Chemosphere 229 (2019) 580–588

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Trace metals in striped dolphins (*Stenella coeruleoalba*) stranded along the Murcia coastline, Mediterranean Sea, during the period 2009–2015.

E. Martínez-López [a, b, *], J. Peñalver [a, c], A. Escriña [a], L. Lara [d], M.J. Gens [d], E. María Dolores [c], A. Alcaraz [e], A.J. García-Fernández [a, b]

[a] *Area of Toxicology, Department of Health Sciences, Faculty of Veterinary, University of Murcia, Campus de Espinardo, 30100, Murcia, Spain*
[b] *Laboratory of Toxicology, Biomedical Research Institute of Murcia (IMIB-Arrixaca), University of Murcia, Spain*
[c] *Fisheries and Aquaculture Service (CARM), 30100, Murcia, Spain*
[d] *"El Valle" Wildlife Recovery Center (CARM), 30100, Murcia, Spain*
[e] *Agrarian and Animal Health Laboratory (CARM), 30100, Murcia, Spain*

HIGHLIGHTS

- First study about trace metals on stranded cetacean in Western Mediterranean, Murcia coatline. Spain.
- Hg, Cd, Pb, As and Se were detected in internal tissues from striped dolphins from the Murcia Region.
- Hg liver levels in some adults of striped dolphins (*Stenella coeruleoalba*) are related with toxic effects in cetacean.
- Ratio Hg:Se in liver from some adults specimens suggest overload of the Hg-Se detoxify function and compromised health.

ARTICLE INFO

Article history:
Received 1 December 2018
Received in revised form
25 April 2019
Accepted 29 April 2019
Available online 30 April 2019

Handling Editor: Martine Leermakers

Keywords:
Striped dolphin
Stenella coeruleoalba
Trace elements
Mercury
Environmental pollutants
Cetacean

ABSTRACT

Mercury (Hg), cadmium (Cd), lead (Pb), selenium (Se) and arsenic (As) concentrations in internal tissues of 72 striped dolphins (*Stenella coeruleoalba*) from Murcia Region (Mediterranean coastline) have been investigated for the first time. Hg showed the highest concentration, followed by Se, Cd, As and Pb. In general, the levels of metal found in this study were similar to those described in similar studies in the Mediterranean Sea. However, in some adult specimens, Hg liver concentrations were related with toxic effects in cetacean. A significant correlation was observed with age, likewise between Se and Hg and Cd in tissues, which agree with detoxify effect attributed to Se through inert complex formation. Molar ratio Hg:Se in liver was close to 1:1 in some specimens, which would indicate overload of the Hg-Se detoxify function and compromised health. These results could contribute to a better knowledge of the distribution of these persistent pollutants in the Mediterranean Sea.

1. Introduction

Increasing human populations and related anthropogenic activities have resulted in the release of contaminants into the environment with temporal trends indicating increases in certain elements, both regionally and globally (Braune, 2007; Dietz et al., 2000; Riget et al., 2004). Although metals generally occur at low concentrations in the oceans, marine organisms bioaccumulate trace elements with a significant increase of metal burdens through the food chain, especially toxic heavy metals such as Hg or Cd (Gerpe et al., 2006; Meador et al., 1999).

Heavy metals are well known environmental pollutants that accumulate in the bodies of odontocetes and potentially constitute a toxicological risk for the species (Caurant et al., 1996; Haraguchi et al., 2000; Endo et al., 2002; Stavros et al.,2008, 2011). Seawater

* Corresponding author. Area of Toxicology Faculty of Veterinary Medicine University of Murcia Campus de Espinardo, 30100 Murcia, Spain.
E-mail address: emmaml@um.es (E. Martínez-López).

https://doi.org/10.1016/j.chemosphere.2019.04.214
0045-6535/

enrichment with heavy metals from natural occurrence or from anthropogenic impact may lead to an increase of metal burdens entering marine food chains (Fernandes et al., 2007). Additionally, they are usually species that live for many years so they can be exposed throughout their lifetimes to high concentrations of metals, from conception to exposure in the uterus, during breast-feeding, and during juvenile and adulthood through the marine trophic chain, especially the super predatory species (Kurzel and Cetrulo, 1985).

