MERCURY ACCUMULATION IN DELPHINIDAE

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ABSTRACT

The aim of this work is an attempt to synthetize the different results of our researches on dolphin's contamination by Hg and their interpretation. It is based on the results obtained following the total Hg determination in several organs of 35 specimens of *Stenella coeruleoalba* stranded on French Atlantic and Mediterranean coasts and 45 *Stenella attenuata* captured in the Eastern tropical Pacific. Considering our present knowledge on Hg ecotoxicological processes, the trophic route, via cumulative Hg transfers through the marine trophic network, can be considered as the major contamination route for the dolphins. However, considering the influence of the geographical origin of the individuals it also seems reasonable to assume that the principal contamination source of the high Hg concentrations observed in pelagic dolphins are natural metal deposits.

1. INTRODUCTION

Because of their position at the end of the trophic network, their long life span, and also because of their specificity of mammals adapted to marine life, Delphinids are considered as a particularly interesting biological material for ecotoxicological studies. However, confronted with many restrictions basically associated with sampling difficulties due to economic, technical and legal reasons, many authors have only published occasional studies on dolphin's contamination by Hg compounds. Thus, among the previous works published in this field, only a few of them had at their disposal enough samples and biological and ecological information in order to conduct a complete study supported by a statistical approach.

Based on two successive research programs (1983-84 and 1984-89) the present work establishes results from 79 individuals, 35 *Stenella coeruleoalba* originating from French Atlantic and Mediterraean coasts, and 44 *Stenella attenuata* captured in the Eastern tropical zone of the Pacific ocean. These results, associated with adapted statistical methods, and compared with available bibliographic information on fish or terrestrial mammals, will allow us to determine the levels of contamination, (concentrations and burdens) and the relative influences of each of the biological or ecological factors taken into account.

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2. MATERIALS AND METHODS

Sampling procedure : During the period 1972-80, 10 specimens of *Stenella coeruleoalba* were collected on the French Atlantic coasts, and 27 on the French Mediterranean coasts. These dolphins were sampled by a network set up by the Centre National d'Etudes des Mammifères Marins (Musée Océanographique, La Rochelle, France). As described in Andre *et al.*, 1990d, samples were obtained from the following organ and tissues : liver (35 individuals), kidneys (36), skeletal dorsal muscle (22), fat of the melon (forehead region)(20), stomach (29) and intestine (13). For the last two organs, almost all samples came from dolphins originating from the Mediterranean sea.

The 44 *Stenella attenuata* specimens used in this study originated from the Eastern tropical Pacific. They were accidentally captured, either in small groups or individually, during commercial tuna seining operations, between 1977 and 1983. The exact locations of capture are known for most of the specimens. They cover a vast area offshore from Central America, between 18° latitude North and 15° latitude South from the coast out to 140° longitude West. The whole sampling procedure for this population has already beeen described in earlier work (Andre *et al*, 1990b). Eleven organs were sampled - liver, right and left kidneys, forestomach (stomach I), fundic stomach (stomach II), intestine, spleen, heart, lungs, brain and pancreas -, and 5 tissue samples were also taken - skeletal muscle, blood, blubber, skin and melon fat -. Each whole organ collected was wiped with absorbent paper and weighed (fresh weight, ± 1g). The age of the dolphin of the *Stenella attenuata* species was estimated at the "Centre National d'Etude des Mammifères Marins", La Rochelle (France), by counting tooth growth layer groups (GLG) and assuming that one GLG is deposited each year, as described by Kasuya (1972), Perrin *et al.* (1977) and Gurevich and Stewart (1980).

Analytical methods : Mesurement of the total Hg was carried out by atomic absorption spectrometry without flame (Spectrophotometer VARIAN AA 475). Each sample, weighing approximately 1g (fresh weight), was first mineralized by a pure HNO_3 treatment, in a pressurized medium (Pyrex glass tube) at 95°C for 3 hr. A treatment with Br salts was applied before addition of stannous chloride (Farey *et al.*, 1978). The detection limit is 5 ng Hg.

The validity of the analytical method was checked periodically, using dosage standards (National Bureau of Standards, Washington ; International Atomic Energy Agency, Monaco ; Kernforschunganlage, Julich) and intercalibration exercises on the same matrix, i.e. dolphin muscle lyophilizate, with other laboratories (Andre *et al.*, 1990b, d)

Results were expressed according to fresh weight of the organs, using two contamination criteria : concentration, in mg $Hg.kg^{-1}$ or ppm ; burden or content, in mg Hg. Burden was calculated only for *Stenella attenuata* from the weight of the collected organs, and for some tissues - muscle and blubber - weights were estimated, using models available in literature, based on the total weight of individuals (Miyazaki *et al.* 1981). For the other three tissue samples - blood, skin and melon fat - we have no available estimation models. Results are thus based only on concentration.

