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CHLORINATED HYDROCARBON (HCB, DDTs AND PCBs) LEVELS IN CETACEANS STRANDED ALONG THE ITALIAN COASTS: AN OVERVIEW

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Abstract. Concentrations of HCB, DDTs and PCBs in the tissues and organs of cetaceans (*Stenella coeruleoalba, Tursiops truncatus, Balaenoptera physalus, Steno bredanensis, Grampus griseus* and *Globicephala melaena*) stranded along the Italian coasts in the period 1987–1993 are reported. The values are compared between species and between specimens of the same species. Chlorinated hydrocarbon (CH) levels were found to increase in relation to the quantity and type of lipids in each tissue and organ. Differences in accumulation encountered in the different species are principally due to different feeding habitats. Remarkable differences found between males and females of each species confirm that during gestation and lactation, females undergo disintoxication by passing much of their total burden of CHs to their young.

Key words: chlorinated hydrocarbons, pollution, cetaceans, marine mammals

1. Introduction

Interest in cetaceans has mainly been related to their economic value. They are actively marketed live for the tourist industry and dead for the food, cosmetic and chemical industries. Cetaceans are not hunted in the Mediterranean Sea and there has never been a tradition of whale hunting in Italy (Cagnolaro et al., 1983). Trawling for tuna, swordfish and albacore causes the death by suffocation of many cetaceans, especially dolphins (Di Natale, 1992). Cetacean populations living in this environment are also jeopardized by the rapid increase in levels of man-made chemicals in the marine environment in the second half of this century (Geyer et al., 1984). The case of chlorinated hydrocarbons (HCB, DDTs and PCBs) is one example. These pollutants are initially taken up by organisms at the very bottom of the food chain and are found in increasing concentrations in the tissues and organs of animals at higher levels. At the top of the food chain, cetaceans are among the animals most exposed to their toxic effects. These marine mammals have been found to have an extremely low capacity to metabolize CHs compared to birds and land mammals (Tanabe et al., 1988; Fossi et al., 1992). Since they do not have sweat and sebaceous glands, fur or active blood-water exchange via gills (as in fishes), they can be regarded as closed systems in which contaminants can act practically without opposition. There is as yet no evidence that pollutants are causing the death of marine mammals, however CHs are known to cause immune and reproductive dysfunction (Helle et al., 1976; De Long et al., 1979; Fuller and Hobson, 1986; Reijnders, 1986; Brouwer et al., 1989).

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Figure 1. Map of the Mediterranean Sea showing stranding sites (*).

Species of cetaceans with limited areas of distribution reflect contaminant levels in the areas where they feed. They can therefore be regarded as good environmental indicators.

In this paper, we report the distribution of PCB congeners and organochlorine pesticides in the organs and tissues of cetaceans stranded along the Italian coasts between 1987 and 1993. The data is then compared in relation to tissue, species, sex, locality and year of stranding.

2. Materials and Methods

Most of the animals analysed were found dead along the Italian coasts in the period 1987–1993 (Figure 1). Collection and transport of the carcasses was authorized and supervised by the Centro Studi Cetacei (Milan). The organs and tissues used for ecotoxicological studies were mainly of two species of delphinids, *Stenella coeruleoalba* (Meyen, 1833) (89 specimens) and *Tursiops truncatus* (Montagu, 1821) (14 specimens). Two individuals of *Balaenoptera physalus* (Linnaeus, 1758), one of *Grampus griseus* (Cuvier, 1812), one of *Globicephala melaena* (Traill, 1809) and one of *Steno bredanensis* (Lesson, 1828) were also sampled. When possible, we sampled blubber, muscle, melon, brain, heart, liver and kidney tissue. In one specimen, the testicles, and in another, the mammary glands and milk, were also sampled.

These organs and tissues were in different states of conservation depending on how long the animals had been dead. In any case, all samples were suitable for analysis. Samples were than frozen and stored from –20 ° to –30 °C. Before toxicological analysis, about 20 g of tissue was lyophilized in an Edwards freeze drier for 2–3 days, depending on its water content. To calculate water content, a sample of about 5 g was placed in an oven at 110 °C for 24 h. The rest was kept in the freezer until analysis.

The percentage water content in the various tissues was as follows:

% Water content	Liver	Muscle	Heart	Kidney	Brain	Melon	Blubber
	(n = 5)						
Mean	78.2	72.3	74.6	79.9	79.1	44.0	35.0
S.D.	7.8	9.7	5.5	5.5	5.8	27.8	22.3

Whatman cellulose thimbles (i.d. 25 mm, e.d. 27 mm, length 100 mm) to be used for extraction of the samples were preheated for about 30 min to 110 °C and preextracted for 9 h in a Soxhlet apparatus with n-hexane specific for the pesticides, in order to remove any organochlorine contamination. Aliquots of 1–1.5 g of freeze dried material were extracted with n-hexane in the thimbles in a Soxhlet apparatus for 9 h. The samples were then purified with sulphuric acid (Murphy, 1972) to obtain a first lipid sedimentation. The extract then underwent liquid chromatography on a column containing Florisil that had been dried for 1 h in an oven at 110 °C. This further purified the apolar phase of lipids that could not be saponified, such as steroids like cholesterol.

The analytical method used was high resolution capillary gas chromatography with a 63Ni electron capture detector and an SBP–5 bonded phase capillary column (30 m long, 0.2 mm i.d.). The carrier gas was N_2 with a head pressure of 15.5 psi (splitting ratio 50/1). The scavenger gas was argon/methane (95/5) at 40 ml/min. Oven temperature was 100 °C for 10 min, after which it was increased to 280 °C at 5 °C/min. Injector and detector temperatures were 200 and 280 °C respectively.

A mixture of specific isomers was used to calibrate the system, evaluate recovery and confirm the results, which were expressed in ng/g or μg/g dry weight (dry wt.). Recoveries were calculated by adding known quantities of standard to homogeneous replicates of the same sample. Recovery varied from a minimum of 85% in blubber to a maximum of 95% in kidney. The blank was evaluated by extracting an empty thimble once every 11 samples. The precision of the method was measured on five homogeneous replicates, calculating the coefficient of variation of the results obtained. It was less than 9% for all compounds analysed.

To ensure accuracy, intercalibration exercises were performed with appropriate standards. Detection limits were 0.001 ppb for HCB. Since the concentrations of CHs in most samples was above 1 ppb, decimals have been omitted from the tables. By this method we were able to detect HCB, op'DDT and pp'DDT and their metabolites (pp' and op'DDD, pp' and op'DDE) and to identify 30 PCB congeners

Table I
IUPAC number and structure of the main PCB congeners detected in all samples

IUPAC number	Structure	IUPAC number	Structure
Pentachlorobiphenyls		Heptachlorobiphenyls	
95	22’35’6	170	22’33’44’5
99	22’44’5	171	22’33’44’6
101	22’455’	172	22’334’55’
118	23’44’5	174	22’334’56’
		177	22’33’4’56
Hexachlorobiphenyls		178	22’33’55’6
		180	22’344’55’
128	22’33’44’	183	22’344’5’6
135	22’33’56’	187	22’34’55’6
138	22’344’5’		
141	22’3455’	Octachlorobiphenyls	
144	22’345’6		
146	22’34’55’	194	22’33’44’55’
149	22’34’5’6	195	22’33’44’56
151	22’355’6	196	22’33’44’5’6
153	22’44’55’	199	22’33’4566’
156	233’44’5	201	22’33’4’55’6
		202	22’33’55’66’
		Nonachlorobiphenyls	
		206	22’33’44’55’6

(Table I). The congeners constituted 80% of the total peak area of PCBs in all tissues (Figure 2).

The data was processed by summary statistics and ANOVA using Statgraphics software (Statistical Graphics Corp.). The parameters considered were site of stranding, length, sex and year of stranding. The statistical analysis was limited by the small number of samples: for example, liver was obtained from 67 striped dolphins but kidney from only nine specimens of this species, and the sex of six of the dolphins was not determined.

3. Results and Discussion

The contaminants of man-made origin analysed in this study are lipophilic compounds. It is therefore essential to calculate the lipid content of all samples, expressed as extracted organic material (EOM%). We calculated the mean and

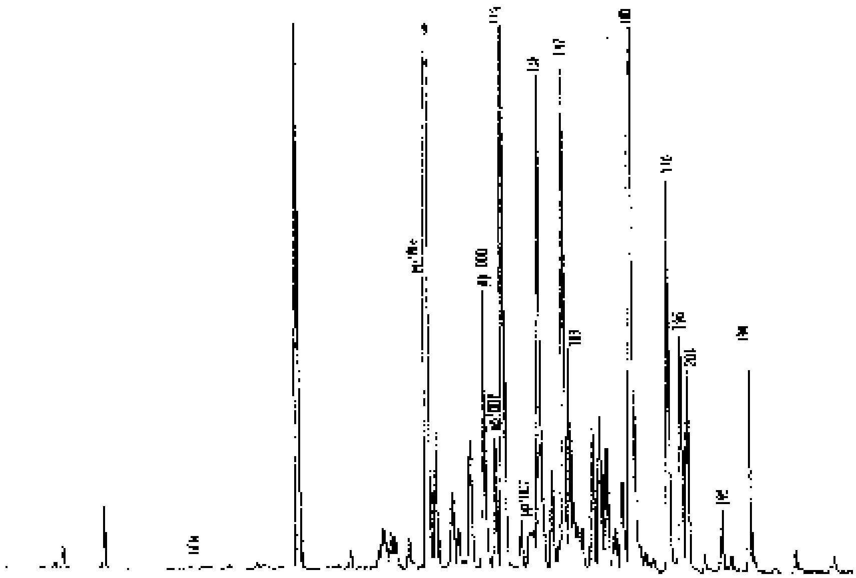

Figure 2. Capillary column ECD chromatogram of the muscle of *Stenella coeruleoalba* (for PCBs, IUPAC numbers are indicated).

standard deviation of this value for each tissue and organ of each species (Table II). The lipid content of the blubber of most specimens was similar to that found in biopsy samples of blubber of presumably healthy cetaceans in transit in Italian waters (Marsili and Focardi, 1996). Similar values have also been found in blubber of marine mammals by other authors (Henry and Best, 1983; Martineau et al., 1987; Geraci, 1989). The levels of lipids found in the blubber of the stranded specimens show that their nutritional status was presumably quite good as they had not metabolized any of their lipid reserves. Another factor that influences data interpretation is the state of conservation of stranded specimens. This depends on how long they had been dead before samples were obtained. Significant losses ($p<0.001$) of CHs have been reported in relation to the state of putrefaction of specimens (Borrell and Aguilar, 1990).

3.1. CHLORINATED HYDROCARBONS IN *STENELLA COERULEOALBA*

Table III shows the parameters of the stranded specimens of *S. coeruleoalba* used in this study. All 89 striped dolphins contained detectable levels of CHs in most tissues. The first approach to data processing was to separate the results of the various organs and tissues and the data according to sex (Table IV). The two tissues with the highest levels of CHs were melon tissue and blubber. In general the pattern of contaminants is known to be related to the lipid content of the various compartments, expressed as EOM%. For DDTs and PCBs, the geometric

Table II
Percentage of extracted organic material (EOM%) in organs and tissues of the various species of cetaceans

Species	Samples (no.)	EOM% (S.D.)
Stenella coeruleoalba	Melon (31)	91 (9)
	Blubber (64)	74 (20)
	Liver (67)	23 (16)
	Muscle (59)	8 (5)
	Brain (27)	42 (9)
	Kidney (9)	19 (12)
	Heart (10)	13 (5)
Tursiops truncatus	Melon (2)	90 (11)
	Blubber (8)	80 (7)
	Liver (13)	21 (13)
	Muscle (12)	16 (9)
	Brain (2)	39 (5)
	Kidney (3)	27 (4)
	Heart (4)	25 (11)
	Milk (1)	32
Balaenoptera physalus	Blubber (2)	60 (52)
	Liver (2)	12 (3)
	Muscle (1)	8
	Kidney (1)	9
Grampus griseus	Melon (1)	90
	Blubber (1)	71
	Liver (1)	10
	Muscle (1)	3
	Kidney (1)	5
	Heart (1)	2
	Testicle (1)	9
Steno bredanensis	Blubber (1)	30
	Liver (1)	14
	Musele (1)	7
	Kidney (1)	18
Globicephala melaena	Melon (1)	91
	Blubber (1)	91
	Liver (1)	3
	Muscle (1)	3
	Kidney (1)	6

