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Chlorinated Hydrocarbons in Coastal Lagoons of the Pacific Coast of Nicaragua

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Abstract. A screening for persistent chlorinated hydrocarbons was carried out in December 1995 in the main coastal lagoons on the Pacific side of Nicaragua, where most of the country's agriculture and pesticide use has been taking place for decades. Results for a wide range of organochlorine pesticides in lagoon sediments show levels that generally were very low in Estero Real, Estero Padre Ramos, and estuary of San Juan del Sur. For example, total DDTs in these lagoons averaged 4.5 ± 3.4 ng g^{-1} dry weight, which may be considered a baseline level for the region. Other compounds such as HCHs, BHC, endosulfan, heptachlor, endrin, toxaphene, and aroclors were present in concentrations even lower, generally below 1 ng g^{-1} dry weight. However, sediments of the Esteros Naranjo–Paso Caballos system at Chinandega district contained pesticide residues in much higher levels, attaining maximum values of 1,420 ng g^{-1} and 270 ng g^{-1} dry weight, respectively, for toxaphene and total DDTs. Other compounds such as aroclors, chlordane, endosulfan, and dieldrin were also present in the sediments of this lagoon system, but in lower concentrations. The very high concentrations of toxaphene and DDTs in this lagoon are a result of the intensive use of these pesticides in cotton growing in the district of Chinandega. Due to the long environmental half-lives of these compounds ($t_{½} > 10$ years in temperate soils), their concentrations in lagoon sediments will likely remain high for years to come. Based on these results, the development of the new shrimp farming activities in the Pacific coastal lagoons should be restricted to selected areas.

The intensive use of pesticides in Nicaragua, which for decades has been one of the biggest pesticide importers and users in Central America (Appel 1991; Castillo *et al.* 1997), is likely to cause severe contamination of aquatic systems. In particular halogenated hydrocarbons, including chlorinated pesticides and industrial chemicals such as the polychlorinated biphenyls (PCBs), are lipophilic toxic compounds that bioaccumulate and transfer in the food chain. Introduced in aquatic environments these chemicals may compromise the health of the ecosystems (Tardiff 1991). This is the case for the coastal lagoons of the Pacific coast of Nicaragua, where most of the country's agriculture and population have been concentrated. In particular, cotton growing, a pesticide intensive agriculture started in the 1950s, was developed in this region of Nicaragua (Appel 1991).

The degradation of these coastal lagoon systems, especially the reduction of mangrove forest and overexploitation of fishery resources, has received focused attention from national authorities. Agrochemical residues are suspected in the degradation of these lagoons, but have not been investigated. Furthermore, with the plans for developing shrimp rearing farms in these coastal lagoons (*esteros*), contamination by agrochemical residues becomes a matter of much concern for the future of this industry. To provide information on the potential impacts from agriculture and urban development, a screening of the contaminants was carried out in the main lagoons of the Pacific coast. This paper presents the results of the analyses of chlorinated hydrocarbons in lagoon sediments and discusses the ecotoxicological hazard posed by the current levels of persistent pesticide residues to aquatic biota.

Materials and Methods

Coastal Lagoons of the Pacific Coast

The following coastal areas were investigated: Estero Real, Estero Padre Ramos, Esteros Naranjo–Paso Caballos, and the estuary of the river San Juan del Sur (Figure 1). These coastal systems are located on the Pacific coast of Nicaragua and receive drainage from fields with diverse agricultural production.

Estero Real, located in northwest Nicaragua, connects with the Gulf of Fonseca near the border with Honduras. Agriculture in the region, especially south of Puerto Morazan, includes sesame, sugar cane, and banana plantations. Aquaculture is a new and rapidly developing activity in this lagoon. Ponds used for shrimp production have displaced mangrove forested wetlands on both banks of the Estero Real. The wetlands of Estero Real comprise the largest extension of mangrove forests in Nicaragua, encompassing 23,000 ha in which *Rhizophora* and *Avicennia* are the predominant trees. The region has a tropical climate with an annual average 1,700 mm rainfall (Polania and Mainardi 1993).

Estero Padre Ramos, which includes 4,600 ha of mangroves, is located further south (Figure 1). Agriculture fields in this region are more extensive than around Estero Real, but they are rarely located close to the lagoon.

