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Toxaphene residues from cotton fields in soils and in the coastal environment of Nicaragua

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Abstract

Toxaphene (camphechlor) was intensively used in the cotton growing fields of Nicaragua for decades with application rates as high as 31 $\text{kg}\,\text{ha}^{-1}$ in 1985. Although the use of this compound has recently been discontinued in the country, its intensive use in the past and its long persistence in soil allowed for the build up of large reservoirs of toxaphene in agriculture soils and a wide dispersal of residues in the environment. Measurements of toxaphene in coastal areas on the coast of the Pacific Ocean show that environmental concentrations are particularly high in the district of Chinandega, the traditional cotton growing region. Toxaphene residues measured in soils attained 44 $\mu\text{g}\,\text{g}^{-1}$ (dry weight) while concentrations in lagoon sediments attained 6.9 $\mu\text{g}\,\text{g}^{-1}$ (dry weight) near the mouth of the rivers flowing across the agricultural region. Measurements in aquatic biota showed concentrations as high as 1.6 $\mu\text{g}\,\text{g}^{-1}$ (dry weight) in the soft tissues of clams. The toxaphene reservoir in soils combined with the obvious persistence of this compound in soils and lagoon sediments allows predicting that toxaphene will remain in the coastal ecosystem at relatively high concentrations for many years. Toxic effects in lagoon fauna are likely to be observed especially in benthic species that may recycle this compound from sediments. Consumption of seafood, in particular of clams (*Anadara* spp.) from the more contaminated areas, may expose the population to unacceptably high intake of toxaphene, 30 $\mu\text{g}\,\text{d}^{-1}$ per person, with the diet.

Keywords: Toxaphene; Tropical coastal lagoons; Bioaccumulation; Dietary intake; Acute toxicity

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1. Introduction

Toxaphene, also known as camphechlor or polychlorinated camphene, is one of the most heavily used pesticides in a global basis, with an estimated usage of 1.33×10^6 tonnes (Voldner and Li, 1995). The production of toxaphene started in the late 40s in the USA and raised from 27 000 tonnes in 1966 to a peak of 55 000 tonnes in 1974. Thereafter, production gradually decreased to 9000 tonnes in 1981 and was finally discontinued in 1982 with the ban on the use of toxaphene in agriculture (Rice and Evans, 1984). In the USA, especially after the ban of DDT in 1972, toxaphene was used to control insects in a variety of crops, but 85% of this chemical was applied to cotton in the Southern part of the USA. According to the strength of emissions and dominant wind circulation,

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toxaphene was transported by atmospheric pathways and deposited everywhere in the North hemisphere (Rice and Evans, 1984; Rapaport and Eisenreich, 1986; Evans et al., 1991; Boer and Wester, 1993). Recent measurements of concentrations in sediment cores from the Arctic Lakes have shown that toxaphene was the major organochlorine pesticide accumulated in lake sediments (Muir et al., 1995). Toxaphene was also used in Europe, and Central and South America.

In 1984 the World Health Organisation (WHO) discouraged the use of this chemical on the basis of potential carcinogenic effects to human beings. Furthermore, the WHO expressed reservations about the safety of this chemical in food, and considered it "a major hazard for aquatic and also some terrestrial species" (WHO, 1984). Despite this, toxaphene was used in some places for as much as another decade (Voldner and Li, 1995).

In Nicaragua toxaphene was applied to cotton growing fields for several decades. Despite being one amongst the "Dirty dozen", a list of persistent chemicals internationally banned for use in agriculture, in 1988 toxaphene was still recommended as a crop protection chemical for cotton plantation in Nicaragua and its use was discontinued only in 1993 (Beck, 1997). Nevertheless, reports had been published on high levels of toxaphene residues in the Lake Xolotlán in the centre of Nicaragua (Calero et al., 1993), in water from wells in the cotton region (Appel, 1991) and in human milk (Boer and Wester, 1993).

The objectives of this work are part of an assessment of the contamination of coastal lagoons on the Pacific coast of Nicaragua by persistent organochlorine pesticides (Carvalho et al., 1997; Carvalho et al., 1999a), and give the first account on toxaphene residues in the coastal and marine environment of the country and on the associated toxic risks.

2. Pesticide use and study area

Although initially imported, toxaphene was produced in Nicaragua in one factory located near Managua since 1974. National production was 9500 tonnes in 1974 and regularly decreased to 290 tonnes in 1989. In 1990 the production of toxaphene ceased. Confirmed by statistics of formulation plants, large stocks of this chemical were used to prepare mixtures of toxaphene with imported DDT, parathion and methyl-parathion for several years (Appel, 1991). The total production of toxaphene in the period 1974–1990 was estimated at about 79 000 tonnes and most of it was used in the country (Rodezno, 1997).