Data processing : The different steps of the data processing refers to those of Andre *et al.*, 1990b, c, d. Averages, coefficients of variation (%), minima and maxima values were quoted to provide a descriptive study of Hg accumulation. To establish and to quantify the influence of the different ecological or biological factors different techniques were used using, the non parametric Mann and Whitney test, the simple linear regression, and the multilinear regression after verification of the current hypotheses relating to this method (Dagnelie, 1974 ; Scherrer, 1982 ; Tomassone *et al.*, 1983).

Multiple regression models were established for the *Stenella attenuata* population with two explained variables - concentration (C) and burden (B) - after logarithmic transformation, considering the following regressors : log age (A) in yr ; log weight (Wt) in kg ; latitude of place of capture (La), in degrees from the equator ; longitude of place of capture (Lo), in degrees ; sex (S), as qualitative variable (male : +2 ; females : -2); date of capture as year (Y) and month (M).

The multiple regression models were based on the following general structure : log (Concentration or Burden) = b0 + b1 log (Age or Total Weight) + b2 (Sex) + b3(Latitude) + b4(Longitude) + b5(Year) + b6(Month).

The final choice of the models was based on the values of "F", with an alpha risk equal to 0.05 or 0.01, according to a procedure by which explicative variables were introduced gradually.

3. RESULTS AND DISCUSSION

The average concentrations of total Hg in the organs and tissues analyzed are given in Table I, as well as the minimal and maximal values, and the coefficients of variation.

PACIFIC	LI	KI -1	KI -2	MU	ME	ST -1	ST -2	IN -1	IN -2	IN -3
X	62,72	5,58	4,86	2,26	0,40	2,68	2,27	2,15	1,71	2,20
CV %	85,64	60,50	61,95	91,83	108,95	88,05	97,44	95,16	106,82	106,52
m	0,18	0,08	0,03	0,10	0,00	0,00	0,00	0,02	0,01	0,03
M	217,52	14,16	13,49	9,17	1,67	9,39	9,18	7,40	6,85	11,17

	SP	BL	HE	LU	SK	BR	PA	BU
X	10,30	0,36	1,81	2,98	1,90	1,95	6,59	7,61
CV %	207,61	86,69	80,30	191,95	96,19	127,36	243,84	237,19
m	0,02	0,01	0,02	0,00	0,00	0,02	0,03	0,01
M	109,04	1,45	5,89	30,33	6,10	8,86	99,03	87,26

MEDITERRANEAN	LI	KI -1	MU	ME	ST -1	IN -1
X	346,06	30,39	28,33	1,76	13,71	16,19
CV %	102,95	111,86	103,45	87,52	71,55	59,41
m	1,20	1,40	1,00	0,18	1,10	2,80
M	1544,00	178,90	81,20	4,70	33,00	31,00

ATLANTIC	LI	KI -1	MU	ME	ST -1	IN -1
X	51,64	7,37	3,76	0,54	3,40	1,70
CV %	56,25	66,04	98,74	56,47	79,03	
m	1,20	2,90	1,50	0,10	1,50	1,70
M	87,00	15,00	12,00	0,90	5,30	1,70

TABLE I Total Hg concentrations in the organs and tissues of *Stenella attenuata.* from the Eastern tropical Pacific, and *Stenella coeruleoalba* from the Mediterranean sea and the Atlantic ocean. Total Hg concentrations in the organs (mg.kg^{-1}, fresh weight) : LI = liver, KI-1 = left kidney, KI-2 = right kidney, MU = muscle, ME = melon fat, ST-1 = forestomach, ST-2 = fundic stomach, IN-1 = pyloric intestine, IN-2 medium intestine, IN-3 rectal intestine, SP = spleen, BL = blood, HE = heart, LU = lungs, SK = skin, Br = brain, PA = pancreas, BU = blubber ; X = average concentration of total Hg ; CV% = coefficient of variation ; m and M = minima and maxima concentration values.