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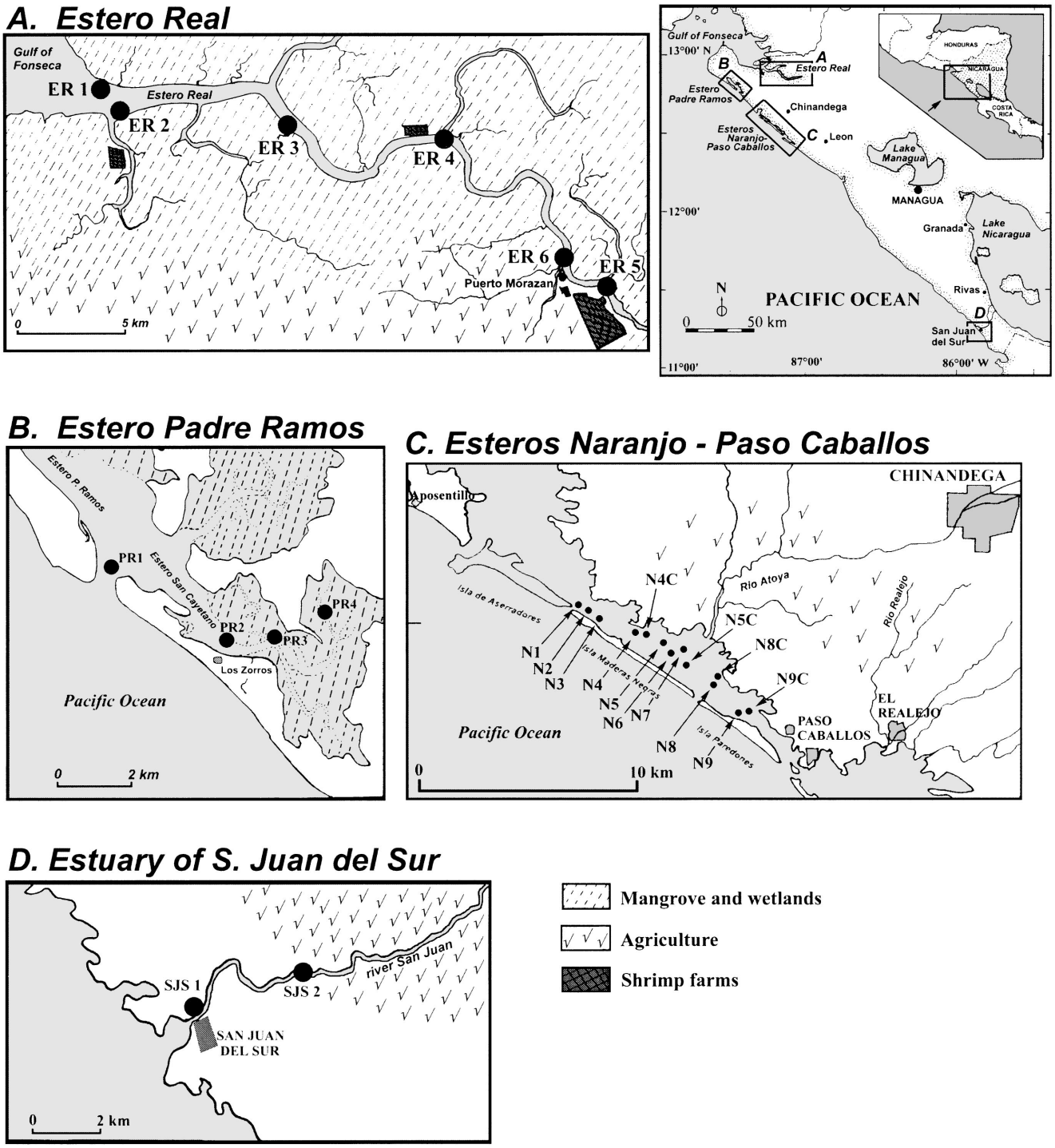

Fig. 1. The coastal lagoon systems of the Pacific coast of Nicaragua investigated for contamination by chlorinated compounds

Esteros Naranjo–Paso Caballos are part of a wider system of communicating coastal lagoons running parallel to the coast and extending from Punta Aposentillo in the north to Ponaloya in the south. This wide lagoon system is surrounded by 10,700 ha of mangrove forests and receives the discharges of several rivers (Atoya, El Realejo, Posoltega, Amalia, etc.) flowing across the district of Chinandega, the traditional cotton-growing region of Nicaragua (Figure 1). Most shrimp larvae harvested to supply national aquaculture and export comes from this lagoon system. Shrimp farms are currently being installed in this lagoon. Annual rainfall in the Chinandega district averages 1,850 mm, with most of the rain delivered between May and October (rainy season). Rains feed the small and sometimes intermittent rivers that flow into the coastal lagoons.

The river San Juan del Sur is located in the southwestern part of Nicaragua, in the district of Rivas (Figure 1). This river connects Lake Nicaragua to the Pacific Ocean and discharges into a small estuary near San Juan del Sur. This estuary is not surrounded by mangrove forests, but land use (farming and habitation) extends close to the shoreline.

Table 1. Sediment samples collected in the main lagoon systems of the Pacific coast of Nicaragua, December 1995

Station	Coordinates		% Organic Matter	Granulometry			
	Latitude N	Longitude W		% Clay <4 µm	% Silt 4–63 µm	% Fine Sand 63–125 µm	% Coarse Sand 125–250 µm
Estero Real							
ER1	12°55.641	87°22.375	8.9	13.92	59.34	18.11	8.18
ER2	12°54.556	87°21.943	7.8	15.07	60.22	16.23	7.95
ER3	12°54.201	87°17.209	4.5	14.88	67.76	13.17	3.99
ER4	12°54.126	87°13.150	8.4	16.19	61.43	16.27	5.88
ER5	12°50.639	87°09.231	8.0	14.86	58.98	17.28	8.29
ER6	12°51.138	87°10.259	8.9	15.1	60.06	16.48	7.88
Estero Padre Ramos							
PR1	12°45.963	87°28.774	2.9	0.36	0.77	16.18	73.50
PR2	12°45.006	87°27.087	1.9	1.51	8.73	18.94	62.37
PR3	12°45.095	87°26.377	3.7	6.17	34.4	13.07	38.14
PR4	12°45.550	87°25.448	9.4	11.82	60.85	13.14	12.91
San Juan del Sur							
SJS1	11°15.465	85°52.196	3.3	5.28	21.02	17.75	49.03
SJS2	11°15.482	85°51.862	6.2	4.46	47.08	29.79	17.37
Esteros Naranjo–Paso Caballos							
N1	12°35.498	87°18.100	2.4	0.64	3.80	22.58	65.25
N2	12°35.499	87°17.902	3.6	1.07	12.28	46.31	38.27
N3	12°35.161	87°17.288	3.4	1.05	9.32	34.19	50.93
N4	12°34.979	87°16.354	13.8	5.38	57.17	22.17	13.21
N4c	12°34.979	87°16.354	16.5	5.78	60.01	23.12	10.41
N5	12°34.401	87°15.375	2.0	5.92	29.72	22.47	38.11
N5c	12°34.401	87°15.375	11.2	11.32	71.53	12.64	4.34
N6	12°34.488	87°14.922	2.1	4.86	23.93	21.52	44.71
N7	12°34.243	87°15.301	14.7	9.31	68.26	15.45	6.53
N8	12°33.546	87°14.283	4.9	1.40	12.17	27.98	52.97
N8c	12°33.546	87°14.283	5.0	1.1	10.03	46.35	40.62
N9	12°33.049	87°13.826	8.0	1.89	23.79	32.77	37.97
N9c	12°33.049	87°13.826	—	—	—	—	—

Agriculture in the district is well developed and includes sugar cane, corn, and tropical fruit.