The main potential effects described for these pollutants are endocrine cycle disruption, failure of the reproductive process, immune system suppression and metabolic disorders that could generate cancer and genetic defects (Borrell et al., 2014). Although the analysis of pollutants in marine mammals, including cetaceans, has a high relevance, there is still a great uncertainty about the specific effects of contaminants in marine mammals, in what measure these effects can occur in these species in their natural environment, and what impact these effects are having on the population dynamics. In response to these concerns, numerous studies have been conducted over the last decades on trace metals in marine mammals (Riget and Dietz, 2000; Bennett et al., 2001; Caurant et al., 2006; Capelli et al., 2008; Law et al., 2012; Robin et al., 2012; Rojo-Nieto and Fernández-Maldonado, 2017.

The Mediterranean Sea, because of geographic and geomorphological characteristics, receives an important amount of pollutants from industrialized countries in Western Europe, in addition to natural inputs of some trace metals such as Hg (Bacci, 1989). Metal contamination has been especially important in the Western Mediterranean due to the proximity of significant metalliferous deposits at the Baetical area exploited from very early ages. In Southeastern Spain, the origin of contamination has been dated at 3900 cal years BP (García-Alix et al., 2013). Besides, one of the most heavily metal-polluted areas of the western Mediterranean Sea is situated on the Murcia coastline (Cartagena marine area) where high concentrations of Pb, Hg and Cd, among other metals, have been reported in sediment and/or biota (Robinson et al., 2016), even sublethal contaminant related effects in mussels and red mullet (Martínez-Gomez et al., 2012). Besides, the limited water movement and replacement enhance the accumulation of these pollutants, contributing to chronic exposure of cetaceans that inhabit it (Tintore et al., 1988).

The striped dolphin is worldwide classified as “Least concern” by IUCN (Hammond et al., 2008). However, Mediterranean Sea populations have been pointed out as “Vulnerable” (Aguilar and Gaspari, 2012) and conform 60% of strandings in this sea.

In this sense, research using stranded marine animals can yield substantial information on the health and ecology of these fascinating but often little understood species, while also helping to highlight some of the conservation issues they may face (Perrin et al., 2002). The long term accumulation of stranding data facilitates the investigation of spatial-temporal trends and patterns in stranding numbers and mortality. Post-mortem examinations additionally provide unique insight into wider metrics such as age, sex, body condition, cause of death, pollutant levels, reproductive patterns, diet, disease burden and pathology of the stranded population (Chan et al., 2017). Besides, the reappearance of dolphin morbillivirus affecting the Mediterranean cetacean population (Raga et al., 2008; Soto et al., 2011a,b; Rubio-Guerri et al., 2013) reinforces the importance of continuous monitoring of cetacean strandings to understand the influence of environmental contaminants. This information can provide essential baseline data to help detect any future outbreaks of disease, unusual mortality events, anthropogenic stressors, and other health issues. It also enables assessment of pressures and threats, possible population dynamics, and responses to environmental stressors as well as specific conservation measures.

The aim of the present study is to evaluate metal concentrations (Hg, Cd, Se, Pb and As) in stranded striped dolphin internal tissues (liver, kidney, brain, lung and muscle) from Murcia's coast during the period 2009–2015, studying the influence of several variables (age, sex and stranding year) in these metal concentrations and discuss the possible effect on animal health of the obtained concentrations. This is the first study of these characteristics in the Murcia Region coastline.

2. Materials and methods

2.1. Species of study

The Striped dolphin is widely extended in the Atlantic, Pacific and Indian oceans, and closed seas such as the Mediterranean. The Mediterranean population has been largely studied (Borrell et al. 2014, 2015; Capelli et al., 2008; Cardellicchio et al.,2000, 2002a, b; Monaci et al., 1998). They have a long life span, reaching a maximum of 30 years. Although they usually prefer deep oceanic waters, they can be seen in coastal areas where there is enough depth. As mammals, they firstly feed on milk and after the weaning process their diet consists of a variety of pelagic or benthopelagic fish such as cod (*Gadus morhua*), anchovy (*Fam.Engraulidae*), lantern fish (*Fam.Myctopidae*) and squid, feeding above the continental slope or in oceanic waters (Perrin et al.,2002; Lahaye et al.,2006). Dominant prey varies among the geographical marine areas. In the Mediterranean, squid are preferred as the main food resource for striped dolphins (Perrin et al., 2002; Ringelstein et al., 2006).