Table III
Details of stranded *Stenella coeruleoalba*

ID no.	Sex	Length (cm)	Weight (kg)	Sea	Year
DOO1	M	175	51	Ligurian	1988
DOO2	F	198	68	Ligurian	1988
DOO3	F	179	51	Ligurian	1988
DOO4	M	159	38	Ligurian	1988
DOO5	F	110	19	Ligurian	1988
DOO6	M	198	N.D.	Ligurian	1988
DOO7	F	185	74	Ligurian	1988
DOO8	M	188	91	Ligurian	1988
DOO9	F	108	17	Ligurian	1988
SM-00	M	183	62	Ligurian	1987
SM-1	M	175	N.D.	Tyrrhenian 1	1989
SM-2	M	210	N.D.	Tyrrhenian 1	1989
SM-3	M	192	N.D.	Tyrrhenian 1	1988
S-6	N.D.	154	N.D.	Tyrrhenian 1	1988
M-23	M	196	N.D.	Tyrrhenian 2	1989
SM-4	M	202	N.D.	Tyrrhenian 2	1988
S-5	F	190	N.D.	Tyrrhenian 2	1988
M-20	M	191	N.D.	Tyrrhenian 2	1988
S-7	F	215	N.D.	Tyrrhenian 2	1989
S-8	F	168	N.D.	Tyrrhenian 2	1988
SM-9	M	194	N.D.	Tyrrhenian 2	1988
S-15	F	115	N.D.	Tyrrhenian 2	1988
S-10	M	158	43	Tyrrhenian 2	1988
6336	M	184	N.D.	Ligurian	1990
6337	M	189	67	Ligurian	1990
6338	F	182	58	Ligurian	1990
6339	M	187	61	Ligurian	1990
6340	M	205	61	Ligurian	1990
6341	M	174	51	Ligurian	1990
6342	M	173	63	Ligurian	1990
6343	M	187	61	Ligurian	1990
6144	M	193	N.D.	Ligurian	1990
6145	M	176	N.D.	Ligurian	1990
6146	F	183	N.D.	Ligurian	1990
6133	F	201	88	Ligurian	1990
6134	M	174	48	Ligurian	1990
6148	M	210	N.D.	Ligurian	1990
6147	M	200	N.D.	Ligurian	1990
27/90	M	215	N.D.	Tyrrhenian 1	1990
28/90	M	166	N.D.	Tyrrhenian 1	1990

Table III
Continued

ID no.	Sex	Length (cm)	Weight (kg)	Sea	Year
10/91	F	128	N.D.	Tyrrhenian 1	1991
12/91	M	110	N.D.	Tyrrhenian 1	1991
14/91	M	122	N.D.	Tyrrhenian 1	1991
7/92	F	116	N.D.	Tyrrhenian 1	1992
20/92	F	198	N.D.	Tyrrhenian 1	1992
A6	F	195	N.D.	Adriatic 2	1991
A7	M	198	N.D.	Ionian 1	1991
A8	N.D.	200	150	Ionian 1	1991
A9	F	180	N.D.	Ionian 1	1991
A12	F	190	N.D.	Ionian 1	1991
A13	M	195	N.D.	Ionian 1	1991
A14	F	190	N.D.	Adriatic 2	1991
PO1	M	163	85	Adriatic 2	1991
PO2	M	201	N.D.	Adriatic 2	1991
PO3	F	173	N.D.	Adriatic 2	1991
PO4	F	201	N.D.	Adriatic 2	1991
PO5	M	170	N.D.	Adriatic 2	1991
SO1	F	197	N.D.	Ionian 2	1991
SO4	F	197	N.D.	Ionian 2	1991
SO5	F	193	N.D.	Ionian 2	1991
SO6	F	205	N.D.	Ionian 2	1991
SO7	M	N.D.	N.D.	Ionian 2	1991
SO8	F	105	N.D.	Ionian 2	1991
65/93	F	195	N.D.	Tyrrhenian 1	1993
66/93	M	100	N.D.	Tyrrhenian 1	1993
X1	F	185	N.D.	Tyrrhenian 1	1990
X2	F	N.D.	N.D.	Tyrrhenian 1	1990
5/02	F	198	N.D.	Tyrrhenian 1	1991
X3	N.D.	126	N.D.	Tyrrhenian 1	1991
X4	N.D.	184	N.D.	Tyrrhenian 1	1991
X5	M	195	N.D.	Tyrrhenian 1	1991
V1	F	200	N.D.	Tyrrhenian 1	1991
V2	F	180	N.D.	Tyrrhenian 1	1991
V3	M	173	N.D.	Tyrrhenian 1	1991
V4	F	200	N.D.	Tyrrhenian 1	1991
X6	M	200	N.D.	Tyrrhenian 1	1989
V5	M	148	N.D.	Tyrrhenian 1	1990
X7	F	143	N.D.	Tyrrhenian 1	1989
P15	M	174	N.D.	Tyrrhenian 1	1992

Table III
Continued

ID no.	Sex	Length (cm)	Weight (kg)	Sea	Year
19/92	F	196	N.D.	Tyrrhenian 1	1992
93/93	F	112	N.D.	Tyrrhenian 1	1993
92/93	M	196	N.D.	Tyrrhenian 1	1993
3/94	M	196	70	Tyrrhenian 1	1994
X10	M	200	N.D.	Tyrrhenian 1	1993
X9	F	192	N.D.	Tyrrhenian 1	1992
4/94	N.D.	194	N.D.	Tyrrhenian 1	1994
A3	N.D.	97	N.D.	Tyrrhenian 1	1990
A4	M	106	N.D.	Tyrrhenian 1	1990
A5	M	188	85	Tyrrhenian 1	1991

N.D. = Not Determined; Tyrrhenian 1 = Northern Tyrrhenian; Tyrrhenian 2 = Central-lower Tyrrhenian; Adriatic 2 = Southern Adriatic; Ionian 1 = Eastern Ionian (Greece, Apulia), Ionian 2 = West Ionian (Sicily).

mean content usually shows a decrease in the following order: melon > blubber > liver > heart > brain > kidney > muscle. In some cases, especially in the brain, CH levels do not agree with the EOM% of the tissue. This is related to the lipid composition of the tissues and the polarity of the lipid components which have different selective affinities for, and binding of, these compounds (Tanabe et al., 1981a; Aguilar, 1985). In other words, the concentration of these compounds in the different tissues does not depend solely on lipid content but also on its composition: 99% of the total lipids in melon tissue and blubber are triglycerides whereas the brain contains more than 50% of phospholipids (Kawai et al., 1988). Phospholipids are polar lipids which are less inclined to bind apolar compounds such as PCBs and CHs in general. Since melon tissue has a mean EOM% of 91%, blubber 74% and brain 42%, we would expect CH concentrations in brain to be about half the values in melon and blubber. What we found, however, were quantities 25–30 times lower for DDTs and 15–20 times lower for PCBs.

Table IV also shows the values of the ratios pp’DDE/DDT and PCBs/DDTs. In the individuals of *S. coeruleoalba* studied, the former ratio was similar in all organs and tissues, with a minimum in blubber (geometric mean 0.68) and a maximum in muscle (geometric mean 0.81). Since pp’DDE is the main metabolite of DDT, this ratio may reflect the efficiency of metabolic processes in a particular species (Borrell and Aguilar, 1987). It can also be used to estimate the time and intensity of exposure to DDT. The quantity of pp’DDE generally increases with the interval since DDT exposure began and with the quantity to which the animal was exposed (O’Shea et al., 1980; Aguilar, 1984). The PCBs/DDTs ratio was greater than one in all organs and tissues, with a minimum in blubber (geometric mean

Table IV
Chlorinated hydrocarbons in tissues and organs of *Stenella coeruleoalba*

	HCB	DDTs	PCBS	pp'DDE/DDTs	PCBs/DDTs
	(ng g^{-1} d.w.)				
Melon (EOM% = 91; S.D. = 9)					
No. samples	31	31	31	31	31
Arithmetic mean	311	116361	174679	0.75	1.99
Median	241	85458	142923	0.76	1.97
Mode	481	81934	130629	0.76	1.91
Geometric mean	203	60464	108986	0.74	1.80
Minimum	4	508	1640	0.26	0.75
Maximum	1084	367018	418192	0.86	3.32
Blubber (EOM% = 74; S.D. = 20)					
No. samples	64	64	64	64	64
Arithmetic mean	785	100561	151878	0.72	1.99
Median	314	49827	87216	0.77	1.86
Mode	294	44385	85860	0.77	1.82
Geometric mean	116	48965	86257	1.68	1.76
Minimum	1	4447	6903	0.06	0.12
Maximum	7916	635157	1345910	0.87	4.70
Liver (EOM% = 23; S.D. = 16)					
No. samples	67	67	67	67	67
Arithmetic mean	203	20390	57834	0.78	3.35
Median	72	6167	20370	0.81	2.95
Mode	21	5153	18626	0.81	2.93
Geometric mean	70	7214	21424	0.77	2.97
Minimum	2	441	1074	0.33	1.15
Maximum	1695	209110	610903	0.93	13.89
Muscle (EOM% = 8; S.D. = 5)					
No. samples	59	59	59	59	59
Arithmetic mean	38	2310	5905	0.82	3.89
Median	6	877	2092	0.84	3.19
Mode	1	702	2091	0.84	3.19
Geometric mean	9	794	2666	0.81	3.36
Minimum	9	46	251	0.60	1.20
Maximum	767	60487	79486	0.91	12.28

Table IV

Continued

	HCB	DDTs	PCBS	pp'DDE/DDTs	PCBs/DDTs
	(ng g^{-1} d.w.)				
Brain (EOM% = 42; S.D. = 9)					
No. samples	27	27	27	27	27
Arithmetic mean	82	3710	10815	0.78	3.41
Median	32	1768	4670	0.81	3.35
Mode	7	1768	4582	0.80	2.95
Geometric mean	34	1927	5984	0.78	3.11
Minimum	3	159	532	0.61	1
Maximum	607	18895	42697	0.89	6.53
Kidney (EOM% = 19; S.D. = 12)					
No. samples	9	9	9	9	9
Arithmetic mean	23	1990	6546	0.80	5.63
Median	14	1042	2913	0.83	2.93
Mode	13	454	1555	0.81	2.50
Geometric mean	15	892	3293	0.79	3.69
Minimum	4	163	716	0.64	1.23
Maximum	86	6861	20824	0.93	21.59
Heart (EOM% = 13; S.D. = 5)					
No. samples	10	10	10	10	10
Arithmetic mean	10	3069	10062	0.78	3.75
Median	9	2502	7953	0.78	3.22
Mode	7	1131	6721	0.76	2.92
Geometric mean	8	2271	8102	0.78	3.57
Minimum	2	803	2343	0.66	2.45
Maximum	19	7083	24015	0.85	6.35

1.76) and a maximum in kidney (geometric mean 3.69). The fact that this ratio was always greater than one reflects the fact that the use of DDT has been restricted in the Mediterranean basin since the seventies whereas PCBs are still used in great quantities.

Figure 3 shows the distribution of the various DDT components in organs and tissues. In kidney and heart, op'DDE and op'DDD do not appear because their levels were below detection limits. We see that the various tissues had different affinities for the various metabolites of DDT, except pp'DDE which was always the main component. In melon and blubber, pp'DDT, the active ingredient, was always the second component in terms of percentage, whereas the second component in

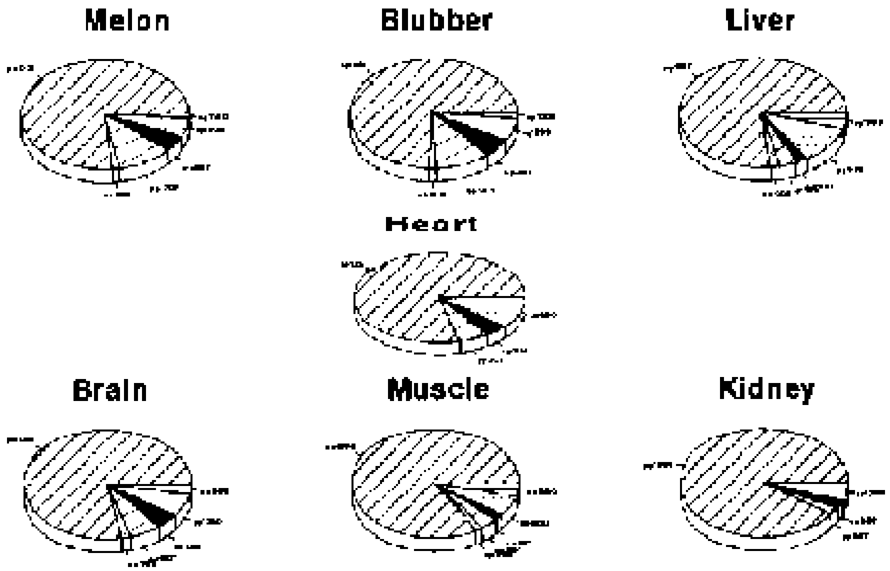

Figure 3. Distribution of the various DDT components in organs and tissues of *Stenella coeruleoalba.*

liver, muscle, kidney and heart was pp'DDD and in brain, pp'DDT and pp'DDD. The different affinity of the various organs and tissues for these xenobiotics also seems to depend on their lipid constitution (Fukushima and Kawai, 1981).