The average concentrations measured varied from the detection limit of our determination method to several tens or several hundreds of mg Hgt.kg^{-1}, with the maximal reading being 1544 mg Hg.kg^{-1} in the liver of a dolphin *Stenella coeruleoalba* stranded on the Mediterranean coasts. More precisely, depending on the organ or tissues considered, the observed average concentrations are between : 0.36 mg Hg.kg^{-1} in the blood, to 62 mg Hg.kg^{-1} in the liver, for the Pacific and Atlantic sub-samples. Note that for these latters the average contamination level in most of the organs was between 1 and 7 mg Hg.kg^{-1} ; and between 1.76 mg Hg.kg^{-1} in the melon fat to 346 mg Hg.kg^{-1} for the Mediterranean sample.

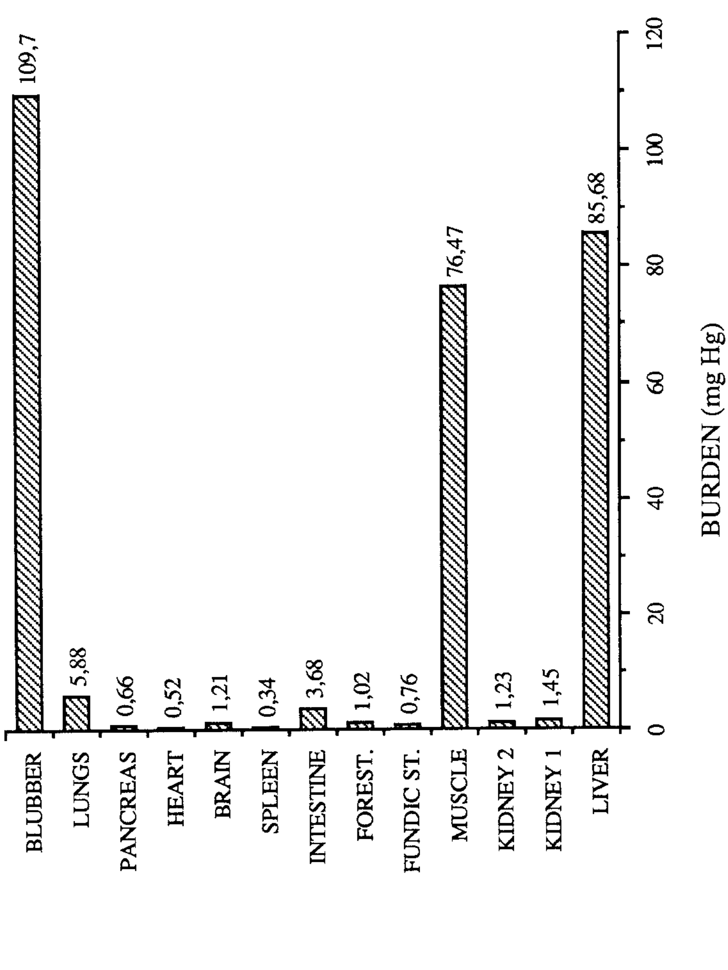

Figure 1. Distribution of total Hg in the different organs and tissues of *Stenella attenuata* according to average burdens - mg Hg -.

For each organ considered there was a very wide scattering of results. Coefficients of variation were between 56 and 250 % .

Such high Hg concentrations in marine mammals have been reported previously, in particular in specimens from the Mediterranean sea ; for instance, a concentration of 905 mg $Hgt.kg^{-1}$ was detected in a *Grampsus griseus* specimen (Carraciolo *et al.*, 1972 ; Thibaud and Duguy, 1973 ; Martoja and Viale, 1977 ; Viale, 1978). But generally, the publications that we have consulted relating to the Cetaceans give concentrations of total Hg, always in relation to the fresh weight, which vary from 3 to 200 $mg.kg^{-1}$ for the liver ; 0.02 to 6 $mg.kg^{-1}$ for the muscle ; and from 1 to 2 $mg.kg^{-1}$ for the kidneys (Falconer *et al.*, 1983 ; Honda *et al.*, 1983a, 1987 ; Wagemann and Muir, 1984 ; Julstamn *et al.*, 1987 ; Fujise *et al.*, 1988).

Considering the species *Stenella coeruleoalba* or *Stenella attenuata* in other geographical areas, high Hgt concentrations have also been observed, especially in the Western Pacific ocean near the Japanese coasts : for *Stenella coeruleoalba* , 30 mg $Hg.kg^{-1}$ in the skeletal muscle or 475 mg $Hg.kg^{-1}$ in the liver (Itano *et al.*, 1984 ; Honda *et al.*, 1983a) ; and for *Stenella attenuata* , (Honda *et al.*, 1983a, b), the Hg concentrations that have been reported range from 0.4 to 15.7 $mg.kg^{-1}$ in the muscle ; from 1.7 to 485 $mg.kg^{-1}$ in the liver ; from 0.9 to 17.6 $mg.kg^{-1}$ in the kidneys. These values are associated with coefficients of variation of 57.9, 67.5 and 69.7 %, respectively.

