Bull. Environ. Contam. Toxicol. (2005) 75:149–156

DOI: 10.1007/s00128-005-0731-y

Bulletin of Environmental Contamination and Toxicology

Mother-Calf Transfer of Organochlorine Compounds in the Common Dolphin (*Delphinus delphis*)

A. Borrell, A. Aguilar

Department of Animal Biology, Av. Diagonal 645, Faculty of Biology, University of Barcelona, Barcelona 08071, Spain

Received: 10 December 2004/Accepted: 21 April 2005

Dolphins belong to one of the groups of wild vertebrates in which the highest organochlorine pollutant (OCs) levels have been detected (Tanabe 2002). This is mainly because dolphins have a high metabolic rate and feed at high trophic levels, and because the large proportion of fat their bodies contain facilitates the accumulation of large loads of organochlorine compounds. Moreover, Tanabe et al. (1988) and Norstrom et al. (1992) have shown that most odontocetes are incapable of metabolising certain PCB congeners, and thus their potential for accumulation is substantially greater than that of other mammals. Propensity to OC accumulation and limited degradation ability combine to make dolphins particularly susceptible to the impact of OCs. In marine mammals, these pollutants have been associated with a wide range of toxic effects, including reproductive impairment, depression of the immune system, carcinogenicity, bone and skeletal growth anomalies, interference with metabolism of retinoids, and a number of other physiological and organ disorders (Brouwer et al.1989; Zakharov et al. 1990; Busbee et al. 1999; Borrell et al. 2002; Martineau et al. 2002; Schwacke et al. 2002).

OCs are particularly toxic in the early developmental stages, and the threshold levels from which effects are to be expected are lower in embryos and calves than in adults. In particular, OCs have been identified as endocrine-disrupting chemicals that interfere with the production and metabolism of the natural hormones responsible for the maintenance of homeostasis and the regulation of reproduction and developmental processes (National Research Council 1999). The extent and form in which chemicals reach the offspring during pregnancy and lactation are thus important determinants of toxicity (Nau 1992; Rogers and Kavlock 2001). Like other lipophilic chemicals, OCs easily traverse placental membranes and are therefore transferred in variable quantities to the foetus. During lactation there is further mobilization of OCs from the blubber to the milk, and the transfer of these contaminants to offspring continues. While the magnitude of the reproductive transfer is extremely variable, ranging from 7 to 100% depending on species and compound (Duinker and Hillebrand 1979; Fukushima and Kawai 1981; Tanabe et al. 1982; Cockcroft et al. 1989; Aguilar and Borrell 1994; Borrell et al. 1995; Salata et al. 1995), it has been measured in only a few cetaceans. The aim of this paper is to determine the form and to quantify the magnitude of the transfer of OCs

Correspondence to: A. Borrell

in a mother-calf pair of common dolphins (*Delphinus delphis*). Little attention has been paid to OC transfer in this species, despite the fact that it inhabits the coastal waters of temperate latitudes and is thus frequently subject to high levels of OC exposure (Birkun et al.1999; Smyth et al. 2000; Borrell et al. 2001).

MATERIALS AND METHODS

On 1st August 1994, a lactating female and a 1.09-m-long male calf were caught entangled together in a driftnet type fishing net off the south-western Mediterranean coast of Spain. Blubber from the region posterior to the dorsal fin was excised from both individuals and stored at -20°C until analysis. Lipids were extracted from blubber using n-hexane in a Soxhlet apparatus, and lipid content was determined gravimetrically. Analysis of organochlorine compounds was carried out using capillary GC-ECS and following the procedures described by Borrell et al. (2001). The samples were analysed for the following compounds: *pp'*-DDE, *pp'*-DDD, *op'*-DDT, *pp'*-DDT and polychlorinated biphenyls (PCBs). tDDT concentration was calculated as the sum of the four DDT compounds and total PCB concentration (tPCB) as the sum of 18 individual peaks (IUPAC# 95, 101, 110+136, 151, 135+144, 149, 153, 138, 187, 183, 174, 177, 180, 170, 201, 196, 194). Since OCs are highly apolar compounds, concentrations in this paper are expressed in parts per million (mg/Kg) calculated on the basis of the weight of the extracted lipids (lipid basis). Recoveries of organochlorine compounds ranged 82-101% (n=12). The laboratory participated in interlaboratory calibration exercises for OCs in biota organized by Quasimeme (1998) and NIST/NOAA (2000 and 2003), obtaining fitting results.