PCBs were quantified as the sum of 30 congeners, ten of which accounted for about 60% of the total. They were hexa-, hepta- and octachlorobiphenyls that constituted 67% of total PCBs in melon, 69% in blubber, 75% in liver, 71% in brain, 78% in muscle, 79% in kidney and 83% in heart tissue. These figures are in line with those of Burse et al. (1976) and Matthews and Tuey (1980) who reported that penta-, hexa-, hepta- and octachlorobiphenyls are eliminated more slowly from organs and tissues than compounds with fewer chlorines. The relative percentages of these ten congeners on total PCBs and the fingerprint of Arochlor 1260 are shown in Figures 4a and b. The prevalent congener in all organs was 22'44'55' (IUPAC no. 153; Ballschmiter and Zell, 1980) which ranged from 9.6% in Arochlor 1260 to 26% in heart tissue. This congener is particularly persistent as it has chlorines in positions 2, 4 and 5 of both rings of the biphenyl (Wolff et al., 1982; Bush et al., 1984, Safe et al., 1985) and no adjacent, unsubstituted carbons in ortho-meta position (Clarke, 1986). We found that congeners 22'344'5', 22'34'55'6, 22'344'55' and 22'33'44'5' (138, 187, 180 and 170) were more abundant in the samples whereas 22'33'44'56 (195) was more abundant in Arochlor. Congeners 22'344'5', 22'344'55' and 22'44'55' (138, 180 and 153) are regarded as being particularly resistant to metabolization by marine mammals (Bonn et al., 1992). Others, 22'344'5'6, 22'33'44'55' and 22'33'4'55'6 (183, 194 and 201), occur in

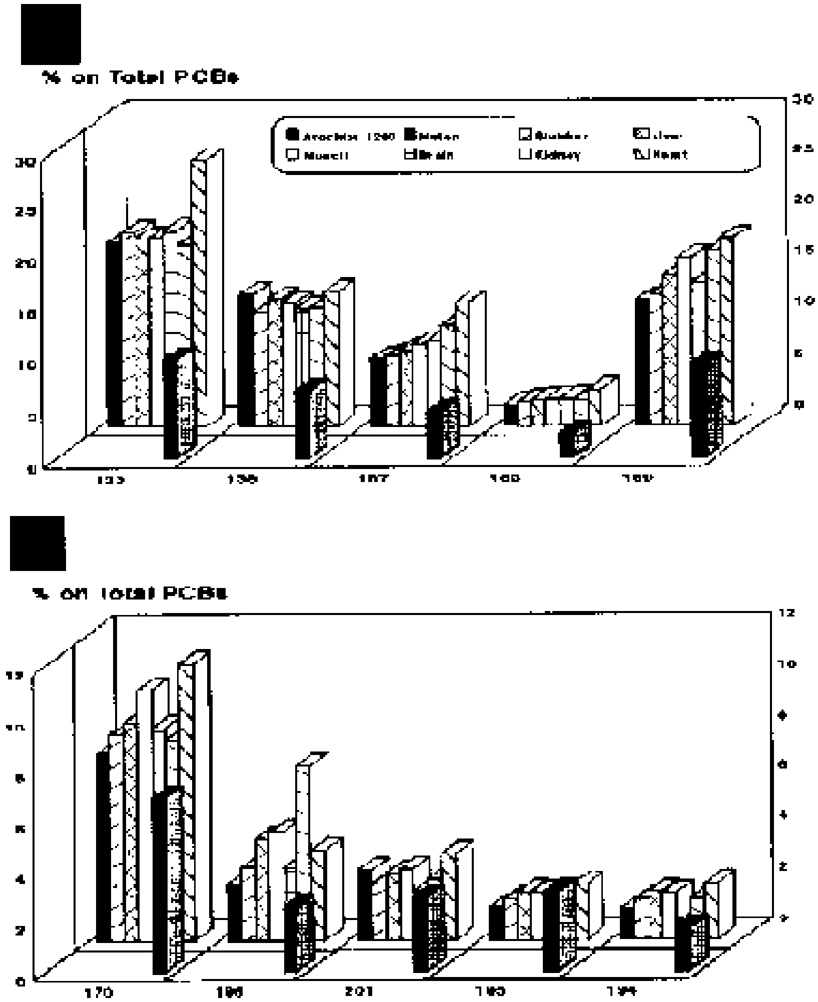

Figure 4. Relative percentages of the main PCB congeners in various organs and tissues of *Stenella coeruleoalba* and those in Arochlor 1260.

equal measure in Arochlor and biological samples. Congener 22’33’44’5’6 (196) showed the most variable pattern in relation to tissue: in kidney tissue it occurred in a percentage three times that in Arochlor, in liver and muscle about twice, in heart slightly higher, in blubber and brain about the same, and in melon it was lower. In brain, congener 22’33’44’55’ (194) occurred in a percentage that was 2.5 times less than in Arochlor.

The results divided according to sex are shown in Table V. In melon, blubber and liver tissue, both total DDTs and PCBs were much higher in males than females. In males, DDTs made up 68, 61, 72, 69 and 60% of total DDTs in the combined

Table V
Concentration of chlorinated hydrocarbons in *Stenella coeruleoalba* in relation to sex

	HCB		DDTs		PCBS		pp'DDE/DDTs		PCBs/DDTs	
	M	F	M	F	M	F	M	F	M	F
	(ng g^{-1} d.w.)									
Melon										
No. samples	18	11	18	11	18	11	18	11	18	11
Arithmetic mean	309	327	149901	69684	214556	112010	0.75	0.76	1.87	2.06
Median	285	222	121471	46686	246390	79317	0.78	0.74	1.86	1.91
Mode	481	213	99907	38069	142923	72689	0.76	0.73	1.41	1.72
Geometric mean	200	224	82899	42811	137690	82232	0.73	0.75	1.66	1.92
Minimum	4	22	508	9302	1640	19315	0.26	0.65	0.75	0.97
Maximum	735	1084	367018	289565	418192	281051	0.86	0.85	3.29	0.32
Blubber										
No. samples	33	26	33	26	33	26	33	26	33	26
Arithmetic mean	888	745	128143	81448	215342	92766	0.72	0.71	1.81	2.05
Median	322	332	72455	33797	152249	73558	0.77	0.77	1.55	2.04
Mode	294	1	72206	24672	149605	68284	0.77	0.77	1.52	1.91
Geometric mean	392	259	71103	39558	117887	69689	0.69	0.64	1.66	1.76
Minimum	16	1	5725	4573	6903	1225	0.20	0.06	0.71	0.12
Maximum	7916	5281	442209	635157	1345910	346950	0.87	0.86	3.51	3.74

Table V
Continued

	HCB		DDTs		PCBS		pp'DDE/DDTs		PCBs/DDTs	
	M	F	M	F	M	F	M	F	M	F
	(ng g^{-1} d.w.)									
Liver										
No. samples	39	26	39	26	39	26	39	26	39	26
Arithmetic mean	211	192	26254	9866	72455	29572	0.80	0.76	3.12	3.67
Median	91	48	8002	2602	27261	8997	0.81	0.81	2.57	3.39
Mode	79	25	7851	2254	26956	8256	0.81	0.80	2.56	3.25
Geometric mean	90	45	10413	3706	28142	12526	0.80	0.75	2.70	3.38
Minimum	9	2	623	441	1074	2076	0.54	0.33	1.15	1.52
Maximum	869	1695	209551	82110	610903	246702	0.93	0.89	13.89	7.46
Muscle										
No. samples	32	23	32	23	32	23	32	23	32	23
Arithmetic mean	27	57	3159	1424	6614	5456	0.85	0.80	3.19	4.69
Median	6	6	1014	448	2520	1685	0.85	0.83	2.87	3.69
Mode	3	1	972	436	2393	1536	0.84	0.80	2.57	3.43
Geometric mean	8	9	1023	596	2862	2438	0.83	0.80	2.80	4.09
Minimum	1	1	170	46	339	251	0.68	0.63	1.20	1.52
Maximum	181	767	60487	7375	79147	38439	0.91	0.91	8.15	12.28

Table V
Continued

	HCB		DDTs		PCBS		pp'DDE/DDTs		PCBs/DDTs	
	M	F	M	F	M	F	M	F	M	F
	(ng g^{-1} d.w.)									
Brain										
No. samples	14	10	14	10	14	10	14	10	14	10
Arithmetic mean	65	62	4668	3163	13899	8950	0.78	0.77	3.47	3.51
Median	30	26	2224	2019	6233	6799	0.80	0.75	3.40	3.38
Mode	27	11	1768	1130	4670	4399	0.76	0.73	2.76	2.83
Geometric mean	32	31	2573	1580	7768	5333	0.77	0.76	3.02	3.38
Minimum	3	7	551	159	1134	532	0.61	0.64	1.00	2.17
Maximum	370	295	18895	13452	42697	29245	0.86	0.87	6.53	4.93
Kidney										
No. samples	6	2	6	2	6	2	6	2	6	2
Arithmetic mean	17	10	1697	3784	5366	12585	0.82	0.81	5.39	4.38
Median	14	10	799	3784	2163	1255	0.84	0.81	2.44	4.38
Mode	10	15	301	6526	736	19090	0.83	0.86	2.37	5.83
Geometric mean	14	8	828	2608	2514	10773	0.81	0.81	3.03	4.13
Minimum	5	4	259	1042	716	6080	0.64	0.76	1.24	2.93
Maximum	32	15	6861	6526	20824	19090	0.93	0.86	21.59	5.83

Table V
Continued

	HCB		DDTs		PCBS		pp'DDE/DDTs		PCBs/DDTs	
	M	F	M	F	M	F	M	F	M	F
	(ng g^{-1} d.w.)									
Heart										
No. samples	6	4	6	4	6	4	6	4	6	4
Arithmetic mean	10	9	3152	2945	9459	10965	0.81	0.74	3.37	4.34
Median	10	8	2717	1913	7720	8056	0.81	0.73	2.91	3.84
Mode	7	2	991	870	5937	3734	0.78	0.66	2.79	3.31
Geometric mean	9	7	2406	2082	7720	8709	0.81	0.74	3.21	4.18
Minimum	3	2	803	870	2343	3734	0.76	0.66	2.45	3.31
Maximum	18	19	6404	7083	20117	24015	0.84	0.84	5.99	6.35

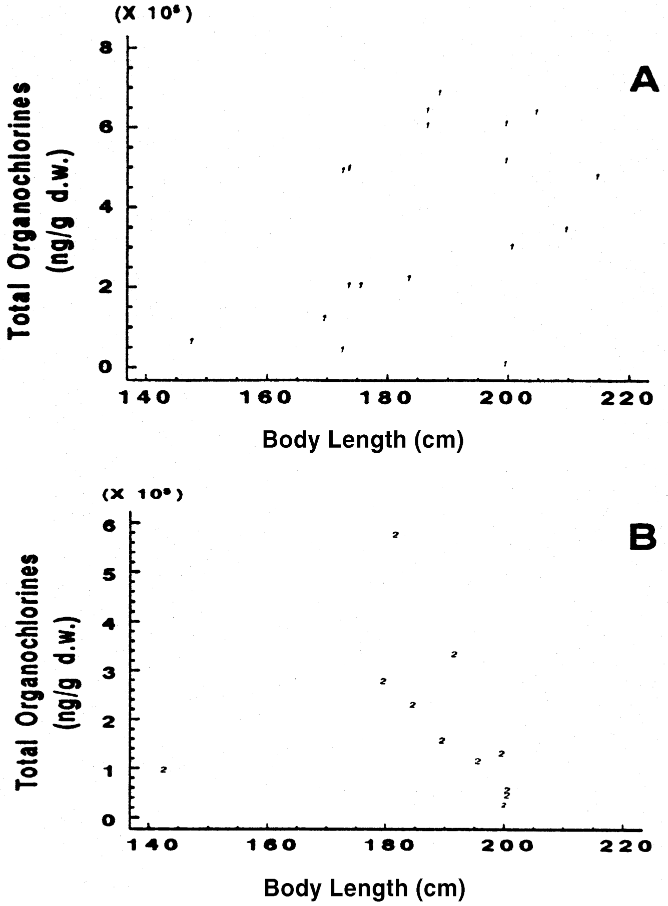

Figure 5. Total organochlorines in melon tissue in relation to body length of *Stenella coeruleoalba* according to sex: A) 1 = male, B) 2 = female.

population in melon, blubber, liver, muscle and brain tissue, respectively, whereas PCBs were 66, 70, 71, 55 and 61% of the total in the same tissues. In kidney tissue, on the other hand, males had only 31% of DDTs and 30% of PCBs. In heart tissue there were similar percentages of both xenobiotics in the two sexes (52% DDTs and 46% PCBs in males).

The fact that CH levels are normally higher in males than females is explained by the fact that females lose up to 90% of their total body burden of these substances during pregnancy and lactation (Tanabe et al., 1981b; Tanabe et al., 1982). This is linked to the fact that the milk of these marine mammals contains very high levels of fats, mostly triglycerides. The milk of *S. coeruleoalba*, for instance, contains 258 mg/g of triglycerides in 280 mg/g total fats (Kawai and Fukushima, 1981). Tanabe et al. (1981b) estimated that a pregnancy followed by a 6- to 7-month period of lactation enable the female of *S. coeruleoalba* to lose 4.7 and 95% of

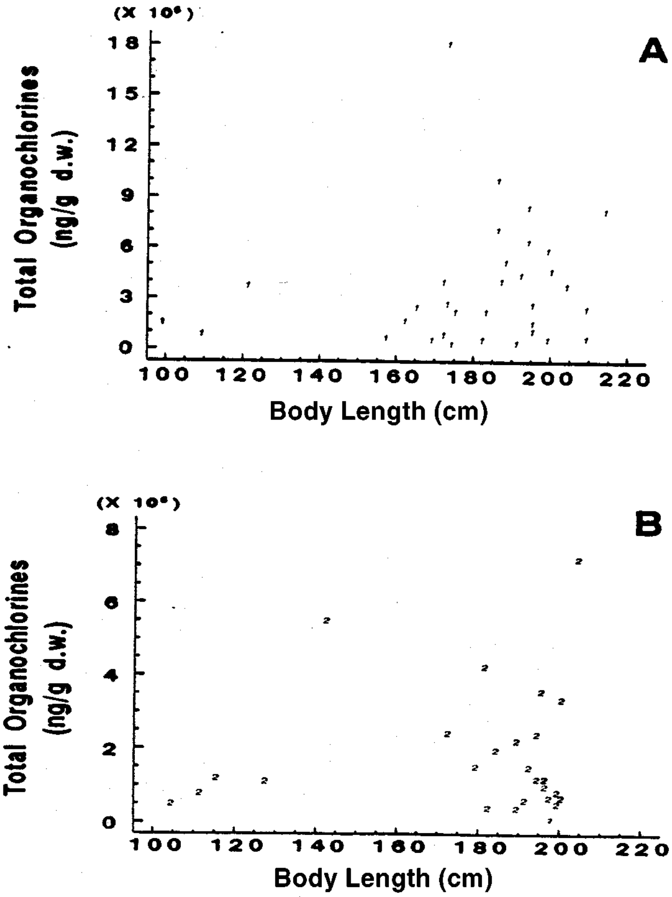

Figure 6. Total organochlorines in blubber tissue in relation to body length of *Stenella coeruleoalba* according to sex: A) 1 = male, B) 2 = female.

her total body burden of DDT, and 4 and 92% of that of PCBs, respectively. These percentages may partly explain the differences in the PCBs/DDTs ratio between males and females (Table V). In fact, there is a small difference in unloading potential between DDT and PCBs during pregnancy and lactation (+0.7% in pregnancy and +3% during lactation in favour of DDT). This apparently insignificant difference, when multiplied by the number of pregnancies and added to the fact that females consume more food in these phases of their life cycle, may justify the differences found in various organs and tissues. Greater food consumption means a greater intake of xenobiotics. Since PCBs have been much more abundant in the environment than DDTs, dietary intake must principally have been of PCBs.