The use of toxaphene in Nicaragua was always closely correlated with cotton production and, still today, the cotton farmers consider toxaphene as the most effective of all pesticides used in cotton protection. The rates of application of toxaphene were as high as 31 kg ha^{-1} in 1985, but with the drop of cotton prices in the international markets in the early 1980s and with the introduction of other pesticides, the use of toxaphene decreased along with the reduction of the area occupied by cotton plantations (Appel, 1991). The cotton growing has always been confined to the districts of Chinandega and León on the Pacific coast. Therefore, all the toxaphene produced in the country was applied in the agriculture soils of this region, 115 000 ha, which accounts for a cumulative application of 560 kg ha^{-1} since 1974.

Such an intensive use of toxaphene has the potential to cause contamination of aquatic ecosystems, in particular coastal lagoons receiving drainage and runoff from the agriculture fields. Several extended lagoon systems exist along the coast of the Pacific, which provide important fishery resources to local communities. Furthermore, shrimp farming in this region is a new and rapidly developing activity that relies on the supply of shrimp larvae from the lagoons and on the quality of lagoon water for successful development. A preliminary screening of contaminants in the Pacific coast of Nicaragua carried out in 1995, had indicated the presence of relatively high levels of toxaphene in the lagoons of the Chinandega district (Carvalho et al., 1997; Carvalho et al., 1999a). A more detailed investigation was thus carried out in this lagoon system in order to determine the magnitude and extent of the contamination by toxaphene residues.

3. Materials and methods

Samples of surface sediments were collected in September 1996 in the coastal lagoons of the district of Chinandega (Fig. 1), using stainless steel sediment grab sampler that penetrates about 10 cm in the sediment. Samples were transferred into hexane-rinsed glass jars, stored in ice-chests and transported within a few hours to the laboratory for deep freezing. Lagoon water samples were drawn directly into 5 l hexane-rinsed brown glass bottles, stored on ice and protected from light. Bottles were transported to the laboratory, kept in the refrigerator and, in the following morning, the water samples were filtered through pre-weighted and 400 °C pre-combusted microfiber glass GF/C filters. Filters with suspended matter were freeze-dried prior to analyses. Samples of biota, including sediment dwelling clams (*Anadara* spp.) and fishes (*Mugil cephalus*, *Lutjanus* sp.) were collected with the collaboration of local fishermen, and transported on ice to the laboratory for further processing. Three grab samples of surface soils were collected in farms around the Estero Naranjo, district of Chinandega (Fig. 1), in the traditional region of cotton growing. These soils were currently in use for growing sugar cane, sesame and cotton.