OC burdens in the blubber, which are considered to represent more than 90% of the total load (Fukushima and Kawai, 1981; Borrell, 1993), were calculated as:

$$\text{OC burden} = \text{Body weight} \times \text{relative mass} \times \text{lipid content} \times \text{OC concentration}$$

where body weight was calculated through the body weight/body length relationship (Evans 1994) as 20 Kg for the calf and 70 Kg for the female, and the relative mass of the blubber, this is, the contribution of blubber to the total body weight expressed as a percentage, was established as 20% by similarity to the striped dolphin, *Stenella coeruleoalba* (Borrell 1993). Transfer rates for the various OC compounds were calculated as:

$$\text{Transfer rate} = \text{calf burden} / \text{female burden} + \text{calf burden}$$

RESULTS AND DISCUSSION

OC concentrations, lipid content, the blubber burdens of the female and the calf, and the percentage of the female concentrations and burdens transferred to the calf are presented in Table 1. Taking into account that neonatal length in the common dolphin is 90 cm and the growth rate during the first year of life 4.6 cm per month (Collet 1981), it is estimated that the calf (109 cm body long) was 3-4 months old.

Also, considering that captive calves have been seen to lactate for approximately 6 months and that the stomach of 6 wild individuals ranging 100-109 cm body length contained both milk and prey (Evans 1994), we assume that the calf here studied was approximately in the middle of its lactation period. As a consequence, if the calculated overall transfer rates were 55.41% of tDDT and 41.48% of tPCB (Table 1), then it is reasonable to infer that the total reproductive transfer at the end of the nursing period would approach 100%, a value that is consistent with previous estimations for other small odontocetes (Tanabe et al. 1982; Borrell et al. 1995; Fukushima and Kawai 1981).

However, the DDTs and PCBs were not transferred in the same proportion (Figure 1). tDDT concentrations were 3.4 times higher in the calf than in the female (Figure 1a), body burdens were also higher in the calf, and the mean transfer rates were estimated at 55.41% (Figure 1b). Conversely, tPCB concentrations were only 1.9 times higher in the calf than in the female (Figure 1a), calf body burdens were lower than those of the female, and the mean transfer rates were estimated at 41.48% (Figure 1b). We can thus conclude that DDTs are more easily transferred to offspring than PCBs, a finding supported by previous comparable studies in cetaceans (Fukushima and Kawai 1981; Tanabe et al. 1982; Aguilar and Borrell 1994; Borrell et al. 1995; Salata et al. 1995). This difference can be associated with the molecular structure of the forms that dominate the OC mixtures that contaminate the tissues of marine top predators.

Thus, the PCBs usually present in marine mammals are dominated by congeners that on average are more highly chlorinated than the DDT forms. In this study, the PCB congeners detected had between 5 and 8 chlorine atoms, while the various DDT molecules only had 4 or 5 chlorines (Table 1). Virtually any substance present in the maternal plasma is transported to some extent to the placenta by simple passive diffusion; however, the rate and extent of transfer is known to be significantly modified by factors such as lipid solubility and the molecular weight of the compound (Nau 1992). Transplacental passage is easier for chemicals of low molecular weight, which in OCs is associated with a low chlorination of the molecule, than for those with high molecular weight, which is associated with a high number of chlorine substitutions (Juchau 1983), thus explaining the differences here observed. Lipophilic compounds are also readily transferred to milk, and again there are some differences, depending on the physicochemical properties of the compound: the highly chlorinated organochlorines, such as the PCBs found here, are less efficiently transferred from the body lipid depots to the circulatory system, and thence to the milk, than are those low-chlorinated substances such as the DDT forms (Aguilar and Borrell 1994).

Also as a consequence of the molecular kinetics described above, the relative concentration of the less chlorinated (5 and 6 chlorines) PCB congeners in relation to the total PCB load was higher in the calf than in the female, while the female had a higher relative concentration of congeners, with 7 or 8 chlorines (Figure 1c). Thus, as can be seen in Figure 1c, the percentage of transfer declines inversely with the number of chlorines (from 46% to 25%).