In all cases, the liver of marine mammals is the most contaminated organ (e.g. Risebrough, 1978 ; Gaskin, 1982 ; Wageman and Muir, 1984).

The analysis of the average concentrations (Table I) shows that the level of contamination in the liver is clearly the highest one. It is about six to ten times greater than the average concentration measured in the organ with the second highest level, respectively the spleen for the Pacific dolphins and the kidneys for the Atlantic samples.

For the *Stenella attenuata* (Pacific species), five groups of organs or tissues can be distinguished in order of decreasing concentrations : liver >> spleen, blubber, kidneys 1 and 2, pancreas > lungs and fundic stomach > intestine 3, forestomach, skeletal muscle, intestine 1, brain heart, skin and intestine 2 > melon fat and blood. Very clear differences in distribution were observed according to the contamination criterion considered (concentration and content - Figure 1). Hence, 95% of the estimated total burden present in the organs collected are localized in three tissue compartments liver, skeletal muscle and blubber.

Based on this results, how can be explained the different steps of the Hg contamination in delphinids, and how the different ecotoxicological factors occur ?

Mercury absorption :

Hg absorption in dolphins can occur via pulmonary, cutaneous and digestive barriers. The direct contamination route, from Hg present in its free state in the water, is thought to be of only minor importance in Delphinids. Concentrations measured in the marine environment indicate a wide range of Hg, but they are indeed very low (Fitzgerald, 1979). The fact that the integumentary barrier has no hair and no sudoriparous glands, which in terrestrial mammals can favor absorption of the metal, and providing that no serious lesions are present, represents an efficient means of protection against penetration by Hg into the organism.

In terrestrial mammals, contamination via the pulmonary barrier generally occurs only when exposure conditions are acute. The Hg content we observed in the lungs of the dolphins from the Pacific ocean was not negligible, representing about 2 % of the accumulated Hg in all the organs studied. This Hg could be endogenous in origin, being derived from exchanges between blood and lung tissue, related to the high rate of irrigation of this organ.

The third contamination route , via consumed prey, is considered by many authors to be the most significant in relation to the bioaccumulation of Hg. Dolphins are at the end of the trophic networks. There are cumulative transfers between the different links in the alimentary chains. They have a long life span. All this means that these organisms are targets for bioamplification processes (Gaskin, 1982). However, absorption via the digestive barrier is very much dependent on the chemical form of Hg ingested. In Dolphins, the Hg content of consumed prey - fish and Cephalopoda - is essentially in methylated form, thus facilitating trophic transfers (Pentreath, 1976 ; Huckabee *et al.*, 1978). Which parts of the dolphin's digestive tract are responsible for Hg absorption is not known. Several statements can be made, however, based on the anatomic and physiological characteristics of this organ and taking into account available data on other species. The function of the forestomach is basically to crush and store the food ; in the fundic stomach, further down the digestive tract, the first stage of digestion is carried out (Desportes, 1985). It is in this second stomach that the Hg, which is fixed mainly on the food proteins, can be partly mobilized and transformed chemically by the acidity of the second gastric cavity. In the proximal part of the intestine, the absorption of nutrients, and probably of Hg, takes place : direct transfer - free Hg - or indirect transfer - metal fixed on the amino-acids or peptides liberated during the digestion process -. In mammals and fish the distal part of the intestine is generally where reabsorption processes occur (Northseth and Clarkson, 1971 ; Fontaine, 1981).

Mercury distribution :

Once the penetration barriers have been crossed, the Hg reaches the blood compartment, which transports it to the other organs and tissues. In terrestrial mammals, as in fish, MeHg is mainly localized in the red cells, fixed on the thiol groups in haemoglobin ; inorganic mercury, on the other hand, is more likely to be bound to plasmatic proteins (albumins and globulins- Giblin and Massaro, 1973, 1977).

The metal distribution in the different organs is influenced by many factors : contamination routes ; amounts absorbed ; length of exposure ; chemical forms and species of Hg ; etc. . It is important to note that the proportion of organic Hg in the dolphins is not homogeneous in all the tissues considered (Gaskin *et al.*, 1979). E.g. the low levels of MeHg in the hepatic tissue could be explained by several hypotheses including demethylation mechanisms, suggested after experimental studies on Pinnipeds (Tillander *et al.*, 1972; Ronald *et al.*, 1975, 1977) or Hg-MeHg interactions, indicated by the formation of tiemannite or mercuric selenide crystals (Martoja and Berry, 1980).