The coastal lagoons of the Pacific coast of Nicaragua, with the surrounding mangroves, offer valuable resources to the local communities including fuelwood (40% of the country's population obtains energy from fuelwood) and fishing resources. The more exploited fisheries include black clams (*Anadara tuberculosa*), shrimp (*Pennaeus* spp.) and fish (*Mugil* spp.; *Lutjanus* spp.). The economic value of the catches made during 1984 in the Estero Real was estimated at $34,000 for crab, $47,000 for clams and $2.5 million for shrimp (Polania and Mainardi 1993). In addition, the newly developing shrimp farming production has the potential for additional economic value.

Pesticide Usage

Pesticides used in Nicaragua in the past included imported persistent organochlorine compounds (DDT, lindane, dieldrin, etc.) supplemented with national production of toxaphene for use in cotton growing (Appel 1991). Toxaphene application rates as high as 31 kg/ha, and mixtures of toxaphene, DDT, and parathion were used on cotton (Appel 1991). In the early 1990s, production of toxaphene was discontinued and use dropped gradually. Exposure of the population to pesticides and the dispersal of persistent residues in the environment is a matter of much concern (Rodezno 1997; Lacayo and Cruz 1997).

Sampling and Analysis

Sediment samples were collected from the lagoons in December 1995, during the dry season (Figure 1). Geographic coordinates of sampling stations were established using a portable GPS with a precision of ± 30 m (Table 1). Water salinity and temperature were also recorded with portable sensors. Bulk samples of sediment were collected with an Eckman-type sampler that penetrates about 10 cm in the sediment. Several samples were also taken with a plexiglass tube corer, and the top 5 cm retained for analysis. Sediments were placed in hexane-rinsed glass jars, transported on ice to the laboratory, and frozen until analyses.

In the laboratory, sediment samples were freeze-dried, homogenized, and aliquots taken for analyses. Sediment granulometry was determined using 0.5 g sediment resuspended in deionized water and analyzed by the reflection of a laser beam (Micro Mastersizer). Total organic matter was determined as the weight loss on ignition at 400°C for 20 h. Hexane-extractable organic matter (lipids) was determined on the weight of the extract residue evaporated on a Perkin-Elmer micro balance.

Chlorinated hydrocarbons were determined on 5–10-g sediment aliquots extracted with dichloromethane-hexane for 8 h in a soxhlet apparatus, using trichlorobiphenyl (PCB no. 29) and ϵ-HCH as internal standards. Sample-extract cleanup was carried out with elemental Hg to remove sulphur, and further cleanup and fractionation of chlorinated compounds performed using a florisil column (Villeneuve and Cattini 1986). Analyses of the fractions were done with two capillary columns SE-54, 25 m and 50 m long, 0.2 mm internal diameter, 0.32 µm film thickness, on gas chromatographs HP-5890 Series II, with ECD. Confirmatory analyses for several compounds were carried out using a gas chromatograph/mass spectrometer Engine 5989B. Quality assurance procedures included the analyses of marine sediment reference materials IAEA-357 and IAEA-383 to determine the precision and accuracy of the method. Blank values and method detection limits for

Table 2. Concentrations of chlorinated compounds in sediments (ng g^{-1} dry weight) of coastal lagoons Estero Real (ER), Estero Padre Ramos (PR), and San Juan del Sur (SJS)

	ER1	ER2	ER3	ER4	ER5	ER6	PR1	PR2	PR3	PR4	SJS1	SJS2
EOM[a] (mg/g)	0.24	0.22	0.17	0.14	0.17	0.25	0.04	0.030	0.025	0.20	0.056	0.12
HCB	—	—	—	0.052	0.041	0.058	—	0.004	0.007	0.017	0.028	0.031
α-HCH	—	—	—	0.022	0.014	0.020	—	ND	ND	0.013	0.037	0.010
β-HCH	—	—	—	ND	0.009	0.016	—	ND	ND	ND	0.11	0.016
Lindane	ND	ND	ND	0.18	0.085	0.22	ND	0.027	0.005	0.066	0.027	0.028
pp′DDE	3.4	2.3	2.0	4.9	5.8	7.7	ND	0.39	1.2	3.8	6.2	1.4
pp′DDD	ND	ND	ND	0.50	0.33	0.43	ND	0.074	0.06	0.20	2.6	0.21
pp′DDT	ND	ND	ND	0.21	0.098	0.24	ND	0.073	0.06	0.11	1.2	0.68
opDDE	—	—	—	0.069	0.11	0.10	—	0.018	0.01	0.044	0.68	0.030
opDDD	—	—	—	0.078	0.058	0.071	—	ND	0.021	0.075	0.60	0.05
opDDT	—	—	—	0.027	0.025	0.030	—	ND	0.004	ND	0.077	ND
DDMU	—	—	—	0.16	0.28	0.19	—	0.056	0.015	0.051	0.095	0.025
ΣDDTs	3.4	2.3	2.0	5.94	6.70	8.76	—	0.61	1.37	4.28	11.45	2.40
Heptachlor	0.758	0.678	0.658	0.006	ND	0.016	ND	0.004	0.004	0.012	0.006	0.005
Aldrin	—	—	—	ND	0.015	ND	—	ND	ND	ND	ND	ND
Dieldrin	30.33	1.38	4.23	0.040	0.11	0.004	0.593	ND	0.013	0.044	0.022	0.021
Endrin	ND	ND	ND	0.024	0.071	ND	ND	0.009	0.016	ND	0.007	0.011
α-Endosulfan	ND	ND	ND	0.010	0.043	0.029	ND	0.018	0.008	0.008	ND	ND
β-Endosulfan	—	—	—	0.047	0.056	ND	—	0.057	0.027	0.082	ND	ND
Endo-sulphate	—	—	—	ND	0.17	0.10	—	0.030	ND	ND	ND	ND
Cis-chlordane	—	—	—	0.067	0.041	0.069	—	0.016	0.012	0.027	0.025	0.010
Trans-chlordane	—	—	—	0.004	0.007	0.022	—	0.004	0.006	0.006	0.039	0.032
Trans-nonachlor	—	—	—	0.013	0.023	0.044	—	0.017	0.007	0.011	0.009	0.005
Toxaphene	ND	ND	ND	ND	6.2	9.3	ND	ND	ND	ND	2.4	2.7
Aroclor 1254	—	—	—	1.5	1.6	1.3	—	0.43	0.37	ND	0.29	0.11
Aroclor 1260	—	—	—	0.27	0.41	ND	—	ND	0.52	ND	0.47	0.42