2.2. Sampling

Samples were collected from 72 striped dolphins (39 males, 17 females and 16 non-identified) stranded along the Murcia coast, in the Southeast of Spain from 2009 to 2015 (Fig. 1). Detailed necropsies were performed, depending on the animal's decomposition state. The specimen decomposition state was: freshly dead (30%), moderately decomposed (18%), advanced decomposition (44%) and mummified (8%). According to Vázquez et al. (2015), we classified the parasites grade in five stages: 0 (none), 1 (<10), 2 (from 11 to 50), 3 (from 51 to 100), 4 (from 101 to 500) and 5 (>500) and body condition in four stages (very good, moderate, poor and very poor). Besides, information about cause of death (infectious disease, traumatism, fishing gears or unknown), stomach content and other basic measurements/information (i.e. length, sex, decomposition state) was collected. Samples of liver, lung, kidney, brain and muscle were taken from each specimen. Data and samples were collected according to standard protocols (Kuiken and Hartmann.,

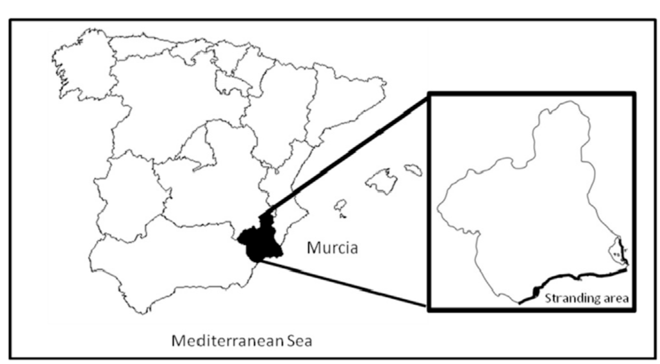

Fig. 1. Sampling area, Region of Murcia, Spain.

1991) and protocol set by The Marine mammals and Turtles Stranding Network (Order 3 of November of 2003, Ministry of Water, Agriculture and Environment of the Region of Murcia) within the "Regional Program of Marine Wildlife Pollutants Monitoring". All samples were stored in glass vials and frozen (−20 °C) for posterior trace element analysis.

Age classification was done according to the guidelines provided by Gómez-Campos et al. (2011). We have considered three groups: neonate, sub-adults and adults. The neonate group (n = 2) includes specimens under 95 cm. The sub-adult group (n = 26) includes females between 95 and 187 cm, and males between 95 and 190 cm. The adult (n = 25) group contains females above 187 cm and males above 190 cm.

2.3. Analytical procedure

The analysis of Cd, Pb, As and Se was done following the metal determination protocol for fish tissues with microwave digestion system (MLS 1200 Mega, MPR 600/12, Milestone), and subsequent detection and quantification with inductively coupled plasma optic emission spectrometry (VISTA-MPX CCD Simultaneous ICP- OES © Varian; LAYMA PA/IN/0219). All manipulations of solutions were done in a laminar flood hood.

The samples (0,8-0,9 g w.w. for muscle, and 0,6-0,7 g for other tissues) were mineralized with 4,5 mL of concentrate nitric acid (Scharlau, for dithizone determinations) and 1 mL of hydrogen peroxide (30%, stabilized for synthesis, Merck) in a closed Teflon PFA vessel. The curve of calibration was prepared from a multi-element standard solution (CertiPUR, Merck). To check the purity of the reagents and contamination, if any, two "blanks" (only reactive) were analyzed and the accuracy was verified with the analysis of Standard Reference Material (Multi-element standard solution and Mercury ICP standard, both CertiPUR, Merck) in each run. After cooling, the solutions were transferred into 10 mL volumetric flasks. All teflon vessels were washed with 3–4 mL ultra pure milli-Q millipore (Gradient A 10) water. After that, it was filtered with a 0,45 μm filter and transferred to 15 mL threaded tubes identified with the sample code. The detection limits were 0,60 μg g −1 for As, 0,05 μg g −1 for Cd, 0,30 μg g −1 for Pb, and 0,60 μg g −1 for Se.