Figures 5, 6, 7, 8 and 9 show plots of total xenobiotic burden in organs and tissues for which there was a significant number of samples (n) against body length, in relation to sex (A, B). In melon, blubber and liver tissue the dispersion of the

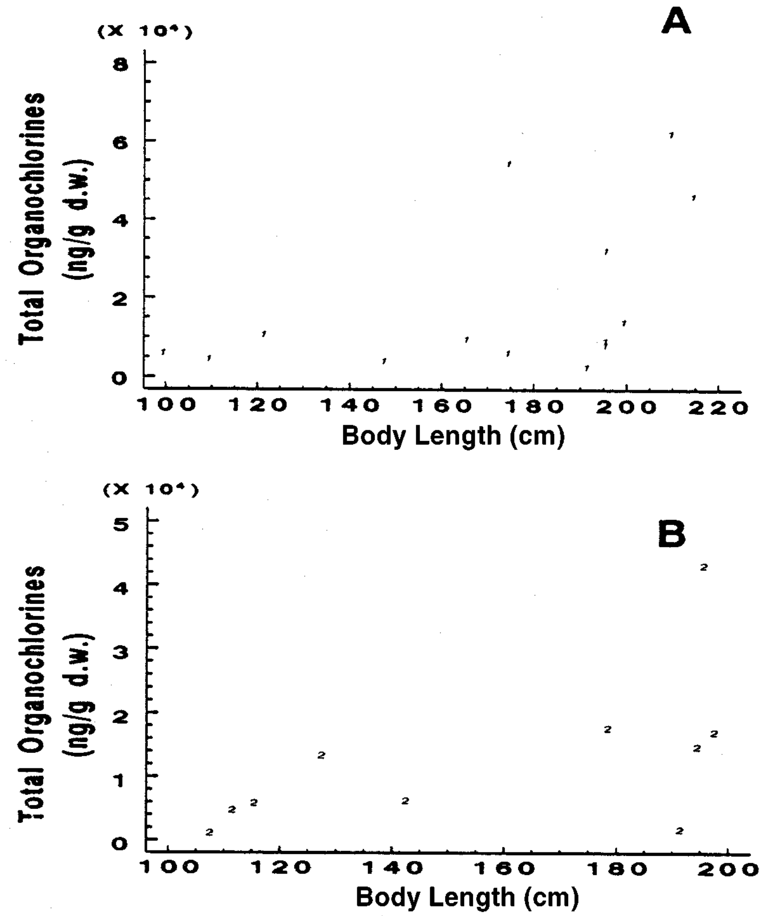

Figure 7. Total organochlorines in brain tissue in relation to body length of *Stenella coeruleoalba* according to sex: A) 1 = male, B) 2 = female.

data was quite similar. In males, contaminants tended to increase with increasing body length, whereas in females, beyond a certain body length, there was a general decrease. In muscle of females the pattern was similar, whereas in males xenobiotic values ranged from 1 to 100 μg/g dry wt. for any length. In brain tissue, there was an increasing trend with increasing body length in both sexes. This could depend on the fact that the quantity of triglycerides in the brain is minimal so that there is no mobilization of fats during lactation.

Contaminant concentrations were plotted against body length, which was used as a measure of age, since age in years could not be determined. It was found that the increase in xenobiotics was directly correlated with increase in body length, up to a certain threshold which differed from species to species, and between populations of the same species living in different waters (e.g. Mediterranean and

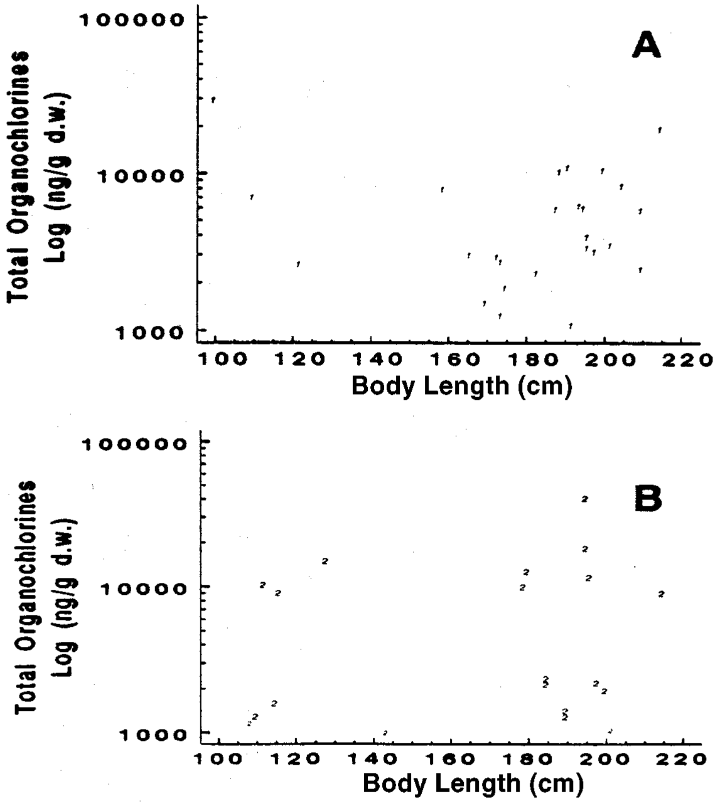

Figure 8. Total organochlorines in muscle tissue in relation to body length of *Stenella coeruleoalba* according to sex: A) 1 = male, B) 2 = female.

oceanic), and generally corresponded to physical maturity. This is followed by sexual maturity which is determinant in the different distribution of CHs between males and females. At this stage the females can reproduce and lose much of the burden of toxic substances.

Since the specimens of organs and tissues of *S. coeruleoalba* came from many parts of Italy, we separated the data of the major CHs in relation to the different seas of origin (Table VI). The results did not show large differences between sampling areas. Using the Kolmogorov-Smirnov test for PCB and DDT levels, the population of the Ligurian Sea was found to be significantly different in CH accumulation in blubber from that of the Tyrrhenian Sea (both for DDTs and PCBs, $p<0.01$), from that of the West Ionian Sea (only for PCBs, $p<0.01$) and from that of the Adriatic Sea for melon (only PCBs, $p<0.05$). Hence the only population that differed at least partly from the other seas was that of the Ligurian Sea, in which xenobiotic concentrations were higher, albeit not significantly, in nearly all organs. This confirms that this part of the Mediterranean basin is more contaminated.

Table VI

Concentrations of CHs in organs and tissues of *Stenella coeruleoalba* in relation to site (sea) of stranding (Tyrrhenian Sea 1 = Northern Tyrrhenian Sea (down to but excluding Lazio); Tyrrhenian Sea 2 = Southern Tyrrhenian Sea; Adriatic Sea 2 = Southern Adriatic Sea; Ionian Sea 1 = Eastern Ionian Sea; Ionian Sea 2 = Western Ionian Sea). All values in ng/g d.w.

	Ligurian Sea		Tyrrhenian Sea 1		Tyrrhenian Sea 2		Adriatic Sea		Ionian Sea 1		Ionian Sea 2	
	DDTs	PCBs	DDTs	PCBs	DDTs	PCBs	DDTs	PCBs	DDTs	PCBs	DDTs	PCBs
Blubber												
No. samples	16	16	32	32	2	2	7	7	2	2	5	5
Arithmetic mean	165647	275786	59399	111540	56579	90278	92788	103655	179759	246130	152522	67993
Median	119836	178935	29325	61166	56579	90278	83669	106965	179759	246130	43436	68284
Mode	99022	149605	24469	52241	87264	159294	61409	85860	349964	469513	24672	66829
Geometric mean	98867	171129	31918	65457	47535	58196	62458	85114	57824	103344	53830	62478
Minimum	8027	24867	4447	6903	25894	21261	14790	21080	9554	22747	14961	26695
Maximum	442209	1345910	229612	573262	87264	159294	260041	185704	349964	469513	635157	100051
Liver												
No. samples	21	21	27	27	7	7	6	6	5	5	1	1
Arithmetic mean	26144	67293	18987	61836	11225	38940	17584	34131	23895	62413	919	2692
Median	4461	20634	4633	10798	6344	18626	13842	33055	14779	56689	919	2692
Mode	4117	20370	3401	10317	5153	14730	8332	25308	3192	5208	919	2692

Table VI
Continued

	Ligurian Sea		Tyrrhenian Sea 1		Tyrrhenian Sea 2		Adriatic Sea		Ionian Sea 1			
	DDTs	PCBs	DDTs	PCBs	DDTs	PCBs	DDTs	PCBs	DDTs	PCBs		
Liver												
No. samples	21	21	27	27	7	7	6	6	5	5	1	1
Geometric mean	7297	23924	6596	19691	6945	21243	12175	26905	24887	24777	919	2692
Minimum	637	3473	441	1074	1036	2069	2216	4824	639	2076	919	2692
Maximum	209551	610903	82110	300993	27864	126049	43281	58808	3192	136354	919	2692
Muscle												
No. samples	18	18	27	27	9	9	3	3	2	2		
Arithmetic mean	4487	7277	1379	6268	861	3400	2781	4355	1112	2252		
Median	686	1858	972	2511	884	2529	531	988	1112	2252		
Mode	255	1660	877	2393	250	1370	436	861	2060	4008		
Geometric mean	811	2472	894	3265	497	2098	1195	2121	581	1410		
Minimum	150	339	58	445	46	251	436	861	164	496		
Maximum	60487	79486	3293	38439	1970	9151	7375	11216	2060	4008		

Table VI
Continued

	Ligurian Sea		Tyrrhenian Sea 1		Tyrrhenian Sea 2	
	DDTs	PCBs	DDTs	PCBs	DDTs	PCBs
Brain						
No. samples	4	4	22	22	1	1
Arithmetic mean	2095	7893	3794	10790	8340	23043
Median	1826	8640	1764	4580	8340	23043
Mode	159	532	1320	4399	8340	23043
Geometric mean	1131	4557	71986	5914	8340	23043
Minimum	159	532	217	1069	8340	23043
maximum	4569	13760	18895	42697	8340	23043

	Ligurian Sea		Tyrrhenian Sea 1		Adriatic Sea 2	
	DDTs	PCBs	DDTs	PCBs	DDTs	PCBs
Melon						
No. samples	13	13	14	14	4	4
Arithmetic mean	174468	228299	73688	152888	76867	76682
Median	114069	266507	50974	121125	60996	72937
Mode	99907	238907	38069	72689	17339	34123
Geometric mean	109371	175560	35491	79731	56857	69108
Minimum	9302	26019	508	1640	17339	34123
Maximum	367018	418192	231084	380608	168131	126732

Table VII

Concentration of CHs in blubber of *Stenella coeruleoalba* in relation to year of sampling

	1987		1988		1989		1990	
	DDTs	PCBs	DDTs	PCBs	DDTs	PCBs	DDTs	PCBs
	(ng/g d.w.)							
No. individuals	1	1	3	3	4	4	19	19
Arithmetic mean	9874	29646	13297	19834	77273	134776	157011	276849
Median	9874	29646	8507	21261	54668	92625	100908	157734
Mode	9874	29646	5491	12423	5725	6903	99022	152249
Geometric mean	9874	29646	10655	18963	38245	56096	94303	172662
S.D.	0	0	11013	6811	85437	156857	134837	303802
Minimum	9874	29646	5491	12423	5725	6903	4447	14814
Maximum	9874	29646	25894	25818	194030	346950	442209	1345910

	1991		1992		1993		1994	
	DDTs	PCBs	DDTs	PCBs	DDTs	PCBs	DDTs	PCBs
	(ng/g d.w.)							
No. individuals	26	26	4	4	5	5	2	2
Arithmetic mean	101581	114776	56893	87204	28891	70857	40363	72281
Median	43911	73803	25472	61119	24469	829118	40363	72281
Mode	33384	68284	11437	42762	23665	46461	44928	91728
Geometric mean	49280	75990	32249	72233	24879	64938	40104	69615
S.D.	140222	114191	72850	66369	16650	30038	6457	27503
Minimum	4573	12225	11437	42762	9319	32693	35797	52833
Maximum	635157	469513	165189	183817	54726	104379	44928	91728

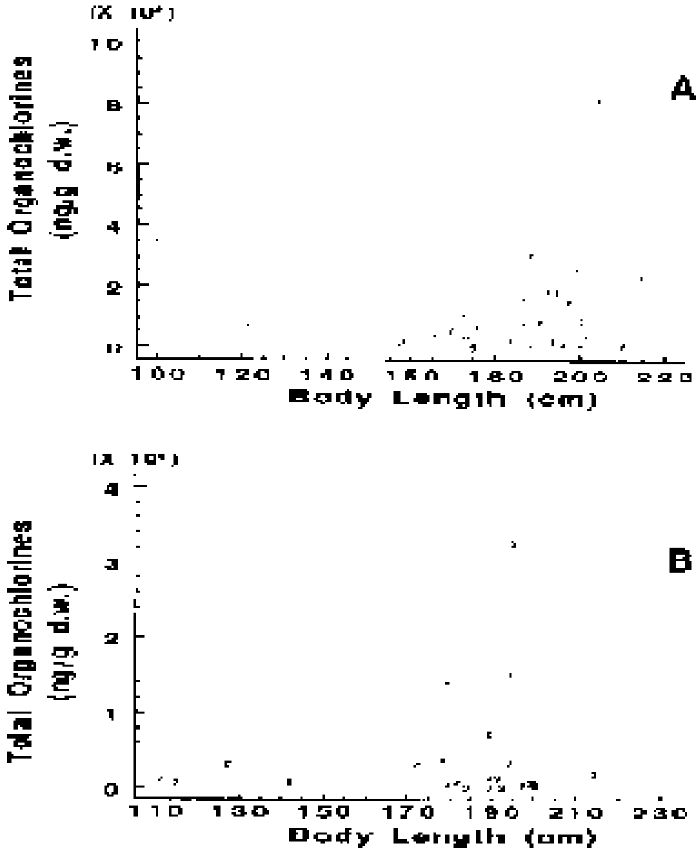

Figure 9. Total organochlorines in liver tissue in relation to body length of *Stenella coeruleoalba* according to sex: A) 1 = male, B) 2 = female.