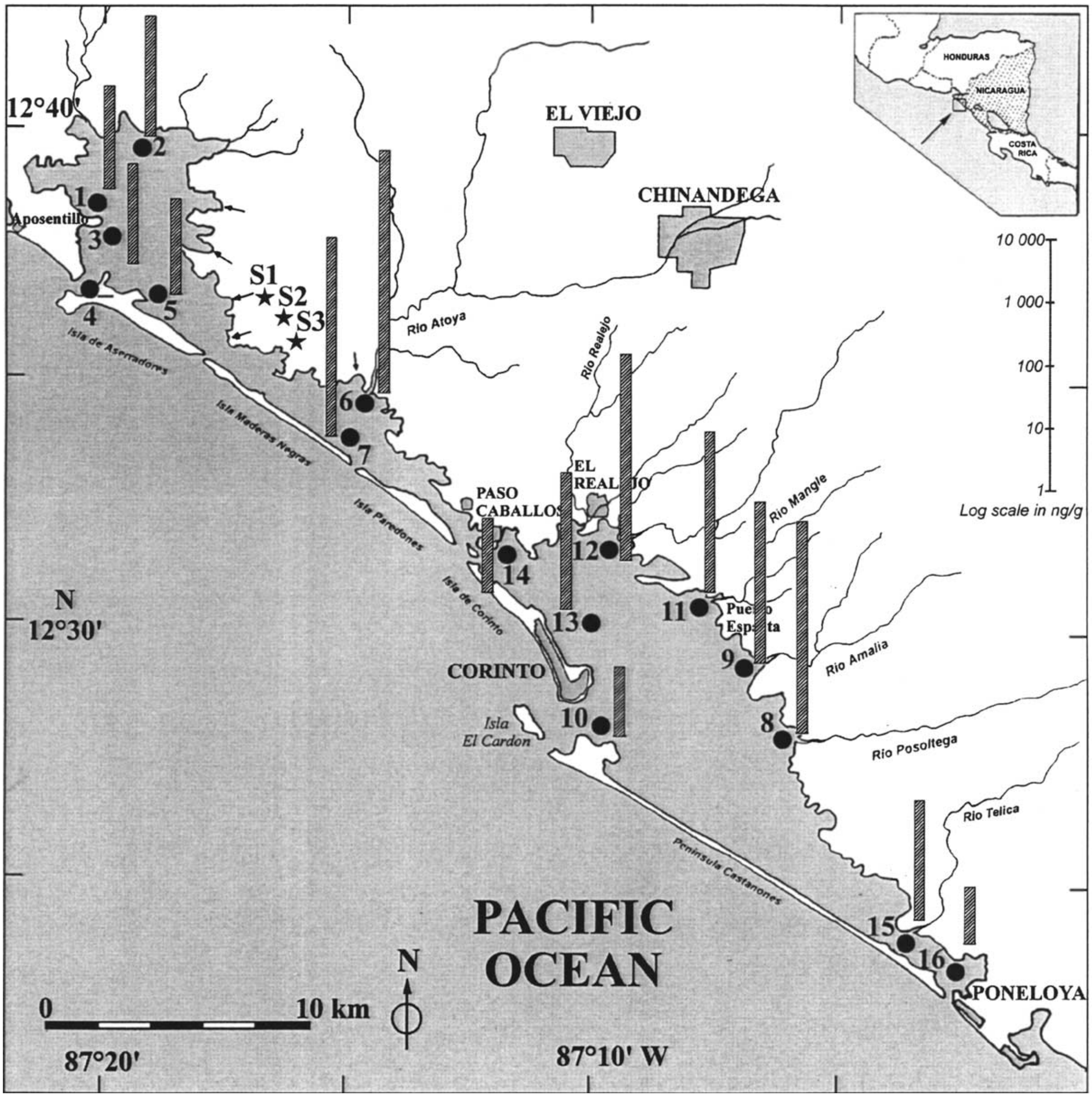

Fig. 1. Coastal lagoon system of the district of Chinandega. Concentrations of toxaphene in lagoon sediments (ng g^{-1} dry weight), September 1996, are indicated with bars. Solid circles: lagoon sediment stations; solid stars: soil sample stations.

Samples were split for analyses to be carried out by the Universidad Nacional Autonoma de Nicaragua—Centro para la Investigación en Recursos Acuaticos (UNAN-CIRA) and the International Atomic Energy Agency—Marine Environment Laboratory (IAEA-MEL). Several amongst them were used for replicate analyses by both laboratories in order to ensure comparability of the results. Organochlorine compounds were analysed following the standard operating procedures (SOPs) used at the IAEA-MEL (UNEP/IOC/IAEA/FAO, 1990; UNEP/FAO/IAEA/IOC, 1991; UNEP/IOC/IAEA, in press). These SOPs include the concurrent analyses of reference materials in a matrix similar to those of the samples, as well as the regular participation in intercomparison exercises (Carvalho et al., 1999b; Villeneuve et al., 2000).

Toxaphene is a complex mixture of over 170 chlorinated compounds and its analysis is delicate (WHO, 1984; Boer and Wester, 1993). The freeze-dried suspended matter (filters), sediments (10 g), and biota (5 g) were spiked with 25 ng of PCB 29 (2,4,5,trichlorobiphenyl) and 15 ng of ε-HCH. Spiked samples were Soxhlet extracted for 8 h with hexane and reextracted with methylene chloride for 8 h. The combined extract was concentrated to a volume of 10 ml in a rotary evaporator, transferred to a Kuderna-Danish tube and further evaporated to 5–6 ml under a gentle stream of nitrogen. Elemental sulfur was removed from the extracts by mercury treatment prior to adsorption chromatography. The free-sulphur organic extracts were transferred on top of a 50 ml glass column (6 mm internal diameter) packed with 14 g of 0.5% desactivated Florisil (activation at 130 °C for 8 h) and topped with 1 g of 400 °C pre-combusted sodium sulphate. The following fractions were collected by elution with solvents of increasing polarity: F-I, 70 ml of *n*-hexane (PCBs, 4,4′-DDE, HCB); F-II, 50 ml of *n*-hexane/methylene chloride (70/30) (toxaphene, 4,4-DDD, 2,4′-DDD, 4,4′-DDT′, 2,4′-DDT, chlordane, HCHs), F-III, 40 ml of methylene chloride (dieldrin, endrin, α-endosulfan, β-endosulfan and endosulfan sulphate). The fractions collected are concentrated down to appropriate volumes (0.5 ml) before injection into the GC.