[a] EOM: hexane-extractable organic matter

each compound were determined according to Wade and Cantillo (1994).

Results and Discussion

Lagoon sediments showed the presence of a wide variety of organochlorine pesticides including HCB, α- and β-HCH, lindane, DDT and DDT metabolites (ΣDDTs), heptachlor, aldrin, dieldrin, endosulfans, chlordane, and toxaphene as well as PCBs (Table 2 and Table 3). Concentrations of all these organochlorine pesticides in sediments of Estero Real were low (Table 2). In this lagoon, ΣDDTs were the most prominent contaminants, having been detected in all samples with a maximum concentration of 8.8 ng g^{-1} dry weight. Toxaphene was detected in two samples out of six, with a maximum concentration of 9.3 ng g^{-1} dry weight. Similarly, in Estero Padre Ramos, another lagoon system of the northwest Nicaragua (Figure 1), toxaphene was not detected in any of the four samples analyzed and ΣDDTs, which were detected in three out of four samples, attained 4.3 ng g^{-1} dry weight. In the estuary of the river San Juan del Sur, ΣDDTs were present at concentrations of 11 ng g^{-1} dry weight, and toxaphene was measured at levels of 2.7 ng g^{-1} dry weight (Table 2). Other organochlorine compounds were present at concentrations below 1 ng g^{-1} dry weight.

The highest concentrations of organochlorine pesticides were measured in the coastal lagoon system of the Chinandega district, *i.e.*, in the Esteros Naranjo–Paso Caballos (Figure 1). Toxaphene was measured in nine out of 13 samples and concentrations were as high as 1,420 ng g^{-1} dry weight. ΣDDTs, detected in all 13 samples, attained levels of 270 ng g^{-1} dry weight. In sediments from this lagoon, toxaphene had the highest concentrations of any other pesticide and aroclors (Table 3). However, other chlorinated compounds were generally comparable to the levels found in the other lagoons of the Pacific coast.

The low concentrations of toxaphene and DDTs in Estero Real, Estero Padre Ramos, and estuary of the river San Juan del Sur suggest little use of these pesticides in adjacent agriculture areas or efficient retention of agrochemical residues in wetlands and mangroves surrounding the lagoons. Some residues detected in the lagoon sediments may be also the result of global atmospheric depositions rather than of agriculture runoff. The ΣDDTs in the sediments of these lagoons averaged at 4.5 ± 3.4 (n = 11) ng g^{-1} dry weight, which may be considered the baseline level for this region and are comparable to the average ΣDDTs in sediments from the coasts of the United States, 6.6 ng g^{-1} dry weight (NOAA 1991). In contrast, sediments from the Chinandega coastal lagoons generally contained much higher concentrations of ΣDDTs and toxaphene (Table 3). These sediments include samples with a wide range of % organic matter and granulometry composition that are comparable to other lagoons and, thus, results are not biased by any of these parameters (Table 1, Figure 2). Instead, these high concentrations reflect the intensive use of pesticides in the cotton fields of Chinandega over many years. Measurements in agriculture soils of this region gave results of 17–44 μg g^{-1} dry weight for toxaphene and 193–977 ng g^{-1} dry weight for ΣDDTs (Carvalho *et al.* 1998).

Table 3. Concentrations of chlorinated compounds in sediments (ng g^{-1} dry weight) of the Esteros Naranjo–Paso Caballos, in the district of Chinandega[a]