The analysis of Hg was done by atomic absorption spectrophotometry using a direct mercury analyzer (AMA-254, Leco®). Due to the high Hg levels present in the sample tissues, after microwave digestion process, a 1/10 dilution was necessary, after which a fraction of this (generally, 20 μl for liver samples and 100 μl for other tissues) was analyzed. The detection limit for Hg was 0.020 μg g $^{-1.}$

2.4. Statistical analysis

Statistical analysis was performed using SPSS ® for Windows ® (15:0, SPSS, Chicago, IL, USA) and Excel 2007. The data were tested for normality using a Kolmogorov-Smirnov test. Since residues were not normally distributed the non-parametric Kruskal–Wallis test was used in order to detect differences between sampling sex, age and decomposition state, followed by Mann–Whitney tests when differences were found. The non-parametric Spearman's correlation coefficient was used to measure the correlation between metal concentrations and variables. The level of significance was set at $\alpha = 0.05$.

In addition, we evaluated the Hg detoxification process through the calculation of the Hg:Se molar ratio described by Méndez-Fernández et al. (2014). This ratio was calculated as Hg:Se = (Hg (μg g-1 ww)/Se (μg g-1 ww)) × (78.96 (g mol-1)/200.59 (g mol-1)), where 200.59 g mol-1 and 78.96 g mol-1 are the atomic mass of Hg and Se, respectively.

3. Results and discussion

3.1. Tissue distribution of trace elements

The heavy metal concentrations in internal tissues of 72 striped dolphins (*Stenella coeruleoalba*) from Murcia Region strandings between 2009 and 2015 are shown in Table 1. The detection of these metals is a strong sign of the assimilation process that has occurred since the first contact with pollutants, until beaching on the Murcia coast.

In concordance with other studies (Andre et al., 1991; Capelli et al., 2000; Cardellicchio et al., 2002a, b) detection rates were 100% for Hg for all the tissues, followed in descending order by Se, Cd, As and Pb in total population. With respect to distribution patterns among tissues and similar to other studies on metals in cetaceans, Hg, Se, As and Pb followed the same patterns among tissues (liver > kidney > muscle > brain ≈ lung) (Table 1). These results seem logical since liver becomes the first accumulation place for metals and toxins before they are distributed to other organs through blood circulation (Campbell et al., 2005). However, the highest Cd concentrations were seen in kidney, due to their affinity for metal-binding proteins, which are highly present in this organ (Gallien et al., 2001).

On the other hand, as aforementioned, Hg showed the highest concentrations in all tissues analyzed, with a maximum of 498 μg g −1 wet weight (ww) in liver, followed by Se (max 205 μg g −1 ww in liver), As (max 2.83 μg g −1 ww in liver), Cd (7.57 μg g −1 ww in kidney) and Pb (0.33 μg g −1 ww, detected in a liver of an adult specimen). This Pb value seems to be consistent

Table 1
Global trace element concentrations (μg/g wet weigth) in tissues of stranded striped dolphins (Stenella coeruleoalba) from Murcia's Region (2009–2015). Median (Mean ± SD) Minimum-Maximum (number of samples).