The quantification of toxaphene was performed by capillary gas chromatography coupled to an electron capture detector (cCG-ECD) with a Hewlett-Packard 5890 Series II instrument. The injector was in the splitless mode and the injector and detector temperature were set at 250 and 300 °C, respectively. The column was fused silica SE-54, 50 m length, 0.2 mm internal diameter and 0.32 μm film thickness. The temperature programming was 70 °C for 1 min, then raised at 3 °C min^{-1} to 280 °C, holding the final temperature for 10 min. The carrier gas was nitrogen at 1 ml min^{-1}. External quantification was obtained by taking into account the relative peak areas of corresponding peaks in-sample and toxaphene technical formulation whose retention times match under identical chromatographic conditions. At it is shown in Fig. 2, the peak pattern in these environmental samples matches pretty well to toxaphene mixture.

Recovery assays for the overall procedure were carried out with spiked sediments. Recoveries of toxaphene were higher than 70% and the RSD below 15% ($n = 5$). Procedure blanks were processed in every set of samples. Method detection limit was determined at 2 ng g^{-1} for sediment and of 9 ng g^{-1} for biota.

The confirmation of toxaphene was performed by negative ion chemical ionisation (NICI) GC-MS in a HP-5890 Engine B. The temperature programming was 60 °C for 1 min, 60–100 °C at 10 °C min^{-1} and then from 100 to 280 °C at 4 °C min^{-1}, holding the final temperature for 10 min. The ion source and mass analyser were held at 180 and 100 °C. The interface was set at 280 °C. Methane was used as reagent gas at an analyser pressure of 1.8 Torr. Masses from 34 to 550 were scanned each 0.8 s. He as carrier gas at 1.5 ml min^{-1} was used. Ion chromatograms obtained are exemplified in Fig. 3. Quantification was made against pure chemical standards from SUPELCO Company.

4. Results and discussion

Analyses of organochlorine compounds in lagoon sediments showed the presence of a wide variety of pesticides including hexachlorobenzene (HCB), α- and β-hexachlorocyclohexane (HCH), lindane, dichloro-diphenyl-trichloroethane (DDT) and DDT metabolites (DDTs), heptachlor, aldrin, dieldrin, endrin, endosulfan, chlordane and toxaphene. In general, the concentrations of most of these compounds were low, below 5 ng g^{-1} dry weight, while toxaphene concentrations were relatively high attaining as much as 6900 ng g^{-1} dry weight (Table 1). Results of analyses of soils from the Chinandega district show also very high concentrations of toxaphene, 17–44 μg g^{-1} dry weight (Table 1). Concentrations in soils are in the average 40 times higher than concentrations measured in the lagoon sediments. Distribution of toxaphene residues in sediments (Table 2 and Fig. 1) indicates lower contamination of Northwest and Southeast parts of the lagoon system, and much higher contamination of the more central lagoon channels (*esteros*, station 6). These *esteros* receive the discharge of the rivers Atoya, El Realejo, Posoltega, Amalia and Telica that flow across the traditional area of cotton growing. In those *esteros*, the highest concentrations of toxaphene were measured at the mouth of the rivers (stations 6, 7, 8 and 12), while the lower concentrations were measured at the openings of the lagoon system to the sea (stations 10, 14, 16), corresponding to dilution of the chemicals transported by rivers with sea water and marine sediments (Fig. 1).

Similar trends in the distribution of toxaphene were also detected in the analyses of suspended matter (Table 2). Statistical correlation between toxaphene concentrations in bottom sediments and suspended matter ($R^2 = 0.95$, $p < 0.001$, after removing station 7 as an outlier) suggests that suspended matter is mostly resuspended bottom sediment with some fresh riverborne toxaphene input. Station 7 in particular, has a much higher toxaphene concentration indicating a large input from the discharge of River Atoya. These samples were collected after a week of heavy rainfall and of high river flow, likely transporting toxaphene washed out from agriculture soils. Toxaphene concentrations in suspended matter are also generally higher than in bulk bottom sediments most likely due to the finer grain size of particulate matter in suspension.