	N1	N2	N3	N4	N4c	N5	N5c	N6	N7	N8	N8c	N9	N9c
EOM (mg/g)	0.058	0.057	0.063	0.08	0.27	0.04	0.10	0.03	0.26	0.042	0.063	0.26	—
HCB	0.006	0.006	0.007	—	1.1	—	0.22	—	0.25	0.18	0.26	—	—
α-HCH	ND	0.006	0.004	—	0.078	—	0.085	—	0.21	0.009	0.013	—	—
β-HCH	0.006	ND	0.008	—	0.17	—	0.20	—	0.17	0.009	0.02	—	—
Lindane	ND	0.015	0.027	ND	0.52	ND	0.64	ND	1.0	0.074	0.08	ND	ND
pp′DDE	0.41	2.7	4.8	130.3	220	38.6	160	17.3	32	2.0	12	9.9	74
pp′DDD	0.093	0.57	0.92	28.8	25	13.8	39	7.2	16	1.2	1.1	ND	9.6
pp′DDT	0.15	0.29	0.51	32.2	8.5	10.5	26	8.6	14	0.75	0.84	1.6	4.31
opDDE	0.005	0.025	0.044	—	2.2	—	1.4	—	2.5	0.017	0.083	—	—
opDDD	0.017	0.042	0.13	—	5.6	—	5.6	—	3.5	0.20	0.29	—	—
opDDT	0.022	0.017	0.069	—	3.7	—	9.2	—	1.2	0.18	0.059	—	—
DDMU	0.014	0.10	0.11	—	5.5	—	2.8	—	3.1	0.035	0.31	—	—
ΣDDTs	0.71	3.74	6.58	191	270.5	62.8	244	33.1	72.3	4.38	14.7	11.5	87.9
Heptachlor	0.004	0.007	0.004	0.678	0.067	ND	0.074	ND	0.042	ND	ND	ND	65.4
Aldrin	ND	0.004	0.005	—	0.083	—	ND	—	0.017	ND	ND	—	—
Dieldrin	ND	ND	ND	2.33	0.74	ND	0.82	1.50	0.081	0.049	0.082	53.7	ND
Endrin	ND	ND	0.033	1.97	0.50	ND	0.70	2.90	0.33	0.026	0.029	ND	ND
α-Endosulfan	0.17	0.041	0.013	ND	0.079	ND	0.079	ND	0.11	0.040	0.096	ND	ND
β-Endosulfan	0.71	0.043	0.018	—	0.086	—	0.10	—	0.29	0.014	0.41	—	—
Endo-sulphate	0.35	0.024	ND	—	0.13	—	0.19	—	0.13	ND	0.053	—	—
Cis-chlordane	0.055	0.069	0.24	—	2.3	—	5.3	—	5.9	0.29	0.074	—	—
Trans-chlordane	ND	0.007	0.011	—	0.28	—	0.78	—	0.39	0.049	0.016	—	—
Trans-nonachlor	0.014	0.019	0.026	—	2.0	—	1.4	—	1.5	0.013	0.03	—	—
Toxaphene	13	24	27	468	720	ND	1420	ND	800	65	37	ND	ND
Aroclor 1254	0.32	0.33	0.36	—	23	—	15	—	5.7	0.3	0.93	—	—
Aroclor 1260	ND	ND	ND	—	45	—	35	—	20	ND	0.94	—	—

[a] c, sediment collected with a tube corer

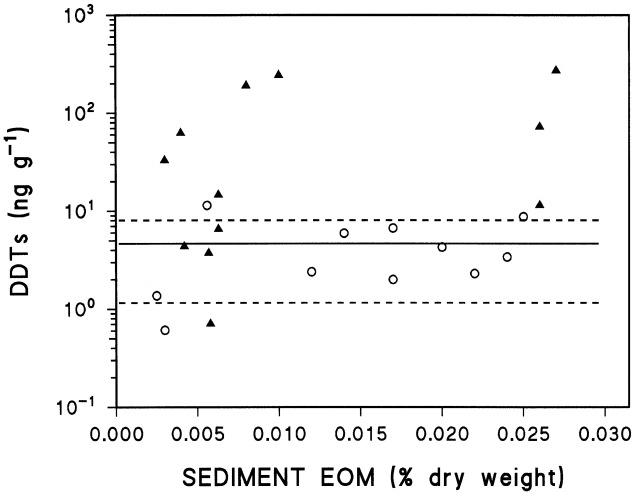

Fig. 2. Concentration of ΣDDTs in sediments from the various lagoons. Triangles, samples from Esteros Naranjo–Paso Caballos in the Chinandega district; circles, samples from other lagoons. Horizontal lines, mean ± 1 standard deviation (4.5 ± 3.4 ng g^{-1} dry weight of ΣDDTs in lagoon sediments, excluding Chinandega), considered as baseline value for the region

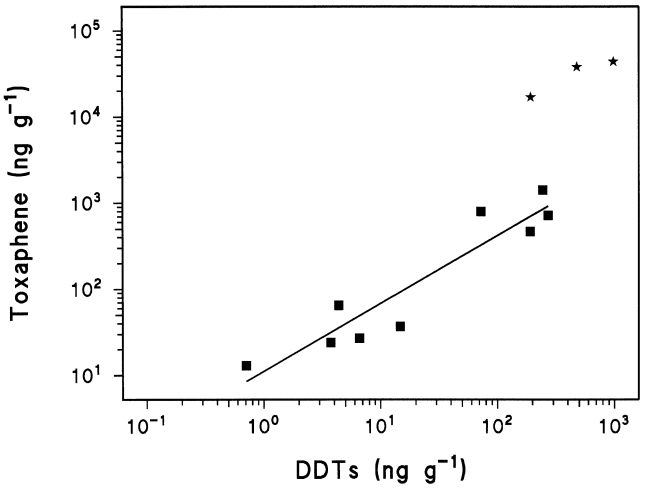

Fig. 3. Concentrations of toxaphene and ΣDDTs in lagoon sediments (squares) from Esteros Naranjo–P. Caballos system. Equation of the regression line is log y = 0.78 (log x) + 1.04 (n = 9, $R^2 = 0.88$, $p < 0.001$). Concentrations in soil samples (stars) from the watershed of the Atoya River are also plotted (data from Carvalho *et al.* 1998)

In the Naranjo–P. Caballos lagoon system, the highest concentrations of toxaphene and DDTs were measured close to the mouth of the Atoya River, which flows across the agriculture area of Chinandega. In the lagoon, concentrations decreased with increasing distance from the river mouth suggesting dilution of the river discharge in the lagoon (Table 3). Furthermore, toxaphene and DDT concentrations in lagoon sediments were positively correlated, which is consistent with a common source for both compounds (Figure 3). It is worth noting that the toxaphene/ΣDDTs ratio in soils of the Atoya watershed averaged 70 but, in lagoon sediments, the ratio was lower than in soils and decreased to the northwest and southeast

with distance to the Atoya River. This trend in toxaphene/ΣDDT ratios indicates higher dissolution of toxaphene than DDTs from the soil particles transported into the aquatic system, which is consistent with the higher water solubility (S) of toxaphene ($\log S = -3.02$ mol m^{-3}) in comparison with DDE ($\log S = -4.60$ mol m^{-3}). In contrast with these observations made in the Chinandega lagoons, it is interesting to note that toxaphene/ΣDDTs ratios in the other lagoons were around or below unity (Table 2), indicating that no application of toxaphene formulations was made nearby and the likely source of both compounds to these lagoons were atmospheric depositions.

