

Previous work on these same sediments from Gulfs of Nicoya and Dulce has shown that they also contain comparatively low concentrations of pesticide contaminants (Spongberg and Davis 1999). Conclusions from that work point to either the absence of contamination in many areas, confounded with the lack of sorptive capacity within the sediments.

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RESUMEN

Se analizó los bifenilos policlorados (PCB) en 31 muestras de sedimentos colectadas entre 1996 -2003 en el estuario del Golfo de Nicoya, costa noroeste de Costa Rica. Esto es parte de un primer estudio para evaluar la contaminación por PCB en aguas costeras de Costa Rica. En general, las concentraciones fueron bajas especialmente cuando se les compara con sedimentos de climas templados y / o sedimentos de areas altamente industrializadas. Los valores promedio son inferiores a 3 ng / dw (peso seco) de sedimento. Sin embargo, unas pocas muestras contienen hasta 7 ng/ g dw de sedimento. Los sedimentos con las concentraciones más altas están localizados en el area de Punta Morales, en cienos de entre raíces de mangle. Las concentraciones de PCB en Puntarenas fueron sorprendentemente bajas, posiblemente por el tipo arenoso del sustrato. La distribución de congéneres dentro de la mayoría de las muestras muestran señal de una reciente contaminación o carencia de degradación . Sin embargo, en unos pocos sitios, específicamente en las islas internas del Golfo y otras areas más remotas tienen distribuciones de congéneres que indican contaminación por vía aerea y /o degradación. Cuando se considera la presencia de PCB transportados por via aerea en el Golfo de Papagayo al Norte, es sorprendente la ausencia en el Golfo de Nicoya de estos PCB y una distribución más variada de congéneres.

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