Toxaphene in soft tissues of clams (*Anadara* spp.) reflect the distribution of this compound in the lagoon sediments as indicated by the statistically significant positive correlation ($R^2 = 0.79$, $p < 0.007$) between concentrations of toxaphene in sediments and in clams from the same sampling stations (Table 2). This is in agreement with the predictable partitioning of this lipophilic compound between the organic matter in the

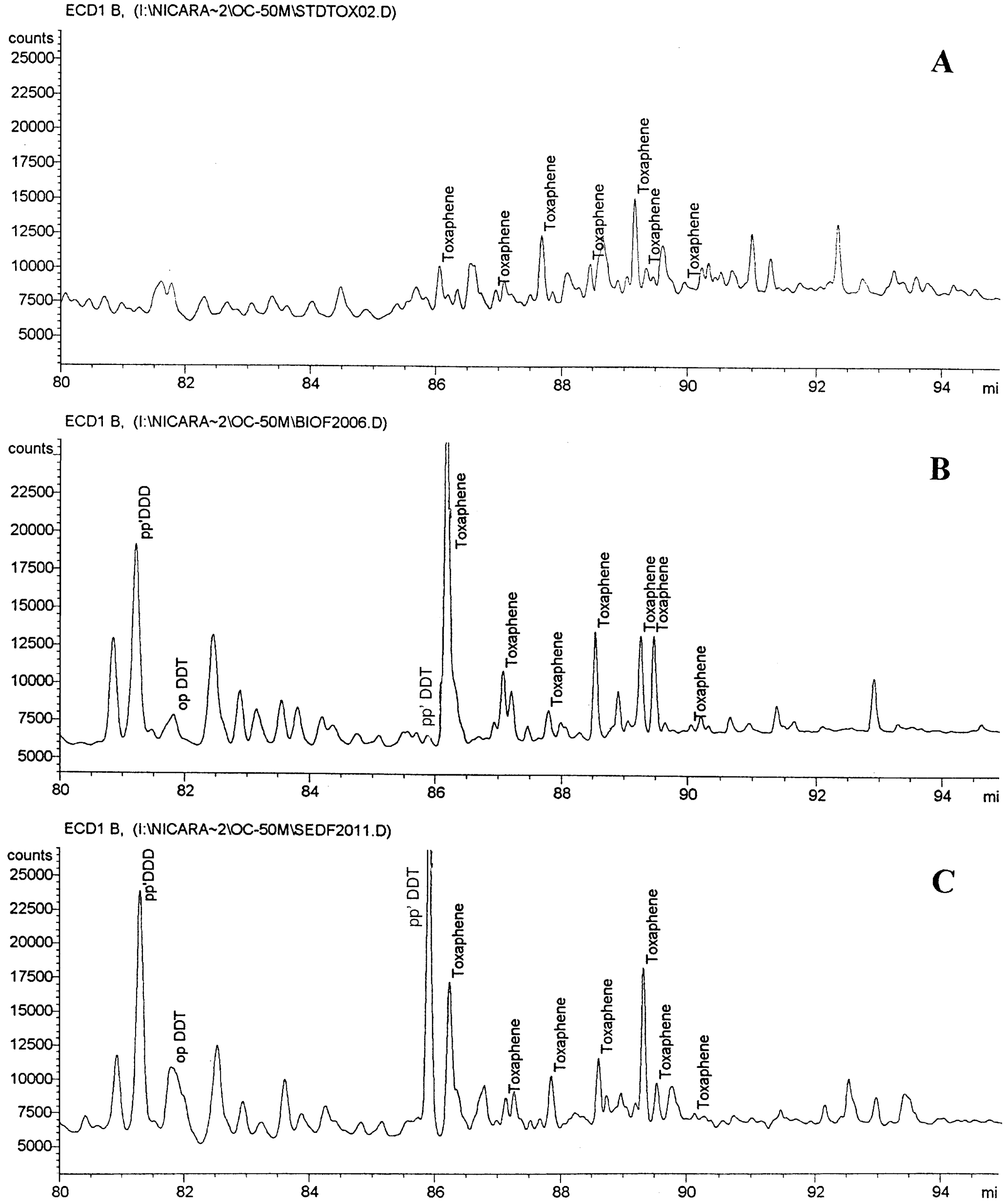

Fig. 2. Chromatograms obtained by gas chromatography with electron capture detector. (A) Technical toxaphene produced in Nicaragua, (B) biota sample and (C) sediment sample collected in the lagoons.

sediments and animal fat tissue (Meador et al., 1997). The higher concentrations, 1600 and 1200 ng g^{-1} dry weight were measured in clams collected near the rivers Atoya and El Realejo. Clams collected in the Northwest part of the lagoon system, near Aposentillo, and in the Southeast part near Poneloya, contained comparatively lower concentrations of toxaphene, in the range of 60–440 ng g^{-1} dry weight (Table 2). Concentrations of toxaphene in the muscle tissue of the stripped mullet (*Mugil cephalus*) and of the grouper (*Lutjanus* sp.) from the *estero* Naranjo, were at 485 and 240 ng g^{-1} dry weight, respectively, and are of the same order of magnitude as in clams (Table 2).