Toxaphene is a complex mixture of polychlorinated terpenes (WHO 1989). Data on toxaphene persistence in soils is variable, and persistence half-life values up to 14 years in temperate soils have been reported (Howard 1989). The release of this substance into aquatic systems does not significantly accelerate degradation by hydrolysis (Howard 1989). Several case studies provide evidence for the long persistence of toxaphene in subtropical aquatic systems where releases were discontinued more than 20 years ago and compounds are still present in measurable concentrations (Brown 1997). In higher latitudes, toxaphene deposited in lake sediments did not degrade significantly over the last decades (Muir *et al.* 1995). Therefore, based on the available information, it seems likely that the levels of toxaphene in Chinandega lagoons will decline slowly over the years. Furthermore, toxaphene from the surrounding agricultural soils will continue to be introduced in the lagoons by surface runoff and river discharges.

In the lagoon sediments at the Chinandega district, individual DDT compounds contributed to ΣDDTs as follows: pp′DDT 13 ± 7%, pp′DDE 68 ± 14%, pp′DDD 16 ± 6%, and DDMU 2 ± 1% (n = 8 to 13) (Table 3). In comparison, the components of ΣDDT from sediments of Estero Real and Estero Padre Ramos were pp′DDT for 4 ± 4%, pp′DDE for 83 ± 9%, pp′DDD for 6 ± 3%, and DDMU for 3 ± 3% (n = 6) of ΣDDTs (Table 2). The higher percentage of nondegraded DDT in Chinandega lagoons suggests more recent usages of DDT in the watershed of the Atoya River. DDD and DDMU were present in all lagoons in very small percentages, which attests to the stability of DDE and the very slow degradation of DDT compounds in this environment. The persistence of DDTs in soils, with half-lives up to 20 years in temperate regions, is well known (Wolfe *et al.* 1977; WHO 1989). Results of experimental research on the rate of DDT degradation in the environmental conditions of tropical coastal lagoons indicate a persistance half-life ($t_{1/2}$) in sediments of about 5 years with a very minor transformation to polar residues and breakdown to small molecules such as CO_2 (Carvalho *et al.* 1992).

Concentrations of ΣDDTs measured in the Naranjo–P. Caballos lagoon system are much higher than concentrations reported for similar coastal environments in the American continent (Marcus and Renfrow 1990; Sericano *et al.* 1990; Readman *et al.* 1992; Carvalho *et al.* 1996). For example, comparing the results for ΣDDTs (Table 3) with the concentrations of chemicals in coastal and estuarine sediments of the United States, most of the lagoon sites would be considered high, *i.e.*, $>$ 22 ng g^{-1} dry weight, and even very high (5 × high), $>$ 110 ng g^{-1} dry weight (Daskalakis and O'Connor 1995). Based on sediment toxicity data obtained with marine sediments, biological effects are likely to be caused at ΣDDT concentrations above 46 ng g^{-1} dry weight (Daskalakis and O'Connor 1995; Long *et al.* 1995). We are not aware of reports on toxaphene residues in coastal ecosystems with which we could compare our results. Nevertheless, in 900 U.S. coastal sites monitored for toxaphene this compound was below detection limit in 865 and could be measured in 35 sites at concentrations less than 40 ng g^{-1} dry weight (Daskalakis and O'Connor 1994).

Endosulfans were quantified in eight out of 13 samples from the Esteros Naranjo–P. Caballos, and in six out of 12 samples from other lagoons (Tables 2 and 3). Endosulfan levels in the Chinandega lagoon system, up to 1.23 ng g^{-1} dry weight, were higher in comparison with the other lagoons. The use of endosulfan in Nicaragua is recent and is used for pest control in coffee, vegetable, and pulse plantations. Use of endosulfan in the Chinandega district was confirmed from analysis of soils that contained concentrations of 500 ng g^{-1} dry weight (Carvalho *et al.* 1998). Technical endosulfan usually is a mixture of α- and β-isomers. Endosulfan sulphate is a degradation product formed by soil bacteria and it is likely introduced in the lagoons by surface runoff (Cotham and Bidleman 1989). The persistence of endosulfan isomers in the marine environment is very short (hours–days) and it is converted into the more soluble endosulfan-diol as determined with ^{14}C-labeled compounds (Carvalho *et al.* unpublished data). The endosulfan concentrations measured in the lagoon sediments are below the $\geq$ 50 ng g^{-1} wet weight acute concentrations for meiobenthic polychaetes and copepods (Chandler and Scott 1991). However, endosulfan sulphate seems to be more stable and its presence in aquatic environments is increasingly reported in the literature (Miles and Pfeuffer 1997).

Chlordanes, as the sum of cis-chlordane, trans-chlordane, and trans-nonachlor, attained 7.8 ng g^{-1} dry weight in sediment of the Estero Naranjo, near the Atoya River. Concentrations of total chlordanes in other lagoons were much lower, attaining a maximum of 0.13 ng g^{-1} dry weight. These results suggest some use of chlordane, an insecticide used to control termites, in the valley of the Atoya River, whereas the concentrations in the other lagoons might be the baseline level. The highest chlordane concentrations measured were, however, below concentrations reported in sediments from coastal areas of California, *e.g.*, 5.36 ± 23.2 (n = 31) ng g^{-1} dry weight (Shigenaka 1990) and are not higher than concentrations in other areas of the United States (Shigenaka 1990; Daskalakis and O'Connor 1995; Miles and Pfeuffer 1997).