Table 1. Organochlorine concentration (mg/Kg lipid weight basis), blubber burden (mg) and relative proportion of individual PCB congeners to total PCBs in the blubber of the female and the calf, and percentage of transfer from female to calf

		Conc. (ppm)		Burden (mg)		% transfer		%cong/tPCB	
		female	calf	female	calf	female to calf		female	calf
length (m)		1.90	1.09						
%lipid content		57	73						
	n.Chlorine						mean		
ppDDE	4	2.10	6.72	16.8	19.6	53.9			
ppTDE	4	0.25	0.82	2.0	2.4	54.5			
opDDT	5	0.18	0.74	1.4	2.2	60.1			
ppDDT	5	0.35	1.50	2.8	4.4	61.1			
tDDT		2.88	9.78	23.0	28.6	55.4	55.4		
congener IUPAC #									
95	5	0.17	0.41	1.3	1.2	47.3		3.3	4.2
101	5	0.22	0.45	1.8	1.3	42.5		4.4	4.7
110/136	5/6	0.04	0.10	0.3	0.3	48.6	46.1	0.7	1.0
151	6	0.15	0.31	1.2	0.9	42.7		2.9	3.2
135/144	6	0.11	0.18	0.9	0.5	37.2		2.1	1.9
149	6	0.50	1.18	4.0	3.4	46.5		9.5	12.2
153	6	0.88	1.89	7.1	5.5	43.9		16.8	19.5
138	6	0.58	1.33	4.7	3.9	45.5	43.2	11.1	13.8
187	7	0.40	0.69	3.2	2.0	38.9		7.5	7.1
183	7	0.20	0.39	1.6	1.1	41.5		3.8	4.0
174	7	0.17	0.36	1.3	1.1	44.1		3.2	3.7
177	7	0.09	0.18	0.7	0.5	42.8		1.7	1.9
180	7	0.58	0.96	4.6	2.8	37.8		11.0	9.9
170	7	0.44	0.71	3.5	2.1	36.9	40.3	8.5	7.3
201	8	0.18	0.19	1.5	0.6	27.6		3.5	2.0
196	8	0.24	0.26	1.9	0.8	28.3		4.6	2.7
194	8	0.12	0.08	1.0	0.2	20.0	25.3	2.3	0.8
tPCB		5.07	9.67	41.9	29.7	41.5	41.5		

(mean=mean of the several compound percentage transfers according to the degree of chlorination).

Previous results in odontocetes (Subramanian et al. 1988; Stern et al. 1994; Salata et al. 1995; McKenzie et al. 1997; Gauthier et al. 1998) are consistent with this pattern: calves always have a higher proportion of the less chlorinated PCB congeners than adult females.