Mercury elimination :

In mammals, the elimination of Hg into the external environment is based on the excretion of urine and, more important, on the intestinal excretion through the faeces (in man, 80% of the metal is excreted in organic form via faecal route - (Haguenoer and Furon, 1982). We should also mention the role played by biliary excretion, although large quantities of MeHg may be reabsorbed by means of the entero-hepatic circulation (Mitra, 1986). By analogy with terrestrial mammals, the reproductive cycle of the dolphins can represent an indirect decontamination route for the female. Indeed, MeHg crosses the placental barrier and can accumulate in the foetus, where the higher haematocritic rate facilitates this transfer even further (Jernelov, 1986). The milk, too, contains Hg, mainly in organic form but in women these concentrations were found to be twenty times lower than in the blood (Neathery *et al.*, 1974 ; Jernelov, 1986).

Bioaccumulation and transformation of mercury in the dolphin's organism :

According to Boudou and Ribeyre, 1989, the bioaccumulation is defined as the difference between biouptake and decontamination mechanisms - the latest being represented by two features, effluxes and biotransformations -. The bioaccumulation processes are influenced by genetic variability within the population studied, but moreover directly or indirectly by actions and interactions between many ecotoxicological factors.

The biological half-life of Hg in the organisms is closely dependent on many variables that intervene in the processes of storage at cell level and on inter-organ transfers. Experimental approaches to decontamination have shown that the elimination of Hg occurs in stages, with the metal being retained for much longer periods as the accumulation level in the organism decrease. Once again published results are very heterogeneous, depending on species, age of individuals, chemical form of the metal, contamination routes, etc. . We should specify that these estimates are based on the concentration criterion, which is directly influenced by organism and organ growth (effect of "growth dilution" - Niimi, 1983). In man, the half-life of CH_3Hg seems to be between 70 to 120 days; for inorganic Hg it is less, at about 40 to 70 days (Venugopal and Luckey, 1979; Clarkson, 1984). In fish results seem to show much longer time for MeHg, ranging from 200 days to 4 to 7 yr for different authors (Yamanaka *et al.*, 1974 ; Buffoni *et al.*, 1982). In Pinnipedes, the half-life is about 500 d (Tillander *et al.*, 1972) ; in dolphins, estimates provided by Itano and Kawai (1981a) are of 1000 days for the species *Stenella coeruleoalba.* There are several mechanisms involved in this retention of Hg in the organisms. The processes of intracellular storage, for instance, tend to increase concentrations of the metal in certain organs, while reducing the ecotoxicological risks. This is the case with i) the complexifying action of Se (Itano and Kawai, 1981b ; Itano *et al.*, 1984) ii) the metallothioneins (MT). Studies carried out on marine mammals (Olafson and Thompson, 1974 ; Lee and Jones, 1977 ; Hamanaka *et al.*, 1982 ; Mochizuki *et al.*, 1985 ; Tohyama *et al.*, 1986) have confirmed the presence of MTs in the liver and kidneys of these organisms. The inductive role of Hg is disputed, however, especially in fish, depending on the chemical form involved (Hamilton and Merhle, 1986). Moreover, we should note that the confining and detoxifying roles played by the MTs are closely dependent on contamination conditions, as the arrival of the metals at the intracellular level has to be matched by adequate production of these molecules ("spillover" theory - Winge *et al.*, 1974). In vertebrates, and in particular in the hepatocytes of marine mammals, other forms of Hg storage have been described, as dense granules, which vary in size. Studies using microanalysis X have shown that this is a type of "fossilization" of an entire group of metals, such as Se, Au, Hg, Cd, ... These granules are virtually undegradable and they thus eliminate part of the toxicity of each element, both for the contaminated individual and also for any possible predators (Martoja and Martoja, 1985). Lastly, we should mention again the presence of tiemannite which is not destroyed by the proteolitic enzymes and which may thus represent a terminal phase in the reactions of MeHg detoxification of the liver (Martoja and Berry, 1980).

These bioaccumulation phenomenons are influenced by various ecotoxicological factors. As explained before, among the numerous possible factors, the present work undertake the following major ones : age, total weight or length, sex, geographical location.