Hexacyclohexanes, *i.e.*, α- and β-HCH isomers as well as γ-HCH (lindane), were detected in all lagoons, but generally at very low concentrations ($<$ 1 ng g^{-1} dry weight). Lindane may have been used in the Chinandega district, originating the slightly higher concentrations measured in these lagoons (Table 3). Small amounts of HCHs in the environment, lindane in particular, could be expected due to the important usage of this compound in other countries of Central America (Li *et al.* 1996). Nevertheless, HCH concentrations in Nicaragua are less than values reported for the Gulf of Mexico (Sericano *et al.* 1990).

The cyclodien compounds aldrin, dieldrin, and endrin were generally detected in relatively low concentrations, below 1 ng g^{-1} dry weight. Dieldrin residues were the more ubiquitous of the three compounds in the lagoon sediments and results suggest localized applications of dieldrin in one place at Estero Real and another at Estero Paso Caballos (Tables 2 and 3).

Concentrations measured at these places can be considered high, > 2.9 ng g^{-1} dry weight, according to sediment quality criteria (Daskalakis and O'Connor 1995). Analyses of soil samples from the watershed of Atoya River indicated that dieldrin, up to 12 ng g^{-1} dry weight in soils, has been used more than endrin and aldrin (Carvalho *et al.* 1998).

Aroclors, technical mixtures of PCBs used in transformers and capacitors, were measured in lagoon sediments at concentrations up to 45 ng g^{-1} dry weight near the mouth of the Atoya River with concentrations decreasing with distance from the mouth (Table 3). Since there are no industries associated with the lagoon banks in this area, it seems likely that aroclors were transported in the river from the town of Chinandega. Concentrations of aroclors in the other lagoons did not exceed 2 ng g^{-1} dry weight (Table 2) and may originate from global atmospheric depositions. These values are low in comparison, for example, with PCB concentrations measured in sediments of the Gulf of Mexico and Florida (Sericano *et al.* 1990; Cantillo *et al.* 1997) and can be compared with the average concentrations of total PCBs, 39 ng g^{-1} dry weight, in the coastal environment of the United States (NOAA 1991). According to observations on sediment concentrations/biological effects, toxic effects of PCBs are likely to occur at PCB levels above 180 ng g^{-1} dry weight (Long *et al.* 1995).

Conclusions

Residues of persistent chlorinated compounds are present in varying levels in the main lagoon systems of the Pacific coast of Nicaragua. In most of the lagoons, including the vast and productive Estero Real, the concentrations of chlorinated pesticides and aroclors (PCBs) in sediments are very low, generally below 5 ng g^{-1} dry weight. In contrast with this, the coastal lagoon system of the Chinandega district or, more precisely, the *esteros* (channels and lagoons with estuarine conditions) receiving the outflow of the Atoya River, display very high concentrations of toxaphene and DDTs, up to 1,420 ng g^{-1} and 270 ng g^{-1} dry weight, respectively.

Chlorinated compounds in the Esteros Real, P. Ramos, and S. Juan del Sur were likely introduced from global atmospheric depositions. Levels measured in these lagoons are low in comparison with values reported for coastal sites from the American continent and can be considered baseline values for the region (Table 2). However, toxaphene and DDT concentrations in sediments from lagoons of the Chinandega district, near the mouth of Atoya River, are elevated when compared to values reported for coastal areas in the Americas. These high concentrations of toxaphene and DDTs are a consequence of the intensive, prolonged use of these compounds in cotton growing in Chinandega and reflect the high reservoirs of these compounds in soils (Appel 1991; Carvalho *et al.* 1998). The half-life of these chlorinated compounds in the environment is generally very long. As a consequence, toxaphene and DDT concentrations in the coastal lagoons of Chinandega district will decline slowly over the years.

Organochlorine pesticides identified in this contaminant screening have high octanol water partition coefficients (K_{ow}) in the range log K_{ow} 3–6 and, thus, are highly hydrophobic (Noble 1993; Lyman 1995). In aquatic systems, hydrophobic compounds are mostly adsorbed onto sediment particles and organic materials and the amount of chemical remaining in the aqueous phase is generally very small. Therefore, for the low concentrations of persistent chlorinated compounds measured in the sediments of Esteros Real, P. Ramos, and S. Juan del Sur, the corresponding water concentrations will be very low, likely at ng L^{-1} level, and thus well below acutely toxic levels to sensitive biota such as planktonic crustaceans, shrimp, and fish (Howard 1989). On the other hand, the much elevated concentrations of chlorinated compounds measured in sediments from Esteros Naranjo–P. Caballos may contribute concentrations in the water phase, which can attain acutely toxic concentrations to shrimp and other biota. This may be the case especially for toxaphene and DDE, which have accumulated in the lagoon sediments for years and are still discharged by the Atoya River (Carvalho *et al.* 1998). Water concentrations of chlorinated hydrocarbons and toxicity of sediment bound residues (Long *et al.* 1995), such as DDTs and toxaphene in some areas of the coastal lagoons of Chinandega, may pose a hazard to aquatic biota and hamper the development of shrimp aquaculture in the lagoon. The extent and magnitude of the contamination of this lagoon system, which is much wider than the *esteros* sampled at the mouth of the Atoya River, should be further investigated. On the basis of the current data, selection of sites for shrimp rearing should be done only after toxicity of sediments and water quality are carefully tested. Integrated management of the coastal lagoons is needed to harmonize the interests of the ecosystem users.