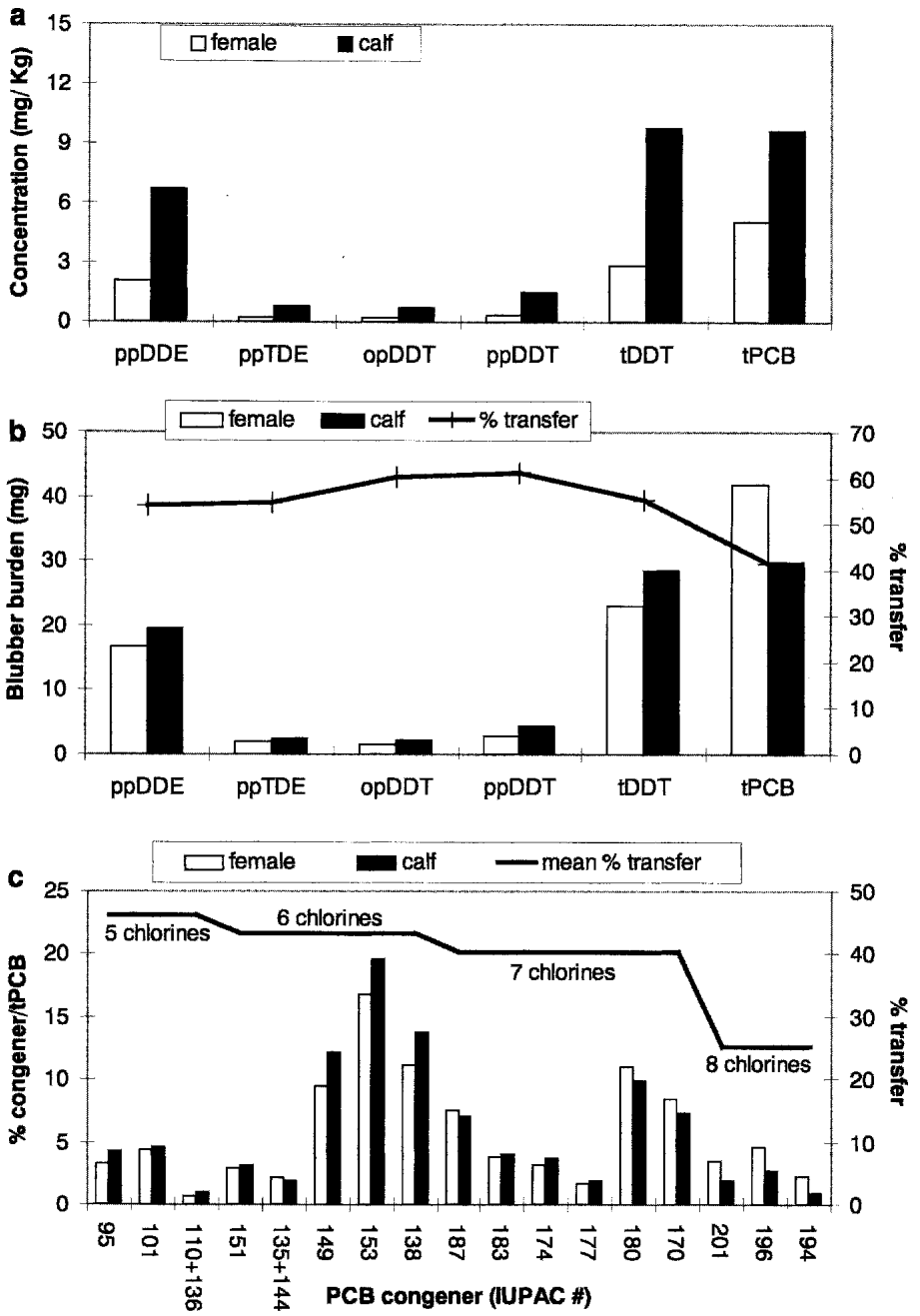

Figure 1. For the female and the calf: **a)** Concentrations of DDTs and tPCB, **b)** Blubber burdens and % reproductive transfer of DDTs and tPCB and **c)** Relative PCB congener concentration to tPCB and the transfer percentage per different chlorinated group.

Toxicity is more likely to occur during pregnancy and lactation than in any other stage of the life cycle. This is so because individuals are more susceptible to chemical insult during their development, but also because there appears to be an overall decrease in hepatic xenobiotic biotransformation during pregnancy (Juchau and Faustman-Watts 1983). Recent research suggests that the toxic effect of OCs in small cetaceans may be severe in newborns and may lead to lowered survivorship (Schwacke et al. 2002; Wells et al. in press; Hall et al. in press). The insult may occur through a direct effect on the descendant, indirectly through toxicity of the agent to the mother and/or the placenta, or a combination of the two (Rogers and Kavlock 2001). Among females, those that are primiparous are the ones that carry the highest levels of OCs (Aguilar et al. 1999). The evidence that reproductive transfer of OCs in common dolphins reaches practically 100% of the mother's burden suggests that common dolphin populations subject to high levels of OC exposure and, particularly, the calves born from primiparous females, are prone to suffer the toxicity of these pollutants and should therefore be monitored with particular attention.

Acknowledgments. This study was possible through funding granted by the Dirección General de Conservación de la Naturaleza-DGCONA, Ministerio de Medio Ambiente of Spain. While this survey was written, A. Borrell was supported by a "Ramón y Cajal" research contract.