Concentrations of toxaphene in the dissolved phase of the lagoon water were not systematically determined. However, these concentrations can approximately be estimated using the value of octanol–water partition coefficient (K_{ow}) reported in the literature, $\log K_{ow} = 4.8$ (Noble, 1993), combined with toxaphene concentrations measured in the lagoon sediments and suspended matter

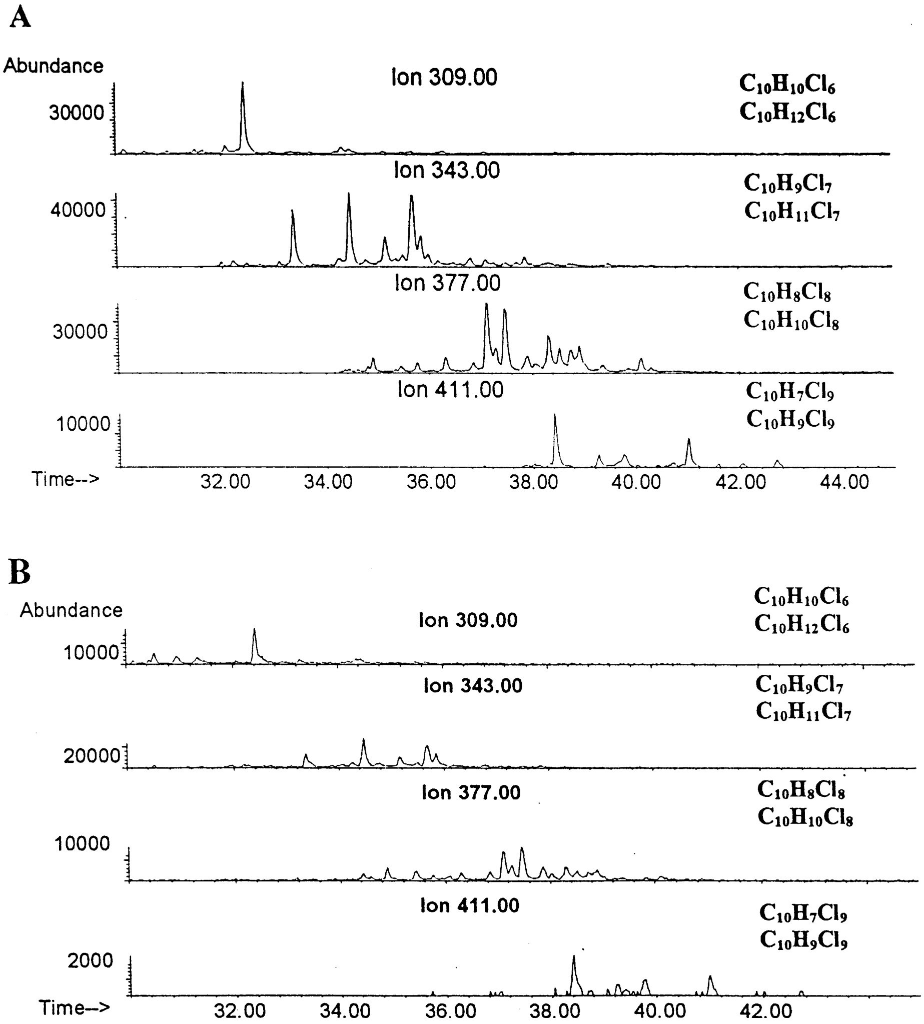

Fig. 3. Mass fragmentogrammes of the corresponding molecular ions of polychlorinated camphene compounds by GC-MS-NICI: M/Z: 309, homologous of 6 chlorine atoms; 343, homologous of 7 chlorine atoms; 377, homologous of 8 chlorine atoms; 411, homologous of 9 chlorine atoms. (A) Dissolved water sample from station no. 6 and (B) toxaphene mixture.

(Table 2) and using known sorption equilibrium models (Lyman, 1995). According to these estimates, and assuming 5% organic carbon in the suspended matter, the concentrations of toxaphene in water may have attained 21 $\mu g\,l^{-1}$ near the mouth of the river Atoya. However, concentration values elsewhere in the lagoon were probably much lower, 0.1–0.7 $\mu g\,l^{-1}$. The highest concentration computed is compatible with the water solubility of toxaphene, 0.55 $mg\,l^{-1}$ (The Agrochemicals Handbook, 1991).