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References

Appel J (1991) Uso, manejo y riesgos associados a plaguicidas en Nicaragua. Proyecto Regional de Plaguicidas, Confederacion Universitaria Centroamericana, Managua, Nicaragua, 143 pp

Brown LR (1997) Concentration of chlorinated organic compounds in biota and bed sediment in streams of the San Joaquin Valley, California. Arch Environ Contam Toxicol 33:357–368

Cantillo AY, Lavenstein GG, O'Connor TP (1997) Mollusc and sediment contaminant levels and trends in South Florida coastal waters. Mar Poll Bull 34:511–521

Carvalho FP, Fowler SW, Gonzalez-Farias F, Mee LD, Readman JW (1996) Agrochemical residues in the Altata—Ensenada del Pabellon coastal lagoon (Sinaloa–Mexico): a need for integrated coastal zone management. Int J Environ Health Res 6:209–220

Carvalho FP, Fowler SW, Readman JW, Mee LD (1992) Pesticide residues in tropical coastal lagoons (1992). Use of ^{14}C-labelled compounds to study the cycling and fate of agrochemicals. In: Applications of isotopes and radiation in conservation of the environment. Proc Int Symp 9–13 March 1992, IAEA, Vienna, pp 637–653

Carvalho FP, Montenegro-Guillen S, Villeneuve J-P, Cattini C, Tolosa I, Bartocci J, Lacayo M, Cruz A (1998) Toxaphene residues from cotton fields in the coastal environment of Nicaragua. Environmental Pollution (submitted)

Castillo LE, Cruz E, Reupert C (1997) Ecotoxicology and pesticides in tropical aquatic ecosystems of Central America. Environ Toxicol Chem 16:41–51

Chandler GT, Scott GI (1991) Effects of sediment-bound endosulfan on survival, reproduction and larval settlement of meiobenthic polychaetes and copepods. Environ Toxicol Chem 10:375–382

Cotham WE, Bidleman TF (1989) Degradation of malathion, endosulfan and fenvalerate in seawater and seawater/sediment microcosms. J Agric Food Chem 37:824–828

Daskalakis KD, O'Connor TP (1994) Inventory of chemical concentrations in coastal and estuarine sediments. NOAA Technical Memorandum NOS ORCA 76, NOAA, Silver Spring, MD, 47 pp

Daskalakis KD, O'Connor TP (1995) Distribution of chemical concentrations in US coastal and estuarine sediment. Mar Environ Res 40(4):381–398

Howard PH (1989) Handbook of environmental fate and exposure data for organic chemicals. Lewis Publishers, Ann Arbor, MI

Lacayo ML, Cruz AC (1997) Plaguicidas organoclorados en leche materna de mujeres Nicaraguenses. Memorias, Congreso Nacional, Impacto de Plaguicidas en Ambiente, Salud, Trabajo y Agricultura, 27–31 October 1997, Managua, Nicaragua. PROMAP—World Bank, pp 183–209

Li YF, McMillan A, Scholtz MT (1996) Global HCH usage with 1° × 1° longitude/latitude resolution. Environ Sci Technol 30:3525–3533

Long ER, MacDonald DD, Smith SL, Calder FD (1995) Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environ Manage 19: 81–97

Lyman WJ (1995) Transport and transformation processes. In: Rand GM (ed) Fundamentals of aquatic toxicology. Taylor & Francis, Washington, DC, pp 449–492

Marcus JM, Renfrow RT (1990) Pesticides and PCBs in South Carolina estuaries. Mar Poll Bull 21:96–99

Miles CJ, Pfeuffer RJ (1997) Pesticides in canals of South Florida. Arch Environ Contam Toxicol 32:337–345

Muir DCG, Grift NP, Lockhart WL, Wilkinson P, Billeck BN, Brunskill GJ (1995) Spatial trends of historical profiles or organochlorine pesticides in Arctic lake sediments. Sci Tot Environ 160/161:447–457

NOAA (1991) Second summary of data on chemical contaminants in sediments from the national status and trends program. NOAA Technical Memorandum NOS OMA 59, Rockville, MD, 29 pp

Noble A (1993) Partition coefficients (n-octanol-water) for pesticides. J Chromatogr 642:3–14

Polania J, Mainardi V (1993) Mangrove forests of Nicaragua. In: Conservation and sustainable utilization of mangrove forests in Latin America and Africa regions. International Society for Mangrove Ecosystems, Technical Report, vol. 2, pp 139–145

Readman JW, Liong Wee Kwong L, Mee LD, Bartocci J, Nilve G, Rodriguez-Solano JA, Gonzalez-Farias F (1992) Persistent organophosphorus pesticides in tropical marine environments. Mar Poll Bull 24:398–402

Rodezno RA (1997) Plaguicidas y salud en Nicaragua. Memorias, Congreso Nacional: Impacto de Plaguicidas en Ambiente, Salud, Trabajo y Agricultura, 27–31 October 1997, Managua, Nicaragua. PROMAP—World Bank, pp 464–482

Sericano JL, Atlas EL, Wade TL, Brooks JM (1990) NOAA's Status and Trends Mussel Watch Programme: chlorinated pesticides and PCBs in oysters (*Crassostrea virginica*) and sediments from the Gulf of Mexico, 1986–1987. Mar Environ Res 29:161–203

Shigenaka G (1990) Chlordane in the marine environment of the United States: review and results from the National Status and Trends Program. NOAA Technical Memorandum NOS OMA 55, Washington, DC, 230 pp

Tardiff RG (1991) Methods to assess adverse effects of pesticides on non-target organisms. SCOPE Report no. 49, John Wiley & Sons, London

Villeneuve J-P, Cattini C (1986) Input of chlorinated hydrocarbons through dry and wet deposition to the western Mediterranean. Chemosphere 15:115–120

Wade TL, Cantillo AY (1994) Use of standards and reference materials in the measurement of chlorinated hydrocarbon residues. NOAA Technical Memorandum NOS ORCA77, Washington DC

WHO (1989) DDT and its derivatives—environmental aspects. Environmental Health Criteria, no. 83, World Health Organization, Geneva

Wolfe NL, Zepp RG, Paris DF, Baughman GL, Hollis RC (1977) Methoxychlor and DDT degradation in water: rates and products. Environ Sci Tech 11:1077–1081