REFERENCES

Aguilar A, Borrell A (1994) Reproductive transfer and variation of body load of organochlorine pollutants with age in fin whales (*Balaenoptera physalus*). Arch Environ Contam Toxicol 27:546-554

Aguilar A, Borrell A, Pastor T (1999) Biological factors affecting variability of persistent pollutant levels in cetaceans. J Cetacean Res Manage Special Issue 1: 83-116

Birkun A, Kuiken T, Krivokhizin S, Haines DM, Osterhaus ADME, van de Bildt MWG, Joiris CR, Siebert U (1999) Epizootic of morbilliviral disease in common dolphins (*Delphinus delphis ponticus*) from the Black Sea. Vet Rec 144:85-92

Borrell A (1993) Dinàmica dels compostos organoclorats en la balena d'aleta el cap d'olla d'aleta llarga i el dofí llistat d'aigues atlàntiques i mediterrànies. Ph D Dissertation, University of Barcelona, Barcelona, Spain

Borrell A, Bloch D, Desportes G (1995) Age trends and reproductive transfer of organochlorine compounds in long-finned pilot whales from the Faroe Islands. Environ Pollut 88:283-292

Borrell A, Cantos G, Pastor T, Aguilar A (2001) Pollution by organochlorine compounds in common dolphins (*Delphinus delphis*) from the Atlantic and Mediterranean waters off Spain. Environ Pollut 114:265-274

Borrell A, Tornero V, Aguilar A (2002) Retinoids in marine mammals and their use as biomarkers of organochlorine compounds. J Cetacean Res Manage 4: 203-211

Brouwer A, Reijnders PJH, Koeman JH (1989) Polychlorinated biphenyl (PCB)-contaminated fish induces vitamin A and thyroid hormone deficiency in the common seal (*Phoca vitulina*). Aquat Toxicol 15:99-106

Busbee D, Tizard I, Stott J, Ferrick D, Ott, R E (1999) Environmental pollutants and marine mammal health: The potential impact of hydrocarbons and halogenated hydrocarbons on immune system dysfunction. J Cetacean Res Manage Special Issue 1:223-248

Cockcroft VG, De Kock AC, Lord AD, Ross GJB (1989) Organochlorines in bottlenose dolphins Tursiops truncatus from the east coast of South Africa. South African J Mar Sci 8:207-217

Collet A (1981) Biologie du dauphin commun Delphinus delphis L en Atlantique Nord-Est. Ph D Dissertation, University of Poitiers, Poitiers, France

Duinker JC, Hillebrand MTJ (1979) Mobilization of organochlorines from female lipid tissue and transplacental transfer to fetus in a harbour porpoise (*Phocaena phocaena*) in a contaminated area. Bull Environ Contam Toxicol 23:728-732,

Evans WE (1994) Common dolphin, white-bellied porpoise *Delphinus delphis* Linnaeus 1758. In Ridgway SH, Harrison R (eds) Handbook of marine mammals, vol 5. The first book of dolphins. Academic Press, London p191

Fukushima M, Kawai S (1981) Variation of organochlorine residue concentration and burden in striped dolphin (*Stenella coeruleoalba*) with growth. In: Fujiyama T (ed) Studies on the levels of organochlorine compounds and heavy metals in the marine organisms. University of the Ryukyus, Okinawa, p 97

Gauthier JM, Pelletier E, Brochu C, Moore S, Metcalfe CD, Beland P (1998) Environmental contaminants in tissues of a neonate St Lawrence beluga whale (*Delphinapterus leucas*). Mar Pollut Bull 36:102-108

Hall AH, McConnell BJ, Rowles TK, Aguilar A, Borrell A, Schwacke L, Wells RS (in press) An individual based model framework to assess the populationconsequences of polychlorinated biphenyl exposure in bottlenose dolphins.Environ Health Persp

Juchau MR (1983) Diposition of chemical contaminants in maternal-embryonic/fetal systems. In: Saxena J (ed) Hazard Assessment of Chemicals. Current developments, vol 2. Academic Press, New York, p95

Juchau MR, Faustman-Watts EM (1983) Pharmacocinetic considerations in the maternal-placental unit. Clin Obstet Gynecol 26:379-390