Lethal acute toxicity (96 h-LC_{50}) of toxaphene has been reported at 1.3 $\mu g\,l^{-1}$ for planktonic crustaceans (*Gammarus* sp.), 1.4–4.4 $\mu g\,l^{-1}$ for several shrimp species (*Penaeus* spp.) and 3.2 $\mu g\,l^{-1}$ for fish (*Mugil cephalus*) (Mayer, 1987). Molluscs are more resistant to acute toxic effects by toxaphene and a LC_{50} value of 740 $\mu g\,l^{-1}$ was reported for freshwater mussels (*Anodonta imbecilis*) (Keller, 1993). It is worth mentioning that LC_{50} values for freshwater shrimp taken from an area that had been regularly treated for cotton pests was 10 times that of shrimp taken from a wildlife reserve, which indicates acquired tolerance to the chemical (Naqvi and Ferguson, 1970). The same was observed with freshwater cyclopoid copepods (WHO, 1984). Given the LC_{50} values, the concentrations of toxaphene in the lagoon water are likely to still attain acute toxic levels for the lagoon fauna in some areas. This may occur, in particular, with high river flow that, in spite of the currently lower application rates of toxaphene in agriculture, will transport leaching from agriculture soils.

Table 1
Concentration of organochlorine compounds (ng g^{-1} dry weight) in surface sediments of the coastal lagoon system Aposentillo-Poneloya and soil samples, district of Chinandega

Compounds	Lagoon sediments			Soil samples		
	Station 6	Station 8	Station 9	S1	S2	S3
EOM (mg/g)	0.94	0.06	0.53	0.10	0.06	0.04
HCB	0.10	0.01	0.04	0.04	0.03	0.02
α-HCH	0.16	0.13	0.04	0.02	0.43	0.18
β-HCH	0.30	0.25	0.10	0.05	1.8	0.26
Lindane	0.85	0.30	0.10	0.05	0.23	0.36
pp′ DDE	92	22	72	280	350	120
pp′ DDD	110	27	16	14	59	4.7
pp′ DDT	100	34	11	100	360	41
op DDE	0.37	0.26	0.90	1.7	4.0	1.3
op DDD	17	4.9	1.5	nd	nd	nd
op DDT	1.3	0.46	0.11	80	200	24
DDMU	0.40	0.36	1.3	1.8	3.8	1.6
Heptachlor	nd	0.02	nd	0.12	0.09	0.04
Aldrin	nd	nd	nd	0.16	0.11	0.09
Dieldrin	3.1	0.75	0.15	4.0	12	3.7
Endrin	3.2	1.2	0.77	6.3	8.6	3.4
α-endosulfan	0.17	0.06	0.01	0.08	0.62	500
β-endosulfan	0.21	0.05	nd	nd	0.82	83
Endos.-sulphate	0.29	0.17	0.02	nd	nd	68
Cis-Chlordane	nd	2.8	nd	6.3	2.7	2.2
Trans-Chlordane	3.4	0.62	0.91	0.78	0.36	2.3
Nonachlor	4.7	1.8	0.39	4.0	4.1	1.0
Toxaphene	6900	2300	370	38 000	44 000	17 000
Aroclor 1254	32	6.8	1.8	27	9.1	7.2
Aroclor 1260	29	nd	nd	nd	nd	nd

For location of the sampling stations see Fig. 1. EOM = hexane extractable organic matter. nd: not detected.

Table 2
Toxaphene concentrations (ng g^{-1} dry weight) in samples collected in the coastal lagoon system of the district of Chinandega

Station no.	Bottom sediment	Suspended matter	Clams[a] soft tissues	Fish muscle
1	42	330	67	
2	8	160		
3	39	170		
4		110		
5	33	220	440, 510	485[b], 240[c]
6	6900	11 200		
7	1420	17 500	1600	
8	2300	4300		
9	370	1270		
10	13	nd		
11	355	2060	600	
12	1900	3300	1200	
13	150	590		
14	15	250		
15	75		320	
16	8		325	

nd: not detected.

[a] Black clams, *Anadara* spp.

[b] Stripped mullet, *Mugil cephalus.*

[c] Grouper, *Lutjanus* sp.

Sub-lethal chronic effects of toxaphene described in the literature include effects on yearling oysters (inhibition of shell deposition at 16 μg l^{-1} toxaphene level and, thus, preventing oyster growth) and the “broken backbone syndrome" observed in fish at levels as low as 37 ng$\,l^{-1}$ (Merhle and Mayer, 1977; Mayer, 1987). Such biological effects were not investigated in the coastal lagoons of Nicaragua, but it seems likely that they may occur in the more contaminated areas of the lagoon system.