Age, total weight and lenth : In many aquatic organisms Hg concentrations increase with age, total wieght or length. We have seen in the last paragraph that a such increase is notably due to the high uptake efficiency of MeHg an its low release.

The pattern of the increase of Hg with size and age can be explained with the characteristic of growth of the dolphins. This is showed in the liver (Figure 2) and muscle (Figure 3).

The Figure 2 for instance, shows that during the very fast-growing young dolphin the Hg concentration increase little with age because of growth dilution. When the growth slows down the continuous intake of alimentary Hg increase the concentration. Finally, when the growth stops at nearly 200 cm corresponding about 12 yr (Andre *et al.*, 1990d), all the Hg taken up is accumulated in a constant volume. Consequently,the Hg concentration increase more rapidly. But the relationships between Hg burdens accumulated in the organs and age or total weight of individuals also reveal an increase in the quantities of Hg absorbed and stored in the organism throughout the dolphin's life. Several hypotheses can be formulated to explain these processes, relating to the Hg entering the organism and also to decontamination mechanisms. Young dolphins, it must be remembered, are suckled by their mothers up to the age of about two years and can thus become contaminated. Even during their foetal life the placental barrier is fairly permeable to Hg compounds present in the maternal blood, MeHg in particular. After this, consumed prey remain qualitatively similar right into adulthood. The size of prey and the quantities of food ingested, however, increase in relation to the growth of the dolphins (Desportes , 1985). Given the very marked positive correlations between the age or the weight of fish and the burdens of accumulated Hg (Spacie and Hamelink, 1985), trophic supplies of the metal increase progressively. The rapid and continuous increase in the quantities of Hg in the different organs is also enhanced by the fact that the majority of organs have a very high capacity of bioaccumulation of the metal. The processes involved have already been described.

The combination of these processes, coupled with the long life span of Delphinids, can thus explain the contamination levels measured in the tissues. Very high concentrations were observed in some organs, e.g. the liver, which could suggest chronic contamination of the organisms too, associated with the described mechanisms for neutralizing Hg as it penetrates within the cell structures (metallothioneins, Hg precipitates, etc.). Lastly, we should note that a reduced degree of participation by decontamination mechanisms is a likely assumption as the age of individual increase.

Sex : It should be noted that if the sex variable does not have a significant effect on the total Hg concentrations measured in the Mediterranean and Atlantic dolphins (confidence limits : 0.05 - Andre *et al.*, 1990d). Nevertheless, for the sample of dolphins from the eastern tropical Pacific, significant differences are established between males and females (Figure 3). The corresponding multilinear regression shown that the concentrations or burdens of the metal are higher in the females : e.g. liver, kidney-2, muscle, stomachs, intestine-1, spleen, lungs, skin, brain and pancreas concentrations (Andre *et al.*, 1990b).