Martineau D, Lemberger K, Dallaire A, Labelle P, Lipscomb TP, Michel P, Mikaelian I (2002) Cancer in wildlife, a case study: Beluga from the St. Lawrence estuary, Quebec, Canada. Environ Health Perspect 110:285-292

McKenzie C, Rogan E, Reid RJ, Wells DE (1997) Concentrations and patterns of organic contaminants in Atlantic white-sided dolphins (*Lagenorhynchus acutus*) from Irish and Scottish coastal waters. Environ Pollut 98:15-27

National Research Council (1999) Hormonally active agents in the environment. National Academy Press, Washington DC

Nau H (1992) Physicochemical and structural properties regulating placenta drug transfer. In: Polin RA, Fox WW (eds) Fetal and Neonatal Physiology, vol 1. Saunders, Philadelphia. p130

NISR/NOAA (2000) Interlaboratory comparison exercise program for organic contaminants and trace elements in marine mammal tissues. NISTIR 6849. Charleston, USA

NIST/NOAA (2003) Interlaboratory comparison exercise program for organic contaminants in marine mammal tissues. Charleston, USA

Norstrom RJ, Muir DCG, Ford CA, Simon M, Macdonald CR, Beland P (1992) Indications of P450 Monooxygenase activities in beluga (*Delphinapterus leucas*) and narwhal (*Monodon monoceros*) from patterns of PCB, PCDD and PCDF accumulation. Mar Environ Res 34:267-272

QUASIMEME (1998) Laboratory Performance Studies Round 14, Exercise 376 BT-2, 1998, Aberdeen, UK

Rogers JM, Kavlock RJ (2001) Developmental toxicology. In Klaassen CD (ed.) Casarett and Doull's Toxicology, 6th Edition. McGraw-Hill, New York. p351

Salata GG, Wade TL, Sericano JL, Davis JW, Brooks JM (1995) Analysis of Gulf of Mexico bottlenose dolphins for organochlorine pesticides and PCBs. Environ Pollut 88:167-175

Schwacke LH, Voit EO, Hansen LJ, Wells RS, Mitchum GB, Hohn AA, Fair PA (2002) Probabilistic risk assessment of reproductive effects of polychlorinated biphenyls on bottlenose dolphins (*Tursiops truncatus*) from the southeast United States coast. Environ Toxicol Chem 21:2752-2764

Smyth M, Berrow S, Nixon E, Rogan E (2000) Polychlorinated biphenyls and organochlorines in by-caught harbour porpoises *Phocoena phocoena* and common dolphins *Delphinus delphis* from Irish coastal waters. Proc Roy Irish Acad 100B:85-96

Stern GA, Muir DCG, Segstro MD, Dietz R Heide-Jorgensen MP (1994) PCB's and other organochlorine contaminants in white whales (*Delphinapterus leucas*) from West Greenland: variations with age and sex. Meddelelser Grønland Biosci 39:245-259

Subramanian A, Tanabe S, Tatsukawa R (1988) Use of organochlorines as chemical tracers in determining some reproductive parameters in Dalli-type Dall's porpoise *Phocoenoides dalli*. Mar Environ Res 25:161-174

Tanabe S (2002) Contamination and toxic effects of persistent endocrine disrupters in marine mammals and birds. Mar Pollut Bull 45:69-77

Tanabe S, Tatsukawa R, Maruyama K, Miyazaki N (1982) Transplacental transfer of PCBs and chlorinated pesticides from the pregnant striped dolphin (*Stenella coeruleoalba*) to her fetus. Agric Biol Chem 46:1249-1254

Tanabe S, Watanabe S, Kan H, Tatsukawa R (1988) Capacity and mode of PCB metabolism in small cetaceans. Mar Mammal Sci 4:103-124

Wells RS, Tornero V, Borrell A, Aguilar A, Rowles T, Rhinehart H L, Hofmann S, Jarman WM, Hohn AA, Sweeney JC (in press) Integrating life history and reproductive success data to examine potential relationships with organochlorine compounds for bottlenose dolphins (*Tursiops truncatus*) in Sarasota Bay, Florida. Sci Total Environ

Zakharov VM, Yablokov AV (1990) Skull asymmetry in the Baltic grey seal: effects of environmental pollution. Ambio 19:266-269