Trace element	Liver	Kidney	Brain	Lung	Muscle
Hg	67.20 (139.53 ± 162.23) 0.10–498 (n = 43)	7.88 (9.93 ± 7.67) 0.11–35.37 (n = 40)	1.32 (9.53 ± 18.66) 0.26–86.64 (n = 28)	5.35 (7.80 ± 8.52) 0.28–28.20 (n = 20)	3.33 (8.14 ± 9.50) n.d.-35.70 (n = 32)
Cd	0.71 (0.84 ± 0.68) n.d-2.88 (n = 43)	2.77 (3.16 ± 1.93) n.d.-7.51 (n = 40)	n.d.(n.d.±0.01) n.d.-0.05 (n = 28)	0.04 (0.04 ± 0.04) n.d.-0.15 (n = 20)	n.d.(n.d.±0.01) n.d.-0.06 (n = 32)
Pb	n.d.(0.01 ± 0.05) n.d.-0.33 (n = 43)	n.d.(n.d.±0.01) n.d- 0.10 (n = 40)	n.d.(n.d.±0.03) n.d.-0.15 (n = 28)	n.d.(n.d.±0.02) n.d.-0.12 (n = 20)	n.d. (n = 32)
As	0.88 (1.23 ± 1.38) n.d.-8.07 (n = 43)	0.50 (0.76 ± 1.44) n.d.-8.85 (n = 40)	n.d.(0.15 ± 0.25) 0.90-n.d. (n = 29)	0.08 (0.23 ± 0.28) n.d.-0.78 (n = 20)	n.d.(1.05 ± 5.37) n.d-30.50 (n = 32)
Se	27.35 (50.53 ± 60.05) 1.26–205 (n = 20)	6.85 (6.82 ± 3.51) 0.88–16.90 (n = 20)	1.72 (3.56 ± 4.67) n.d-16.60 (n = 14)	6.36 (6.58 ± 3.61) n.d.-11.80 (n = 10)	2.99 (3.98 ± 3.81) n.d.-15.90 (n = 22)

*n.d. Not detected.

with those described in marine mammals by Cardellicchio et al. (2002a, b), Cardellicchio et al. (2000) and Das et al. (2003) where detected Pb concentrations were rarely over 1 μg/g d.w. However, according to Pb toxicokinetic and levels found by others authors in bone of striped dolphins (Caurant et al., 2006; Honda et al., 1986) future studies should take into account these internal tissues in order to evaluate Pb accumulation pattern.

The As concentration medians were close to the detection limit in all tissues analyzed. Feeding habits of dolphins suggest lower intakes of this trace element than other cetaceans (Kubota et al., 2001; Storelli et al.,2005). The scarce studies in marine mammals showed levels of As rarely exceeding 1.0 μg g-1 ww, in any tissue; the hepatic levels generally being below this level (Thompson, 1990). Our results are in agreement with these references. Nevertheless, the values of one individual stand out, which showed higher values in liver (8.07 μg g-1 ww), kidney (8.85 μg g-1 ww) and muscle (30 μg g-1 ww) that could suppose a higher exposition to this element (Table 1). In any case, there are few studies about As in cetacean tissues.

3.2. *Influence of variables on trace elements concentration*

No significant differences among metal concentration have been observed between sexes nor decomposition state and only Hg concentration in kidney was there a statistically significant difference between years of stranding ($p = 0.005$). So, males and females were pooled together without taking into account the decomposition state or stranding year. On the other hand, we have only found a slightly significant relationship between parasites grade and Hg in muscle ($rho = 0.4$, $p = 0.044$). Fifty specimens from our study were evaluated and classified from 0 to 5 parasites grades following protocol described by Vázquez et al. (2015). In this sense, only 21 individuals showed parasites in lung and/or subcutaneous and just 13 were classified above 3 level (>51 parasites). Only in 20 individuals were indicated the cause of the death where more than 64% of them were stranded because of traumatisms (30% due to fishing gear and 34% to trauma). Respect to body condition the 46% showed a poor or very poor stage and the stomach content founded was divided in 22% empty, 27% with food and 51% unknown. However, we have not detected relation with metals concentrations and these variables. On the contrary, the heavy metal concentrations increased with age (Table 2), showing the following significant differences between age groups: Hg in all tissues ($U = 0.00$; $p < 0.001$); Cd in liver ($U = 80$, $p = 0.002$) and lung ($U = 10.5$, $p = 0.002$); and Se in liver ($U = 4$, $p < 0.001$), brain ($U = 8$, $p = 0.043$) and muscle ($U = 15.5$, $p = 0.024$). However, due to decomposition state and other factors only 53 individuals were able to be to classified by age.