The last type of statistical analysis was performed in relation to the year of sampling, taking blubber as representative of all organs and tissues (Table VII). The small number of specimens stranded in certain years prompted us to group the data into three periods: before 1990, 1990–1991 and after 1991. These divisions were decided on the basis of a viral epidemic that affected many dolphin populations throughout the Mediterranean in 1990 and 1991 (Bortolotto et al., 1992; Marsili et al., 1992; Aguilar and Raga, 1993; Borrell, 1993a). Analysis of many of these animals led to the isolation of a virus of the genus *Morbillivirus* (Domingo et al., 1991) that affects the lungs and could be one of the main causes of the high mortality. In other cases, the virus was not isolated but a large number of larval forms of cestodes, nematodes and trematodes were found. Anatomical pathology examination frequently revealed sub-acute pneumonia (Podesta' et al., 1992). Lev-

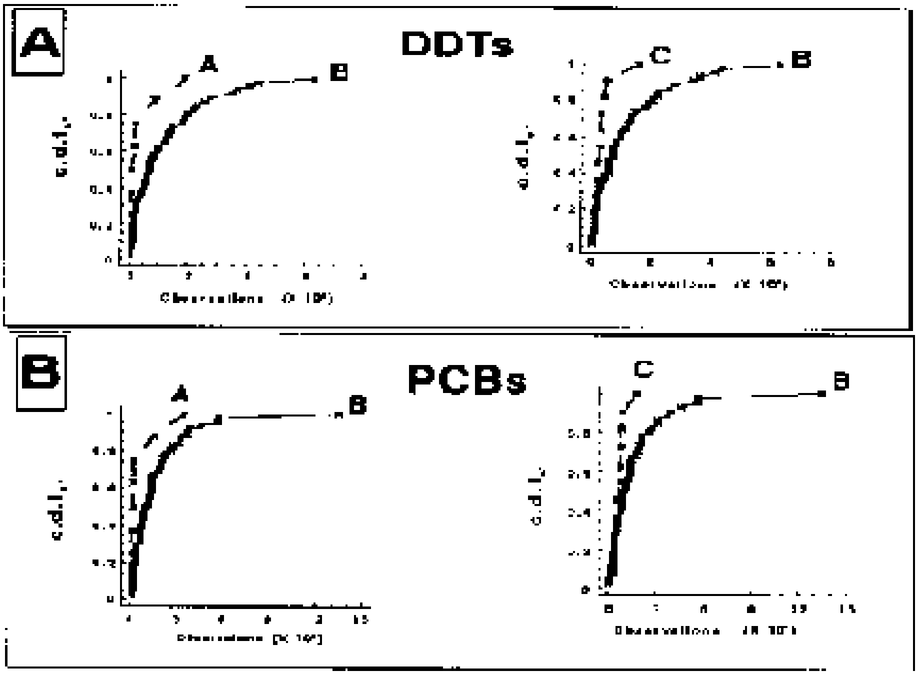

Figure 10. Cumulative distribution frequences (c.d.f$_s$.) of DDTs and PCBs in blubber of *Stenella coeruleoalba* related to period of stranding. A: before 1990; B: 1990–1991; C: after 1991.

els of CHs several times higher than in specimens stranded without an apparent cause of death, or dying as a result of accidents, were found in the organs and tissues of dolphins infected with *Morbillivirus* (Borrell and Aguilar, 1991; Aguilar and Borrell, 1994).

The Kolmogorov-Smirnov test showed significant differences in the cumulative distributions of PCBs between populations before 1990 and those in the period 1990–1991 ($p<0.05$). For DDTs significant differences were found between the period 1990–1991 and after 1991 ($p<0.01$) (Figure 10). The decrease in total DDTs expected since restriction of the use of this pesticide in most of the Mediterranean is probably masked by the disease that, whether cause of effect of the phenomenon, determined in either case the stranding of animals with the highest levels of xenobiotics. As far as PCBs are concerned, a slight increase was expected, or at least a stabilization of levels. The increase was so high between 1987 and 1990–1991 for the reasons explained above. The fact that after 1991, there was no further increase in PCB concentrations seems to confirm this.

Table VIII gives the mean PCB and DDT concentrations found in *S. coeruleoalba* specimens stranded on the Atlantic coasts of the U.S.A., the eastern Pacific, Japan, Wales, the Straits of Gibraltar and other parts of the Mediterranean. With-

Table VIII
Mean concentration of PCBs and DDTs in *Stenella coeruleoalba* living in different seas

Area	No. dolphins	DDTs (ppm f.b.)	PCBs (ppm f.b.)	References
USA (Atlantic)	3	36	59	Taruski et al., 1975
East Pacific	15	43	6	O'Shea et al., 1980
West Pacific (1978)	8	38	29	Loganathan et al., 1990
West Pacific (1986)	8	37	28	Loganathan et al., 1990
Japan	4	21	29	Tanabe et al., 1983
Japan	49	27	14	Fukushima and Kawai, 1981
Wales	7	30	39	Borrell, 1993b
Gibraltar	3	94	67	Borrell, 1993a
Catalonia (biopsies)	109	156	314	Borrell, 1993a
Catalonia (epizoosis)	72	456	846	Borrell, 1993a
Mediterranean France	8	71	267	Alzieu and Duguy, 1979
Italy	64	136	205	This paper

out considering the deaths in Catalonia due to *Morbillivirus*, the concentrations in blubber of *S. coeruleoalba* living in the Mediterranean are elevated and much higher than in specimens of the same species living in oceans. The latter have DDT levels between 21 and 43 ppm (fat basis) and PCB levels between 6 and 59 ppm (fat bs.). The Gibraltar Straits are a transition zone as far as xenobiotic concentrations are concerned. The lowest DDT values in the Mediterranean are from the French coasts; the lowest PCB values are those of this study. In Catalonia there is high CH contamination, as shown by the high levels found in the "healthy" population sampled by biopsy methods (Borrell, 1993a).

3.2. Chlorinated hydrocarbons in *Tursiops truncatus*

Fourteen specimens of *T. truncatus* stranded along the Italian coasts between 1987 and 1992 were analyzed for CHs. Table IX gives the details of the various individuals: identification number, length, sex, date and place (sea) of stranding. The organs and tissues analyzed for HCB, DDTs and PCBs were melon, blubber, liver, muscle, brain, kidney and heart. The CH concentrations found in the different tissues are reported in Table X. The contaminant found in the lowest concentrations was HCB. The organ with the highest accumulation was the melon. Geometric means of total DDT concentrations decreased in the following order: melon $>$ blubber $>$ liver $>$ heart $>$ muscle $>$ kidney $>$ brain; for PCBs the pattern was slightly different: melon $>$ liver $>$ blubber $>$ heart $>$ muscle $>$ brain $>$ kidney. Except for liver, muscle and blubber, the number of specimens per organ was small, so the data is only illustrative.

Table IX
Details of *Tursiops truncatus* stranded on the Italian coasts

ID no.	Sex	Length (cm)	Sea	Year
TM-01	M	225	Northern Adriatic	1987
TM-4	M	259	Northern Tyrrhenian	1988
T-5	F	270	Southern Tyrrhenian	1988
T-7	M	208	Southern Tyrrhenian	1989
T-8	M	123	Southern Tyrrhenian	1989
T-9	M	134	Southern Tyrrhenian	1989
T-6	M	263	Southern Tyrrhenian	1989
A-1	F	278	Northern Tyrrhenian	1990
A-11	M	235	Eastern Ionian	1991
G-1	M	288	Northern Adriatic	1992
G-2	F	290	Northern Adriatic	1992
5/91	F	310	Northern Tyrrhenian	1991
XT-1	M	298	Northern Tyrrhenian	1992
XT-2	IND.	279	Northern Tyrrhenian	1991

The pp'DDE/DDTs ratio (Table X) was lowest in blubber (geometric mean 0.62) and highest in muscle (0.80). pp'DDE, the main metabolite of pp'DDT, was always more than 60% of total DDTs. The PCBs/DDTs ratio (Table X) showed a predominance of PCBs in all compartments. The lowest value was again in blubber (2.6) and the highest in brain (22.34).

The results divided according to organ or tissue and sex are shown in Table XI. Comparison of the arithmetic means shows that males contained higher quantities of these xenobiotics than females in all organs. However, the large dispersion of the data makes it more logical to compare geometric means. In this case, two females showed the highest concentrations of PCBs in blubber.

There were also marked differences in the value of the two ratios: the pp'DDE/DDTs ratio in males was higher in kidney, muscle and heart, and in females it was higher in blubber and brain. In liver it was the same in the two sexes. The PCBs/DDTs ratio was always greater than one, and was higher in females in all organs and tissues except brain.

Since the organs and tissues of *T. truncatus* were from specimens stranded in different places along the Italian coasts, we plotted the sum of total concentrations of the three CHs assayed in each organ in relation to sea of origin (Figures 11a-g). In the three organs for which samples were most numerous (liver, muscle and blubber), there was no correlation between sea of origin and xenobiotic levels. For liver, dolphins with the highest concentrations were from the northern Adriatic, whereas for muscle and blubber, the Ionian dolphin had much higher levels than all

Table X
Organochlorines in tissues and organs of *Tursiops truncatus*

	HCB	DDTs	PCBS	pp'DDE/DDTs	PCBs/DDTs
	(ng g^{-1} d.w.)				
Melon (EOM = 90%; S.D. = 11)					
No. samples	2	2	2	2	2
Arithmetic mean	127	9149	47495	0.65	8.06
Median	127	9149	47495	0.65	8.06
Mode	234	16769	77385	0.74	11.51
Geometric mean	67	5064	36910	0.64	7.29
Minimum	19	1529	17605	0.55	4.61
Maximum	234	16769	77385	0.74	11.51
Blubber (EOM = 80%; S.D. = 7)					
No. samples	8	8	8	8	8
Arithmetic mean	378	9270	33323	0.67	3.88
Median	272	4765	21558	0.71	3.07
Mode	49	2639	18030	0.69	2.97
Geometric mean	191	3136	10223	0.62	2.60
Minimum	32	515	200	0.20	0.25
Maximum	950	46144	139854	0.84	9.4
Liver (EOM = 21%; S.D. = 13)					
No. samples	13	13	13	13	13
Arithmetic mean	301	10985	48171	0.78	7.30
Median	113	2714	25077	0.79	5.08
Mode	4	1713	5086	0.78	5.04
Geometric mean	65	2397	14031	1.77	5.85
Minimum	2	67	607	0.59	1.85
Maximum	1439	82665	208726	0.86	26.03
Muscle (EOM = 16%; S.D. = 9)					
No. samples	12	12	12	12	12
Arithmetic mean	64	5411	29313	0.80	5.47
Median	27	931	4671	0.82	5.16
Mode	11	419	2316	0.78	4.90
Geometric mean	23	1068	5380	0.80	5.04
Minimum	1	11	55	0.67	2.27
Maximum	185	31913	213811	0.89	8.30

Table X
Continued

	HCB	DDTs	PCBS	pp'DDE/DDTs	PCBs/DDTs
	(ng g^{-1} d.w.)				
Brain (EOM = 39%; S.D. = 5)					
No. samples	2	2	2	2	2
Arithmetic mean	47	185	5583	0.72	27.63
Median	47	185	5583	0.72	27.63
Mode	89	214	9391	0.74	43.88
Geometric mean	19	183	4082	0.72	22.34
Minimum	4	156	1774	0.71	11.37
Maximum	89	214	9391	0.74	43.88
Kidney (EOM = 27%; S.D. = 4)					
No. samples	3	3	3	3	3
Arithmetic mean	58	851	5578	0.72	14.15
Median	78	907	7921	0.76	9.25
Mode	1	15	425	0.60	4.86
Geometric mean	20	281	3045	0.72	10.84
Minimum	1	15	425	0.60	4.86
Maximum	96	1630	8387	0.81	28.33
Heart (EOM = 25%; S.D. = 11)					
No. samples	4	4	4	4	4
Arithmetic mean	27	11326	35416	0.68	5.84
Median	19	7585	29900	0.70	3.88
Mode	1	4	52	0.50	2.72
Geometric mean	12	1619	7694	0.67	4.75
Minimum	1	4	52	0.50	2.72
Maximum	71	30130	81812	0.82	12.88

the others. A pattern more or less common to all organs and seas of origin, showed males with higher levels than females.