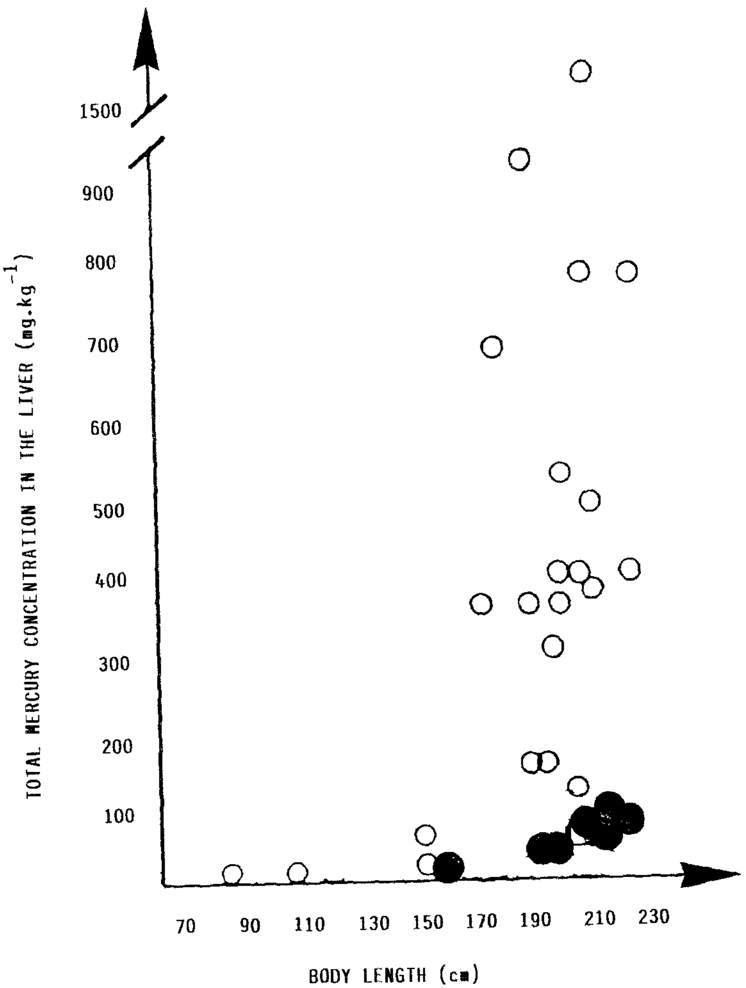

Figure 2 . Total mercury concentrations (mgHgt.kg^{-1}) in the liver of *Stenella coeruleoalba* versus body length (cm), for the two geographic samples : Atlantic ● and Mediterranean ○ .

It is difficult to put forward any detailed hypotheses which could explain these differences between contamination levels in the organs of males and those of females. Added to the known hypotheses such as the effect of certain mechanisms like gestation, parturition, suckling, etc., it can perhaps be attributed to specific differences in diet, which lead indirectly to an unequal intake of Hg via the trophic route. Comparative analyses of consumed prey, however, carried out when the stomach content were examined, revealed no significant difference between males and females (Desportes, 1985). We should also perhaps consider the variation in the capacity to accumulate metals which may be related to metabolic activity. The weight data collected from our sample revealed a significant difference in favor of males in total weight of organism and weight of principal organs.

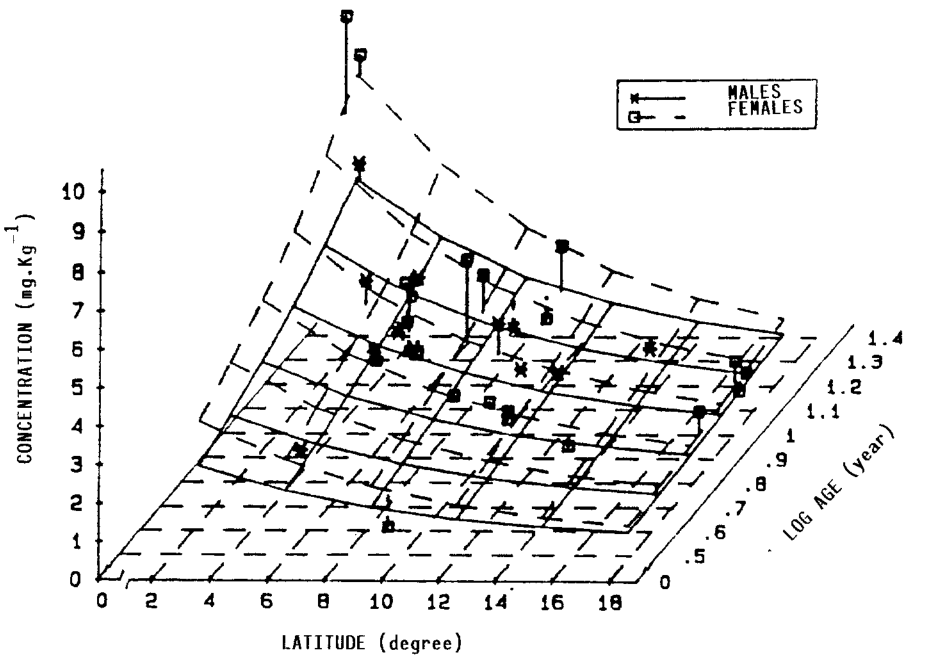

Figure 3. Total mercury concentrations in the skeletal muscle in relation to sex and age of the dolphins, and to latitude of the place of capture.

Several authors mention in their publications an influence of the sex factor on contamination of marine mammals by metals (Gaskin *et al.*, 1979 ; Honda *et al.*, 1983b ; Wagemann *et al.*, 1983), though few have considered the action of this factor from a quantitative point of view, especially in Delphinids. Moreover, the studies we consulted dealt with only a limited number of organs (liver, kidneys, muscle, blubber and brain) and give any clear result on this point either.

Geographical location : Our study of the influence of the geographical location on Hg accumulation is divided in two approaches. The first one concerns individuals of the same species *Stenella coeruleoalba* in two separate characteristic biotopes (Atlantic ocean and Mediteranean sea). The second undertakes dolphins of the same species, *Stenella attenuata*, in a large but continuous oceanic area in the Pacific. In both cases the similarity of the analytical method guarantee the value of the comparison between individuals. We extended our research in an attempt to find elements that might explain our result, and carried out a bibliographical study to determine the main hydrological characteristics of both of the concerned region, Mediteranean basin and eastern equatorial region of the Pacific Ocean, and also any links between these features and levels of Hg contamination in the biotopes.