It is well known that metals are accumulated with age/body length in marine mammal tissues (Das et al., 2003; Law, 1996). Besides, distribution of trace elements in the individuals belonging to different age groups could reflect on their feeding habits in some cases. An age-related increase of Hg is explained due to the characteristic growth pattern of dolphins, together with feeding changes. Neonate or younger specimens with lower Hg concentrations may be because milk and placenta are the only forms of transfer at these stages and also due to the fast-growing dilution effect. However, sub-adult specimens with high concentrations had a continuous input of metals through their diet (fish and squid, mainly), together with progressive deceleration of grown. Adult specimens showed the highest levels, due to accumulation through diet inputs and no variation of body volume, considering that growth detention occurs at ~12 years and specimens between 200 and 250 cm length would bearound 10–30 years old (Andre et al., 1991).

With regards to Cd, cephalopods are known to accumulate environmental pollutants and, particularly, high levels of Cd have been previously reported (Pastorelli et al., 2012; Mok et al., 2014). Borrell et al. (2015) suggested metal positive correlation with age because of a rich cephalopod based diet (Law et al., 1992;

Table 2
Trace element concentrations (μg g-1 wet weigth) in tissues of stranded striped dolphins (*Stenella coeruleoalba*) from Murcia's Region (2009–2015) according to age group. Median (Mean ± SD) Minimum-Maximum.

Age	Trace Element	Liver	Kidney	Brain	Lung	Muscle
Neonate (n = 2)	Hg	2.48 (2.48 ± 1.04) 1.74–3.22	0.59 (0.59 ± 0.55) 0.21–0.98	0.59 (0.59 ± 0.46) 0.26–0.92	0.66 (0.66 ± NA) 0.66–0.66	1.45 (1.45 ± NA) 1.45–1.45
	Cd	n.d.	n.d.	n.d.	n.d.	n.d.
	Pb	n.d.	n.d.	n.d.	n.d.	n.d.
	As	0.30 (0.30 ± 0.42) n.d.-0.60	0.40 (0.40 ± 0.57) n.d.-0.81	n.d.	n.d.	n.d.
	Se	1.99 (1.99 ± 1.03) 1.26–2.72	0.89 (0.89 ± 0.01) 0.88–0.90	n.d.	n.d.	n.d.
Subadult (n = 26)	Hg	15.70 (27.15 ± 32.34) 0.10–98.76	4.68 (5.37 ± 4.14) 0.11–15.04	1.15 (1.02 ± 0.46) 0.27–1.76	0.94 (1.48 ± 1.69) 0.28–5.55	1.92 (1.88 ± 1.11) n.d.-3.51
	Cd	0.56 (0.53 ± 0.38) n.d.-1.19	2.61 (2.83 ± 1.77) n.d.-6.63	n.d.	n.d.(0.1 ± 0.2) n.d.-0.07	n.d.
	Pb	n.d.	n.d.	n.d.	n.d.	n.d.
	As	0.88 (1.62 ± 1.89) n.d.-8.07	0.32 (1.02 ± 2.14) n.d.-8.85	n.d.(0.17 ± 0.23) n.d.-0.77	0.33 (0.31 ± 0.30) n.d.-0.78	n.d.(2.49 ± 8.41) n.d.-30.50
	Se	11.30 (15.96 ± 15.73) 1.61–48.70	6.90 (6.74 ± 2.53) 2.53–11.10	1.57 (2.03 ± 1.46) 0.62–4.75	4.75 (4.75 ± 2.80) 2.77–6.73	1.65 (2.24 ± 1.40) 0.97–5.11
Adult (n = 25)	Hg	180.00 (241.41 ± 158.20) 27.70–498.00	13.09 (14.17 ± 7.28) 5.70–35.37	20.78 (22.80 ± 24.91) 2.18–86.64	9.50 (13.04 ± 8.29) 4.04–28.20	11.75 (14.11 ± 9.31) 3.04–33.50
	Cd	1.10 (1.12 ± 0.61) 0.06–2.29	3.51 (3.78 ± 1.86) 0.71–7.51	n.d(n.d.±0.01) n.d.-0.05	0.06 (0.07 ± 0.03) n.d.-0.15	n.d.(n.d.±0.01) n.d.-0.06
	Pb	n.d.(0.02 ± 0.07) n.d.-0.33	n.d.	n.d.	n.d.	n.d.
	As	0.98 (1.02 ± 0.81) n.d.-2.83	0.58 (0.59 ± 0.51) n.d.-1.65	n.d.(0.17 ± 0.23) n.d.-0.77	n.d.(0.20–0.27) n.d.-0.73	n.d.(0.11 ± 0.20) n.d.-0.60
	Se	63.30 (87.91 ± 65.44) 20.50–205.00	7.27 (8.06 ± 3.40) 4.86–16.90	3.51 (6.27 ± 6.15) 1.47–16.60	7.45 (7.73 ± 2.91) 4.28–11.80	3.76 (5.05 ± 3.31) 1.19–10.10