Concentrations of chlorinated contaminants in *T. truncatus* blubber measured in other parts of the world are reported in Table XII. Although these levels show wide variations, the number of specimens was extremely small in all these studies, and the highest levels often refer to a single individual. Comparing these levels with the minimum and maximum DDT and PCB concentrations in blubber in our Table X, we find substantial agreement.

Table XI
Concentration of CHs in tissues and organs of *Tursiops truncatus* in relation to sex

	HCB		DDTs		PCBS		pp'DDE/DDTs		PCBs/DDTs	
	M	F	M	F	M	F	M	F	M	F
	($ng\ g^{-1}$ d.w.)									
Melon										
No. samples	0	2	0	2	0	2	0	2	0	2
Arithmetic mean		127		9149		47495		0.65		8.06
Median		127		9149		47495		0.65		8.06
Mode		234		16769		77385		0.74		11.51
Geometric mean		67		5064		36910		0.64		7.29
Minimum		19		1529		17605		0.55		4.61
Maximum		234		16769		77385		0.74		11.51
Blubber										
No. samples	5	2	5	2	5	2	5	2	5	2
Arithmetic mean	533	159	11992	3183	35698	24019	0.61	0.72	2.07	7.82
Median	570	159	5802	3183	18030	24019	0.70	0.72	2.97	7.82
Mode	258	286	811	3727	18030	24811	0.69	0.77	1	9.40
Geometric mean	356	96	3757	3136	5529	24006	0.56	0.72	1.47	7.65
Minimum	49	32	515	2639	200	23227	0.20	0.68	0.25	6.23
Maximum	950	286	46144	3727	139854	24811	0.77	0.77	3.11	9.40

Table XI
Continued

	HCB		DDTs		PCBS		pp'DDE/DDTs		PCBs/DDTs	
	M	F	M	F	M	F	M	F	M	F
	($ng\ g^{-1}$ d.w.)									
Liver										
No. samples	8	4	8	4	8	4	8	4	8	4
Arithmetic mean	380	101	16218	3081	68703	17880	0.77	0.78	7.05	7.89
Median	113	59	6081	1554	35258	14238	0.77	0.80	4.81	8.84
Mode	14	2	1713	67	4173	607	0.75	0.66	3.88	4.63
Geometric mean	87	22	4532	900	22806	6845	0.76	0.77	5.03	7.61
Minimum	4	2	168	67	1251	607	0.59	0.66	1.85	4.64
Maximum	1439	283	82665	9149	208726	42437	0.86	0.85	26.03	9.24
Muscle										
No. samples	7	4	7	4	7	4	7	4	7	4
Arithmetic mean	94	18	9105	194	49228	1553	0.80	0.77	4.89	7.89
Median	117	5	7725	239	22470	1921	0.82	0.78	4.90	8.84
Mode	15	1	1740	11	8260	55	0.78	0.72	4.75	4.64
Geometric mean	48	5	4365	115	10184	820	0.80	0.77	4.62	7.61
Minimum	6	1	515	11	2744	55	0.67	0.72	2.71	4.64
Maximum	185	61	31913	286	213811	2316	0.89	0.82	6.92	9.24

Table XI

Continued

	HCB		DDTs		PCBS		pp'DDE/DDTs		PCBs/DDTs	
	M	F	M	F	M	F	M	F	M	F
	(ng g^{-1} d.w.)									
Brain										
No. samples	1	1	1	1	1	1	1	1	1	1
Arithmetic mean	89	4	214	156	9391	1774	0.71	0.74	43.88	11.37
Median	89	4	214	156	9391	1774	0.71	0.74	43.88	11.37
Mode	89	4	214	156	9391	1774	0.71	0.74	43.88	11.37
Geometric mean	89	4	214	156	9391	1774	0.71	0.74	43.88	11.37
Minimum	89	4	214	156	9391	1774	0.71	0.74	43.88	11.37
Maximum	89	4	214	156	9391	1774	0.71	0.74	43.88	11.37
Kidney										
Kil)LNEY No. samples	1	2	1	2	1	2	1	2	1	2
Arithmetic mean	96	40	1630	461	7921	4406	0.81	0.68	4.86	18.79
Median	96	40	1630	461	7921	4406	0.81	0.68	4.86	18.79
Mode	96	78	1630	907	7921	8387	0.81	0.76	4.86	28.33
Geometric mean	96	9	1630	117	7921	1889	0.81	0.68	4.86	16.19
Minimum	96	1	1630	15	7921	425	0.81	0.60	4.86	9.25
Maximum	96	78	1630	907	7921	8387	0.81	0.76	4.86	28.33

Table XI
Continued

	HCB		DDTs		PCBS		pp'DDE/DDTs		PCBs/DDTs	
	M	F	M	F	M	F	M	F	M	F
	(ng g^{-1} d.w.)									
Heart										
No. samples	3	1	3	1	3	1	3	1	3	1
Arithmetic mean	36	1	15100	4	47204	52	0.74	0.50	3.49	12.88
Median	20	1	8331	4	37810	52	0.78	0.50	3.22	12.88
Mode	17	1	6838	4	21990	52	0.63	0.50	2.72	12.88
Geometric mean	29	1	11973	4	40821	52	0.74	0.50	3.41	12.88
Minimum	17	1	6838	4	21990	52	0.63	0.50	2.72	12.88
Maximum	71	1	30130	4	81812	52	0.82	0.50	4.54	12.88

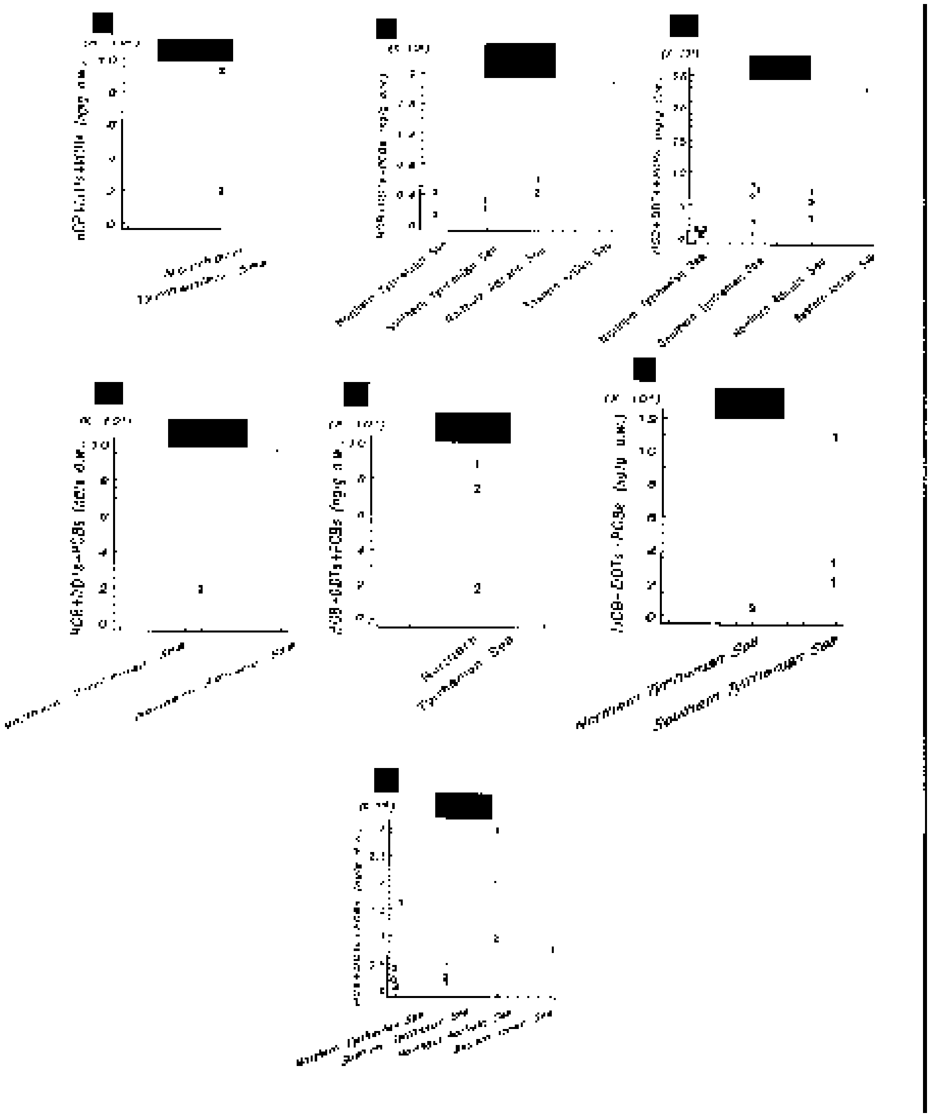

Figure 11. Concentrations of chlorinated hydrocarbons in organs and tissues of *Tursiops truncatus* in relation to site (sea) of stranding. 1 = males, 2 = females; 0 = sex not determined.

On 24th May 1990, a female bottlenose dolphin, 278 cm long, suffocated in a fishing net. Since this dolphin was also lactating, we were able to measure CH levels in the milk. In view of the exceptional nature of this case, the concentrations of xenobiotics in the various organs and tissues of this dolphin are reported in Table XIII. The percentage EOM in milk was 32%. This level agrees perfectly with others reported in the literature, which give a quantity of total fats in milk of

Table XII
CH levels in blubber of *Tursiops truncatus* from different parts of the world

Area	No. individuals	DDTs (ppm)	PCBs (ppm)	References
Australia (f.w.)	6	1.3	0.06	Kemper et al., 1994
Wales (f.w.)	3	78	290	Morris et al., 1989
South Africa (f.w.)	6	4	2.5	de Kock et al., 1994
Mediterranean Spain (f.w.)	1	24	234	Corsolini et al., 1995a
Mediterranean France (d.w.)	1	–	321	Alzieu and Duguy, 1979
Italy (d.w.)	8	4	10	This study

330 mg/g. Of these, 290 mg/g are triglycerides, 14 mg/g phospholipids and 4.5 mg/g cholesterols (Kawai and Fukushima, 1981). The percentage of fats is also very high (13–31% of the total weight) in the mammary gland (Kawai and Fukushima, 1981), with triglycerides accounting for more than 60% of total fats while phospholipid and cholesterol levels were no greater than 10 and 2% respectively.

In milk and the mammary gland, the fat composition reflected the levels of xenobiotics found, which were as high as in the two main storage tissues, blubber and melon. If we consider the levels in the other organs, we see that xenobiotic levels were sometimes so low as to be undetectable, except in brain where levels were similar in terms of geometric means, in all the dolphins of this species analyzed (Table X). The massive mobilization of fats that occurs with lactation presumably led these compartments to unload most of their contaminant burden.

3.3. Chlorinated hydrocarbons in other species

Unless otherwise indicated, the specimens were stranded on the northern Tyrrhenian coast.

3.3.1. *Balaenoptera physalus*

In October 1990, a whale was found stranded live. It was an adult female 19.2 m long. She was examined and since her condition was good, she was returned to the sea. This was a very difficult operation and unfortunately the whale was damaged, especially the lateral fins. A few days later (27th October), she was found dead. Organ and tissue samples were taken for ecotoxicological studies.

A small female, 5.92 m long, was found dead on 23rd November 1992. Liver and blubber samples were taken.