As statistically established in earlier work (with a non parametric Mann and Whitney test - Andre *et al.*, 1990d), the comparison between the total Hg accumulations levels in the two geographic groups of Stenella coeruleoalba shows that the Mediterranean individuals have much higher concentrations than specimens from the Atlantic (Figure 2). In the Mediteranean basin, large natural sources exist. Indeed, the Mediterranean area is part of the orogenic and volcanic Mediterranean-Himalaya belt. Numerous disused and working Hg mines show the wide distribution of Hg in the Mediterranean sea (Nriagu, 1979). The view that the origin of high levels of Hg measured in Mediterranean species of biological oraganisms is due to these natural deposits was advanced several years ago (Bernhard and Renzoni, 1977; Bernhard, 1988). Bacci (1989) has suggested that differences observed between pelagic organisms from the Atlantic and Mediterranean may be due to biological causes such differential growth rates, influence of water temperature on the methylation rate of Hg, but these hypotheses has already been discounted (Andre *et al.*, 1990d).

Taking the muscle tissue as an example, the Figure 3 and the associated multiple regression models show that latitude has a very important influence on values for total Hg concentration and burden in the organs and tissues collected on dolphins from the eastern equatorial region of the Pacific Ocean. The accumulation levels in the organs are greater, the nearer the equator the capture site. Longitude, however, was never among those regressors that had any significant influence on the contamination criteria (Andre *et al.*, 1990b).The Eastern equatorial region of the Pacific Ocean is a complex area, due to the presence of strong ocean currents. Moreover, between latitude 5°N and 10°S, to the North of the area we are considering, emerges the phenomenon of upwelling, under the California Current. This brings up to the surface, from depths of 100 to 200 m, cold water rich in mineral nutrients. Primary production and biological activity at the surface are thus increased (Wyrtki, 1967 ; Fitzgerald *et al.*, 1984). In this same zone, Fitzgerald *et al.* (1984) have observed Hg exchanges, in the gaseous state at the interface between atmosphere and marine environment. Near the equator (5°S - 5°N), these exchanges lead to an increase in daily readings of Hg concentration in the air and to an appreciable decrease in Hg concentrations in the surface layer of water between latitudes 0° and 10° S. To explain these results, the authors suggest that these Hg emissions into the atmosphere are closely linked with biological activity of certain organisms - algae and bacteria - which have the capacity to transform dissolved inorganic Hg into volatile chemical forms - Hg° and $(CH_3)_2Hg$ - (Bernhard *et al.*, 1986 ; Jensen and Jernelov, 1969 ; Wood, 1987). This hypothesis suggest that there is a high degree of flux between the environment and the trophic network base, which then favors transfer into consumer organisms. Thus, with the cumulation of Hg transfers, MeHg in particular, the dolphin's position at the end of the food chain would contribute to an increase in the quantities of metal bioaccumulated, when compared with individuals of the same species living in zones further from the equator.

Thus, considering our present knowledge in Hg biogeochemistry, it still seems to be more reasonable to assume that the origin of the high Hg levels observed in dolphins from both area of this study (Pacific and Mediteranean/Atlantic) is certainly natural. Dolphins are pelagic organisms and, therefore, do not normally dwell close to the coasts where they could be contaminated by anthropogenic Hg sources. Moreover, investigations conducted on anthropogenic Hg discharges have shown that even very large sources contaminate only a limited area. For example in the Mediterranean, at about

10 km away from the source, Hg contamination levels return to the background values (review : Bernhard, 1988).

4. CONCLUSION

To our knowledge, the dolphins exhibit the highest Hg concentrations which have been measured in marine organisms. Except in very local areas under high anthropogenic pressure, this contamination is certainly due to natural exposure. Even though the influence of such factors as age is clearly evident, and in spite of the supposed erratic behavior of dolphins, the contamination level appears to be strongly dependant on the geographical origin of the individuals.The high level of accumulation in delphinids has to be linked, obviously, with their position at the end of the food chain and their long life span. Lastly, in spite of their high adaptation to tan aquatic life, they seem to be subject to similar bioaccumulation mechanisms (absorption, distribution, exretion and biotransformation) as in other (terrestrial) mammals.

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