*n.d. = no detected.

Komarnicki, 2000). Owing to this, changes during the winter and spring season or low squid availability could be a variation factor for metal accumulation. We detected higher levels in adults (Table 2). This metal is transferred via milk from mother to calf, in which the element bioaccumulates (Honda and Tatsukawa, 1983; Fujise et al., 1988; Law, 1996; Becker et al., 1997; Das et al., 2003; Yang et al., 2004; Lahaye et al., 2007). Ingested Cd reacts with sulfhydryl-rich proteins or metallothioneins mainly in the kidney, forming complexes that are highly stable and persistent that lead to an increasing Cd concentration with age (Komarnicki, 2000; Law, 1996). Some authors have described a rapid Cd concentration increase from birth to a maximum of 20–30 μg g-1 ww which might be maintained for the rest of the dolphin's life (Honda and Tatsukawa, 1983; Monaci et al., 1998; Lahaye et al., 2006). However, our results showed lower concentrations in the whole population with a median of 3.78 μg g-1 ww and a maximum of 7.51 μg g-1 ww in kidney for adult specimens.

Se accumulation related to age would be explained by the Hg detoxification process, whereby Se accumulates according to Hg intake giving rise to HgSe inert complexes. In addition, Se bioaccumulation factor might be much lower than that of Hg, based on the observation of approximately same Se concentration level between dolphins and their prey (Itano et al., 1984).

No age-related accumulation has been observed in our results and reviewed studies for As. As levels in marine organisms would also be largely influenced by feeding habits. Thus, animals feeding on marine algae, crustaceans and cephalopods appear to retain higher As concentrations than piscivorous species (Kubota et al., 2001; Storelli et al., 2005). Considering striped dolphins' mixed diet without consumption of algae or crustaceans, lower intakes of this trace element seem reasonable and agree with lower tissue concentrations found.

In spite of the aforementioned, the variability in metal concentration noticed among individuals with similar length (age) suggest that despite age as a main variable for trace element accumulation, other individual factors could affect this pattern, such as seasonal diet variations and regional pollutant release and availability. Besides, Gaspari (2004) revealed the existence of different lineages in the Mediterranean striped dolphins: partly coastal and partly oceanic dolphins, and these different habits could cause differences in diet and therefore intakes of contaminants.

3.3. Relationships among trace elements

A significant positive correlation was observed between Hg and Se (liver, kidney, lung, brain and muscle), Hg and Cd (liver, kidney, muscle and lung) and Cd and Se (kidney, liver) (Table 3). Similar to our results several studies have demonstrated significant correlation between Hg and Se contents in liver and also stressed the role of Se in protection against Hg toxicity. A 1:1 Hg:Se molar ratio would indicate that almost all available Se is bound to Hg. Owing to the oxy-radical scavenging involvement of Se, tissue ratios close to 1:1 could indicate compromised health (Dietz et al., 2000). Whenever possible, the liver ratio Hg:Se was calculated (Table 4). This ratio showed ranges among 0.77–1.21 for adults ($n = 10$), 0.06–0.87 for subadults ($n = 8$) and 0.47–0.54 for neonates ($n = 2$). Palmisano et al. (1995), proposed that a significant correlation and co-accumulation among Se and Hg could be found when approximately 100 μg g-1 of total Hg concentration in liver is exceeded. This hypothesis would not correspond with our results, since a Se:Hg ratio close to or above 1 was observed for adults and subadult

Table 4
Hg:Se molar ratio in liver tissue of striped dolphins from Murcia's Coastline among 2012–2015 sampling period. ($n = 19$). Hg and Se concentrations are given as μg g^{-1} wet weigth.