The results of analysis of CHs are reported in Table XIV. The great difference in contaminant levels between the two whales is immediately evident. In the 1992 specimen, total DDT and PCBs were 27 and 68 times higher in liver and 14 and 7 times higher in blubber than in the older whale. The only plausible explanation is that the older whale may have had many young in her lifetime, whereas the

Table XIII
CH levels in tissues and organs of a dolphin *Tursiops truncatus* suffocating in a fishing net

	Tursiops truncatus 24–5–90 (ng/g dry weight)								
	Melon	Blubber	Brain	Liver	Kidney	Heart	Muscle	Mammary gland	Milk
HCB	**19**	**32**	**4**	**2**	**1**	**1**	**1**	**7**	**23**
pp'DDE	1130	2525	115	53	9	2	9	886	2360
op'DDD	54	84	9	3	<1	1	<1	43	70
pp'DDD	34	364	7	6	4	<1	<1	89	153
op'DDT	41	126	3	1	<1	<1	2	45	36
pp'DDT	261	537	21	3	1	<1	<1	241	424
op'DDE	9	91	1	1	<1	<1	<1	5	<1
DDTs	**1529**	**3727**	**156**	**67**	**15**	**4**	**12**	**1309**	**3043**
95	282	402	35	12	<1	2	<1	155	378
101	338	578	44	9	<1	2	<1	223	507
99	876	697	108	29	<1	<1	<1	592	1271
151	249	388	33	10	<1	1	1	183	382
144+135	109	158	13	5	<1	1	<1	85	162
149+118	1330	1852	157	44	9	6	4	897	1932
146	435	674	60	14	4	1	<1	362	739
153	2938	4399	405	109	38	7	11	2352	4890
138	2086	2367	276	85	46	6	9	1673	3584
178	187	287	21	8	3	1	<1	145	285
187	1033	1611	136	42	28	3	5	778	1597
183	453	665	51	15	9	1	2	331	674
128	176	272	17	6	4	<1	1	132	295
174	338	572	35	15	16	2	2	263	470
177	230	419	23	10	10	1	1	68	342
156+171+202	304	456	23	9	8	1	1	213	472
180	2116	2778	237	77	97	5	9	1454	2945
199	28	53	5	3	5	<1	<1	11	<1
170	1235	1022	63	46	65	8	5	887	1892
196	586	771	19	14	26	1	2	287	533
201	717	935	11	15	21	1	2	300	573
195	643	761	2	15	17	<1	<1	221	483
194	551	631	<1	11	13	1	<1	185	374
206	363	479	<1	4	3	<1	<1	54	139
Total PCBs	**17603**	**23227**	**1774**	**597**	**423**	**52**	**56**	**11851**	**24919**
EOM%	**97**	**72**	**35**	**10**	**27**	**13**	**8**	**30**	**32**

small whale was in the fullness of her accumulation capacity with a considerable burden of contaminants from birth and suckling. In fact, CH levels were anomalous in the younger whale but not in the one stranded in 1990. DDT and PCB levels of 0.85 mg/kg fat bs. (S.D. 0.46) and 1.26 mg/kg fat bs. (S.D. 0.61) respectively

Table XIV
CH levels in tissues and organs of two *Balaenoptera physalus* stranded on the Tyrrhenian coast

	B. physalus 1990 (ng/g d.w.)				*B. physalus* 1992 (ng/g d.w.)	
	Kidney	Muscle	Liver	Blubber	Liver	Blubber
HCB	0.8	1.1	1.9	9.5	139.1	110.5
pp'DDE	71.0	104.7	42.5	652.3	1086.4	10528.0
op'DDD	3.3	2.9	2.9	24.3	117.7	280.4
pp'DDD	2.1	2.7	4.1	45.8	200.0	1151.9
op'DDT	0.4	2.0	2.4	75.2	58.8	474.7
pp'DDT	1.8	3.4	1.9	171.4	60.6	770.4
op'DDE	0.5	1.2	1.6	16.3	0.0	180.6
DDTs	**79.1**	**116.9**	**55.4**	**985.3**	**1523.5**	**13386.0**
95	0.9	2.6	7.0	78.3	42.1	301.1
101	6.4	9.6	6.4	91.7	80.0	381.3
99	4.3	12.8	10.5	168.4	27.6	328.7
151	2.9	5.8	2.9	47.3	87.3	288.9
144+135	1.3	3.8	2.1	38.3	41.7	298.6
149+118	21.2	31.9	20.2	319.2	454.6	1444.4
146	7.0	10.5	6.2	105.9	127.0	479.2
153	28.0	4.6	20.7	577.1	1466.7	4448.9
138	19.3	26.0	15.9	453.9	1000.0	3094.1
178	3.2	4.0	2.6	39.3	109.1	260.0
187	16.6	22.3	16.1	255.8	680.0	1747.8
183	4.8	7.2	3.5	74.4	259.3	1618.3
128	2.2	2.6	1.5	41.7	82.5	311.2
174	7.6	11.4	7.5	118.1	6.7	1271.1
177	4.1	6.1	4.3	70.8	196.7	494.9
156+171+202	4.0	4.6	2.5	47.4	172.4	410.9
180	19.2	27.8	14.1	388.6	2764.7	5841.5
199	1.0	0.9	3.2	25.5	11.8	46.7
170	19.5	23.9	23.3	233.3	2090.9	3105.5
196	6.6	10.0	5.5	102.6	685.7	771.7
201	5.7	8.6	5.1	73.3	725.0	844.1
195	3.5	6.4	2.9	0.0	666.7	593.2
194	4.6	5.5	4.6	226.1	603.8	479.7
206	0.7	0.0	0.5	0.0	129.0	123.0
PCBs	**194.6**	**284.9**	**189.1**	**4281.7**	**12971.3**	**28684.8**
EOM%	**9**	**8**	**14**	**97**	**10**	**23**

in the blubber of 48 males of *B. physalus* living in Icelandic waters have been reported. In three females from the same area, levels were even lower: 0.61 mg/kg fat bs. (S.D. 0.14) for DDTs and 0.94 mg/kg fat bs. (S.D. 0.12) for PCBs (Borrell 1993b). Pantoja et al. (1984) found DDT concentrations of 0.0544 ppm wet weight in blubber and 0.0042 ppm wet wt. in liver of this species of whale off the coasts of Chile. Levels similar to those of our 1990 individual, namely 14.8 ppm fat bs. for DDTs and 4.96 ppm fat bs. for PCBs, were reported by Alzieu and Duguy (1979) in blubber of a young whale from Mediterranean France. The same authors found even higher levels (62 ppm fat bs. DDTs and 47 ppm fat bs. PCBs) in a young individual in the north Atlantic.

3.3.2. *Grampus griseus*

On 8th March 1990 the stranding of a specimen of *G. griseus* was reported. The presumed date of death was the previous day, so its condition was excellent. Necroscopy revealed infarction of the right ventricle of the heart, marked lung stasis with areas of collapse, cysts in the pelvic region of the peritoneum, and stomach in good condition but almost empty (only a few cephalopod beaks). The cetacean was 294 cm long and male. The results of CH analysis in various organs and tissues are given in Table XV. Levels were particularly high and closely related to EOM%. The only exceptions were blubber and testicle which while having EOM% lower and ten times lower than that of melon tissue, respectively, had CH concentrations twice as high (blubber) and DDT and PCB levels only a quarter and a third respectively (testicle).

The DDT and PCB levels found in this specimen were similar to, and lower than, respectively, those reported by Corsolini et al. (1995a) in blubber of two specimens stranded on the Mediterranean coasts of Spain. These authors reported levels of 254 ppm wet wt. for DDTs and 1264 ppm wet wt. for PCBs. Two grampi stranded in the northern Adriatic had quite different levels: 5.2–400 ppm wet wt. for DDTs and 20–610 ppm wet wt. for PCBs (Corsolini et al., 1995b). Alzieu and Duguy (1979) reported 68 ppm dry wt. for PCBs and 70 ppm dry wt. for DDTs in three grampi stranded on the Mediterranean coasts of France. Much lower levels were found by de Kock et al. (1994) in 2 grampi from South Africa (DDTs 4.4 ppm wet wt., PCBs 1.56 ppm wet wt.).

3.3.3. *Steno bredanensis*

A female of *S. bredanensis*, 289 cm long and weighing 300 kg, was stranded, probably already dead, on the southern Adriatic coasts of Apulia on 22nd September 1991. The date of death was estimated to be 10 days before the finding. The mammal did not show any signs that could explain its death. Organochlorine levels found in blubber, muscle and liver are reported in Table XVI. We are unaware of any other papers on chlorinated contaminants in this species of odontocete.

3.3.4. *Globicephala melaena*

In 1990, a male of *G. melaena*, 344 cm long, was stranded in the Province of Imperia. The results of CH analysis are reported in Table XVII. Comparisons with other data published for this species appear in Table XVIII. The levels found in this individual were much higher than in those found in ocean specimens, but

Table XV

Concentrations of HCB, pp'DDT and its metabolites and certain PCB congeners in organs and tissues of a *Grampus griseus* stranded on Elba Island

	Grampus griseus (ng/g dry weight)						
	Melon	Blubber	Muscle	Liver	Kidney	Heart	Testicle
HCB	**171**	**938**	**3**	**13**	**8**	**1**	**35**
pp'DDE	102990	264885	1600	2290	3320	228	29119
op'DDD	1778	3125	79	844	185	4	582
pp'DDD	4395	9315	47	796	256	4	245
op'DDT	8221	13497	44	73	454	8	922
pp'DDT	7228	10829	46	128	325	6	1120
op'DDE	2006	2254	34	168	119	3	799
DDTs	**126618**	**303905**	**1850**	**4299**	**4660**	**254**	**32787**
95	5577	11164	96	348	321	17	1407
101	8077	18229	147	662	513	22	899
99	13503	16234	221	1031	843	38	6192
151	4535	9921	104	583	396	12	1497
144+135	2731	5469	57	247	207	6	845
149+118	22744	34404	448	3741	805	62	7155
146	7546	17090	186	975	747	21	2768
153	45112	98917	1778	4016	4684	138	17001
138	36988	59851	1455	4093	3413	100	12524
178	2973	6944	91	743	338	9	1444
187	15111	34725	1206	2272	1938	52	7094
183	5436	12422	172	880	686	18	2599
128	3068	6250	64	309	249	7	953
174	8512	18876	250	1268	953	25	3608
177	4490	9679	126	599	477	14	1822
156+171+202	6620	1330	110	746	431	11	1626
180	26807	59163	1102	3401	4166	114	13319
199	389	868	11	54	58	19	160
170	17104	22733	493	2579	2025	55	7435
196	5116	12153	200	1014	855	23	2954
201	4371	10610	163	855	739	17	2614
195	2661	4596	102	533	449	11	1307
194	2727	7075	102	582	506	12	153
206	518	1211	20	101	87	2	297
PCBs	**252716**	**480114**	**8704**	**42082**	**25886**	**806**	**97673**
EOM%	**90**	**71**	**3**	**10**	**5**	**2**	**9**

lower than those reported by Alzieu and Duguy (1979) in seven specimens from Mediterranean France.

Table XVI

CHs in organs and tissues of a *Steno bredanensis* stranded on the coasts of Apulia

	Steno bredanensis (ng/g dry weight)			
	Blubber	Muscle	Liver	Kidney
HCB	**154**	**20**	**42**	**10**
pp'DDE	6506	190	284	1076
op'DDD	74	3	5	28
pp'DDD	300	12	24	110
op'DDT	174	1	6	9
pp'DDT	233	7	12	27
op'DDE	36	1	1	7
DDTs	**7323**	**214**	**332**	**1257**
95	118	17	14	0
101	125	7	16	33
99	333	12	22	53
151	169	8	17	35
149+118	822	43	76	197
146	263	19	36	73
1153	2558	150	251	494
138	1954	102	159	309
178	194	10	18	41
187	1064	60	100	217
183	359	21	34	78
128	211	8	14	30
174	510	18	30	95
177	354	9	20	53
156+171+202	314	14	22	56
180	3691	13	179	472
199	39	2	5	9
170	3846	101	120	393
196	1389	40	48	152
201	1258	45	47	158
195	1364	48	41	148
194	2549	53	47	184
206	1017	30	30	84
PCBs	**24501**	**949**	**1346**	**3364**
EOM%	**30**	**7**	**14**	**18**

3.4. Comparison of CH concentrations in *Stenella coeruleoalba* and *Tursiops truncatus*. Reference to other studied species

The most numerous strandings along the Italian coasts were recorded for *S. coeruleoalba*, which is also the most abundant cetacean in our seas. Of the 934

Table XVII

CHs in organs and tissues of a *Globicephala melaena* stranded on the Ligurian coast

	Globicephala melaena (ng/g dry weight)				
	Melone	Blubber	Muscle	Liver	Kidney
HCB	**277**	**143**	**11**	**16**	**24**
pp'DDE	60453	42125	1401	1240	2466
op'DDD	740	457	44	77	120
pp'DDD	5069	3846	147	152	352
op'DDT	4425	3038	44	40	73
pp'DDT	9707	7997	94	53	188
op'DDE	960	659	21	32	44
DDTs	**81354**	**58122**	**1751**	**1594**	**3243**
95	3632	2494	72	46	80
101	4162	3810	82	39	87
99	4613	3265	114	313	434
151	2731	2041	71	42	92
144+135	1221	1029	33	24	50
149+118	15274	11744	366	191	363
146	4740	4167	146	88	182
153	31402	26242	925	418	832
138	18903	16030	525	307	635
178	1850	1397	73	38	91
187	10603	9314	380	195	436
183	3715	2869	128	71	152
128	2049	1477	54	38	73
174	6108	5061	191	116	219
177	3536	3034	107	53	111
156+171+202	2361	1945	75	49	101
180	17257	143	613	353	807
199	308	127	12	2	6
170	6740	5553	211	246	538
196	3083	3175	146	93	202
201	2740	2469	124	79	158
195	1632	1681	90	70	125
194	1675	1294	74	66	117
206	430	443	25	30	41
PCBs	**150765**	**125025**	**4637**	**2967**	**5932**
EOM%	**91**	**91**	**3**	**3**	**6**

specimens of cetaceans found and inspected from 15th May 1986 to 31st December 1990, 360 were of *S. coeruleoalba* (Cagnolaro and Notarbartolo di Sciara, 1992).