The high concentrations of toxaphene in edible species of the lagoon fauna, in particular the clams (*Anadara* spp.) and the mullets (*Mugil cephalus*) which are very common components of the diet of local communities, may also represent an additional route of exposure for consumers of aquatic wildlife, including humans. Concentrations of toxaphene in the soft tissues of clams attained 1600 ng$\,g^{-1}$ dry weight (about 320 ng$\,g^{-1}$ wet weight) and 485 ng$\,g^{-1}$ dry weight in fish filet (about 97 ng$\,g^{-1}$ wet weight). These values exceed or are at the limit of recommended safe level for the health of fish-eating wildlife of 100 ng$\,g^{-1}$ wet weight, set by the USA National Academy of Sciences (NAS, 1973) and of 6.3 ng$\,g^{-1}$ wet weight set by Canada (Environment Canada, 2001). Therefore, current levels may put at risk wildlife species through food chain transfer of toxaphene residues.

Taking a different approach for humans, a person ingesting 100 g of clams per day (corresponding to 5–6 clams) would intake about 30 μg of toxaphene per day. Similarly, a person consuming 100 g of lagoon fish filet (*Mugil*) per day would ingest 10 μg of toxaphene per day. Assuming that the carcinogenic power of toxaphene is identical to that of DDT/DDE—although this has not been demonstrated—the carcinogenic dose for a lifetime exposure would be 2.2 μg$\,d^{-1}$ (Ames et al., 1987). This dose may, thus, be largely exceeded in the local populations living on lagoon fishery resources.

One may also use as a reference the fish advisories adopted by several states in USA and the USA Environmental Protection Agency (USEPA). The USEPA has classified toxaphene as a probable human carcinogen. The USEPA recommended monthly consumption limits for toxaphene for fish consumers, is one fish meal of 227 grammes (wet weight) with a maximum fish tissue concentration of 88 ng$\,g^{-1}$ (wet weight). This corresponds to the ingestion of 656 μg toxaphene per month (averaging 22 μg toxaphene per day) based on a cancer health endpoint (EPA, 1999). This consumption limit would be depassed in Chinandega with one meal of clams or two meals of fish in a month.

Recent analysis of toxaphene and other organochlorine compounds in humans from the valley of Atoya river, Nicaragua, including analyses of abdominal fat and breast-milk of lactant women, confirmed the presence of worrisome levels of DDT residues but has shown no accumulation of toxaphene (Cruz-Granja et al., 1997; Lacayo-Romero et al., 2000). This failure to demonstrate accumulation of toxaphene in adipose tissues, reported also by WHO (1984), likely comes from a different metabolism of toxaphene when compared with DDT and other organochlorine compounds, although difficulties with the analysis of toxaphene may be recognized also (Stern et al., 1992). Nevertheless, the apparent absence of a body depot of toxaphene does not imply that exposure and effects do not take place.

Although there is no conclusive epidemiological study available for toxaphene in humans, the available data indicate that following oral administration toxaphene resulted in incidence of hepatocellular carcinomas and neoplasic nodules in mice and thyroid tumours in rats. Furthermore, toxaphene was observed to have estrogenic effects on human breast cancer (EPA, 1999).

The current levels of toxaphene in aquatic biota of these lagoons may, therefore, represent a serious health hazard to human consumers.

5. Conclusions

The measurements of toxaphene in bottom sediments and suspended matter of the coastal lagoons of the district of Chinandega showed that levels of residues are generally high. Toxaphene residues in these lagoons originate in the heavy use of this pesticide for several decades in cotton plantations. Although the use of toxaphene has been banned in Nicaragua in the early 90s, the high concentrations existing in the agricultural soils still allow today for leaching, transport and discharge of significant amounts of toxaphene with the surface runoff and river discharges into the lagoons. The extent of contamination and the high concentrations of toxaphene in lagoon sediments further indicate a long persistence of the compound in this coastal system and do not confirm early reports on very rapid chemical degradation of toxaphene in estuarine mud flats (Williams and Bidleman, 1978). Therefore, the reservoir of toxaphene in lagoon sediments and in soils associated with its long environmental half-life ($T_{1/2}$), reported up to 14 years in soils (The Agrochemicals Handbook, 1991), will result in a slow decrease of toxaphene levels in the lagoon system with time.

There are no simple practical actions that could help mitigate the current levels of toxaphene in lagoon sediments and biota. However, protection and preservation of the wetlands and mangrove forests surrounding the lagoons could reduce the discharge of residues from agriculture fields by surface runoff into the lagoons (Carvalho et al., 2002).

In the coastal lagoon system, the higher concentrations of toxaphene were systematically measured at the mouth of the rivers and lower concentrations were measured at the sea entrances of the lagoons. Concentrations measured in biota, particularly in clams, follow the same pattern of distribution and, thus, the more heavily contaminated clams are from the more productive beds at the mouth of the rivers.

With the knowledge currently available, it seems likely that the regular ingestion of clams from the more contaminated areas may be an additional route of exposure for humans to toxaphene residues at intake rates which are of much health concern.

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