There were also many cases of stranding of *T. truncatus*: 125 specimens found dead on the Italian coasts in the same period. This dolphin is also frequent in the

Table XVIII
Mean levels of PCBs and DDTs in *Globicephela melaena* specimens from different seas

Area	No. individuals	DDTs (ppm)	PCBs (ppm)	References
Australia (f.w.)	8	<1	<0.05	Kemper et al., 1994
North Atlantic (f.w.)	52 M	31	49	Borrell, 1993b
	159 F	13	26	
Canada (f.w.)	5 M	12	9	Muir et al., 1988
	9 F	5	3	
Mediterranean France (d.w.)	7	94	189	Alzieu and Duguy, 1979
Italy (d.w.)	1	58	125	This study

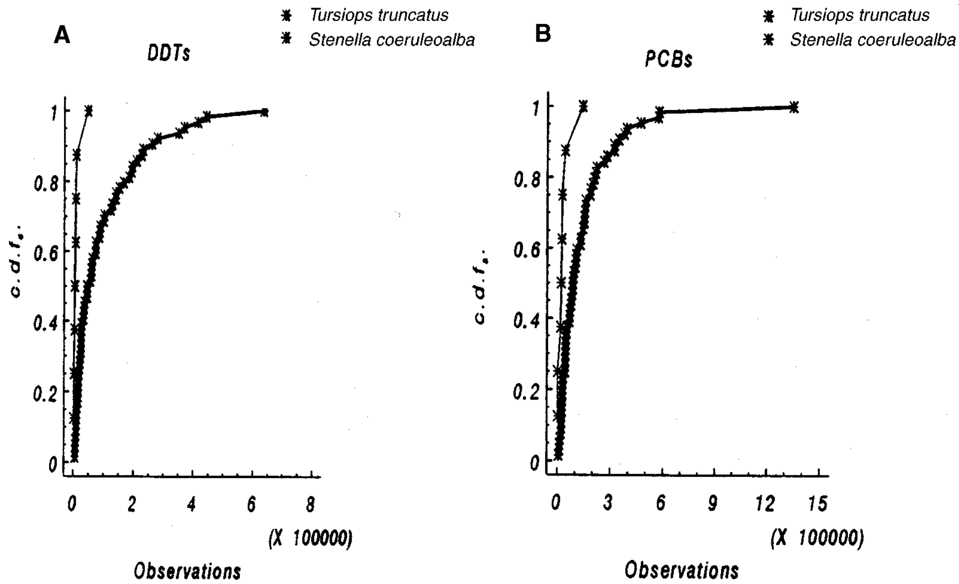

Figure 12. Cumulative distribution frequences (c.d.f_s.) of total DDT (A) and PCBs (B) in fat of *Stenella coeruleoalba* and *Tursiops truncatus.*

Mediterranean, especially in shallower waters such as the Adriatic. One of the main differences between the two species is the part of the sea in which they live. *S. coeruleoalba* is pelagic whereas *T. truncatus* is coastal, though a pelagic form does exist. There is no selective competition between the two, as there might be between striped dolphin and the common dolphin, and no other type of interaction.

Taking as reference the three organs of which the greatest number of samples were analysed (blubber, liver and muscle), we compared the concentrations of chlorinated xenobiotics in the two species (Table XIX). Using the Kolmogorov-Smirnov statistical test for non parametric distributions, we found that the distributions of

Table XIX
Levels of chlorinated xenobiotics in blubber (A), liver (B) and muscle of *Stenella coeruleoalba* and *Tursiops truncatus Tursiops truncatus*

	HCB	DDTs	PCBS	pp'DDE/DDTs	PCBs/DDTs
	(ng g^{-1} d.w.)				
A *Stenella coeruleoalba*: *Blubber* (EOM% = 74; S.D. = 20)					
No. samples	64	64	64	64	64
Arithmetic mean	785	100561	151878	0.72	1.99
Median	314	49827	87216	0.77	1.86
Mode	294	44385	85860	0.77	1.82
Geometric mean	965	48965	86257	0.68	1.76
Minimum	1	4447	6903	0.06	0.12
Maximum	7916	635157	1345910	0.87	4.70
A *Tursiops truncatus*: *Blubber* (EOM% = 80; S.D. = 7)					
No. samples	8	8	8	8	8
Arithmetic mean	378	9270	33323	0.67	3.88
Median	272	4765	21558	0.71	3.07
Mode	49	2639	18030	0.69	2.97
Geometric mean	198	3936	11113	0.62	2.60
Minimum	32	515	200	0.20	0.25
Maximum	950	46144	139854	0.84	9.4
B *Stenella coeruleoalba*: *Liver* (EOM% = 23; S.D. = 16)					
No. samples	67	67	67	67	67
Arithmetic mean	203	20390	57834	0.78	3.35
Median	72	6167	20370	0.81	2.95
Mode	21	5153	18626	0.81	2.93
Geometric mean	70	7214	21424	0.77	2.97
Minimum	2	441	1074	0.33	c1.15
Maximum	1695	209110	610903	0.93	13.89
B *Tursiops truncatus*: *Liver* (EOM% = 21; S.D. = 13)					
No. samples	13	13	13	13	13
Arithmetic mean	301	10985	48171	0.78	7.30
Median	113	2714	25077	0.79	5.08
Mode	4	1713	5086	0.78	5.04
Geometric mean	65	2397	14031	0.77	5.85
Minimum	2	67	607	0.59	1.85
Maximum	1439	82665	208726	0.86	26.03

Table XIX
Continued

	HCB	DDTs	PCBS	pp'DDE/DDTs	PCBs/DDTs
	(ng g^{-1} d.w.)				
C *Stenella coeruleoalba*: *Muscle* (EOM% = 8; S.D. = 8-5)					
No. samples	59	59	59	59	59
Arithmetic mean	38	2310	5905	0.82	3.89
Median	6	877	2092	0.84	3.19
Mode	1	702	2091	0.84	3.19
Geometric mean	9	794	2666	0.81	3.36
Minimum	1	46	251	0.60	1.20
Maximum	767	60487	79486	0.91	12.28
C *Tursiops truncatus*: *Muscle* (EOM% = 16; S.D. = 9)					
No. samples	12	12	12	12	12
Arithmetic mean	64	5411	29313	0.80	5.47
Median	27	931	4671	0.82	5.16
Mode	11	419	2316	0.78	4.90
Geometric mean	23	1068	5380	0.80	5.04
Minimum	11	11	55	0.67	2.27
Maximum	185	31913	213811	0.89	8.30

total DDTs and PCBs in blubber were significantly different in the two species ($p<0.001$ and 0.01 respectively) (Figures 12a-b). In liver and muscle, however, we did not find significant differences between the two populations. The fact that in the blubber of striped dolphin, the mean quantities of these CHs are 10 times higher than in bottlenose dolphin, is difficult to explain, if not by different dietary input or different lipid constitution of the tissues. The first hypothesis is invalid because the two species have a similar diet, consisting of small fish of the herring family and ink-fish. The only difference is that *T. truncatus*, being coastal, mainly eats fish and *S. coeruleoalba* mainly cephalopods. As far as lipid content is concerned, *T. truncatus* is favoured by a higher EOM% too, and only different lipid composition of this tissue is presumably the basis of the differences observed. We were unable to find any literature relevant to the question.

The pp'DDE/DDTs ratio showed similar values in the organs and tissues of the two species, and any differences were not significant. On the other hand, there were significant differences in the PCBs/DDTs ratio in all tissues, with maximum significance in liver ($p<0.0001$ compared to 0.01 in blubber and muscle). The values of this ratio indicate that *T. truncatus* accumulates more PCBs relative to DDTs than *S. coeruleoalba*.

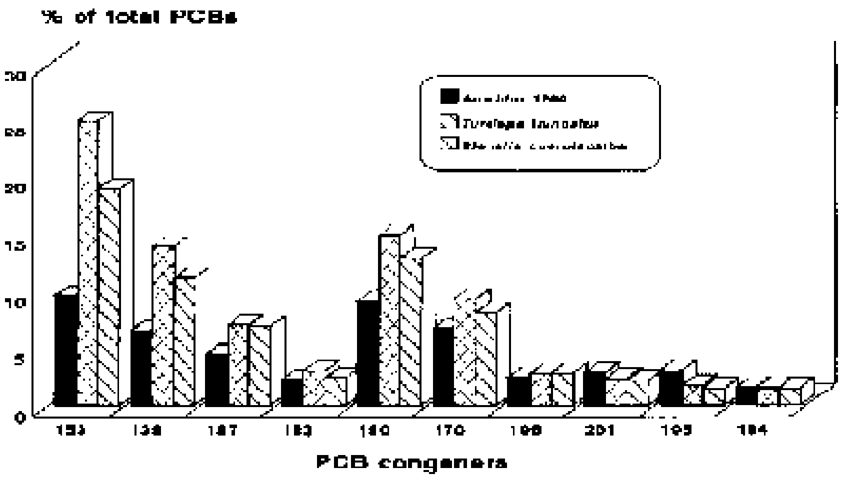

Figure 13. Relative percentages of the ten most frequent PCB congeners in blubber of *Stenella coeruleoalba* and *Tursiops truncatus* in relation to percentages in Arochlor 1260.

Table XX
PCBs and DDTs in blubber of the various species of cetaceans found stranded (geometric mean in ng/g d.w.)

Species	no. individuals	PCBs (ng/g d.w.)	DDTs (ng/g d.w.)
Stenella coeruleoalba	64	48965	86257
Tursiops truncatus	8	3936	10223
Steno bredanensis	1	7323	24501
Grampus griseus	1	303905	480114
Globicephala melaena	1	81354	150765
Balaenoptera physalus	2	3632	11082

As far as PCBs are concerned, the relative percentages with respect to total PCBs of the ten most frequent congeners in blubber are reported in Figure 13, together with the percentages of the same congeners in Arochlor 1260. The two dolphin species had a similar fingerprint: the congeners stored in greater percentages were 22’44’55’, 22’344’5’, 22’34’55’6, 22’344’55’ and 22’33’44’5’ (153, 138, 187, 180 and 170). All occurred in similar proportions in the dolphins and Arochlor 1260, except for 22’33’44’56 (195), which is slightly more abundant in the reference product.

Although the number of individuals was small, we thought it worthwhile comparing CH levels in blubber of the different species stranded along the Italian coasts. Table XX gives the geometric mean values of total DDTs and PCBs in these species. The cetacean having the highest levels of these xenobiotics was the grampus, and the lowest levels were found in *T. truncatus* and *B. physalus*. In this whale, low levels may be explained by its position in the food chain, but the same cannot be said for the dolphin. In their "Guide per il riconoscimento delle specie animali delle acque lagunari e costiere italiane. Cetacei", Cagnolaro et al. (1983) state that because *T. truncatus* often lives in close contact with man, it has adapted to various forms of pollution, including noise, and this may explain the success of this species in captivity. If it is really true that this species stores few contaminants by virtue of its capacity to adapt, it would be most interesting to study its biological responses to chemical stress.

4. Conclusions

It can be concluded from the present study that cetaceans are an extraordinary example of organochlorine bioaccumulators. There are marked differences between species and in a given species, storage is related to many parameters such as sex and age. Since we knew the sex of the animals found stranded, we were able to observe that differences between males and females were almost always significant in most of the organs and tissues analyzed, especially after sexual maturity.

The main storage tissue in all species was confirmed to be blubber. In view of its contribution to total body weight (about 20%) (Miyazaki et al., 1981; Ridgway and Harrison, 1986) its importance in the total burden of contaminants is evident.

pp'DDE accounted for more than 65% of total DDTs in all samples analyzed. This refers to contamination occurring considerable time ago and indicates the good metabolic capacity of these marine mammals to transform DDT.

The values of the PCBs/DDTs ratio show that most CH input in these animals has been due to PCBs. In the various tables showing levels in relation to sampling years, it is evident that this ratio is shifting in favour of PCBs. All congeners detected by gas chromatography had chlorine substitutions in positions 2, 3 and 5 and/or 2, 4 and 5 of at least one ring of the biphenyl radical. Those with fewer chlorines, except 22'44'5 (99), are quickly metabolized by these mammals, and so are those having adjacent carbons substituted in ortho-meta position. Congener 22'44'55' (153) was the most abundant in all samples analyzed.

HCB was detectable in most samples, but its concentrations were sufficiently low not to be determinant in total CH burden.

Although epidemics such as that of *Morbillivirus* can influence xenobiotic storage, we do not know whether the disease is the cause or effect of high concentrations of organochlorines in the tissues. There were large epidemics of this virus in the Mediterranean in 1990 and 1991. The levels of CHs found in the organs and tissues of cetaceans stranded in this period were significantly higher than in prior and successive years.

Because of their limited range, dolphins can be used to evaluate contamination in particular parts of the Mediterranean, such as the Ligurian or Ionian Seas. Our results indicate that the Sea with the highest toxicological risk is the Ligurian Sea. This is confirmed by the fact that its coasts are highly industrialized and there are many plant greenhouses. Products such as pesticides and fertilizers have these CHs as the active ingredient or a secondary product.

Another interesting indication emerging from our data is that there are considerable differences in xenobiotic accumulation in different species of delphinids. Sometimes, as in the case of *T. truncatus*, it is difficult to understand the results, because although *T. truncatus* is at about the same position in the food chain as *S. coeruleoalba*, it has much lower CH levels. Further study of its metabolic capacity may explain this phenomenon.

The main aim of this study was to provide an estimate of the toxicological risk to which these marine mammals are subject. Our cautious conclusion is that, considering the very high levels of CHs found in the organs and tissues of stranded individuals and their low detoxifying capacity with respect to land mammals (Watanabe et al., 1989) and without undervaluing the power of PCBs to depress the mammal immune system (Loose et al., 1977; Thomas and Hindsdill, 1978; Kunita et al., 1985; Vos and Luster, 1989; Brouwer et al., 1989), the toxicological risk to which these cetaceans are exposed is truly very high. The geographic characteristics of the Mediterranean Sea, a semi-closed basin with a single connection with the ocean via the Straits of Gibraltar, certainly make the situation worse. It is therefore essential to prohibit input of these substances if the marine ecosystem, and especially species at higher levels of the food chain, are to be conserved.

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