SEX	LENGTH (cm)	Hg	Se	Hg:Se
Male	88	3.22	2.72	0.47
Male	89	1.74	1.26	0.54
Female	101	1.94	1.61	0.47
Male	149	25.8	12.5	0.81
Female	156	1.77	11.3	0.06
Male	159	67.2	30.2	0.87
Male	163	7.69	5.7	0.53
Female	166	12.7	6.37	0.78
Female	178	95.2	48.7	0.77
Female	195	51.3	24.5	0.82
Male	195	303	98.4	1.21
Female	196	180	91.7	0.77
Female	197	495	205	0.95
Male	198	145	56.2	1.01
Female	198	154	55.2	1.10
Male	202	135	57.3	0.92
Male	205	59.9	20.5	1.15
Male	207	177	69.3	1
Male	214	498	201	0.97

*Neonate(<95 cm); Subadults(95 < females<187 cm; 95 < males<190 cm), Adults (>190 cm).

Table 3
Significant correlation coefficients ($p < 0.05$; Spearman r) between metal concentrations (μg g-1 w.w.) in each tissue (Li=Liver, Ki = Kidney, Mu = Muscle, Br=Brain, Lu=Lung). Relevant ones considered for this study are listed in bold letters (*p < 0.01; **p < 0.05).

		Hg					Cd					Se				
		Li	Ki	Mu	Br	Lu	Li	Ki	Mu	Br	Lu	Li	Ki	Mu	Br	Lu
Hg	**Li**			**0.93***												
	Ki	**0.85***		**0.89***	**0.88***	**0.89***		**0.32****		**0.64***		**0.94***				**0.72***
	Mu	**0.93***	**0.89***			**0.88***		**0.45****	**0.41****	**0.67***		**0.85***			**0.70***	
	Br	**0.90***		**0.96***				**0.50***		**0.80***		**0.94***			**0.80***	
	Lu	**0.91***		**0.88***				**0.68***		**0.69***		**0.88***			**0.69***	
												0.96*			**0.88***	
Cd	**Li**	**0.77***						**0.58****		**0.83***						
	Ki	**0.64***								**0.83***						
	Mu	**0.66***														
	Br	**0.80***														
	Lu	**0.76***														
Se	**Li**						**0.78****	**0.50****						**0.74***	**0.85***	
	Ki		**0.46****				**0.55****	**0.51****							**0.77***	
	Mu	**0.65***	**0.62****	**0.64***	**0.76****	**0.92***						**0.74***			**0.59****	**0.69****
	Br						**0.63****	**0.65****						**0.59****		
	Lu	**0.75****	**0.70****	**0.74****	**0.71***	**0.75****						**0.72***		**0.69****	**0.90***	

specimens with total Hg liver concentrations below this threshold. In any case, further analysis of the samples with speciation of inorganic and organic Hg forms would be necessary for a better understanding of this pattern.

Furthermore, positive correlation between Cd and Se was found in kidney, liver and brain suggesting plausible similarities in the metabolic pathways of these elements. Previous studies showed that co-administration of Se succeeded in reducing Cd-induced toxicity, most probably via formation of Cd/Se complexes, altough the mechanism and the complex identity remain elusive (Becker et al. 1995; Lindh et al., 1996; Sasakura et al., 1998; Włodarczyk et al., 2000; Gajdosechova et al., 2016).

3.4. Geographical differences of trace metal concentrations

The comparison of metal concentrations detected in striped dolphins from different geographic areas and populations is difficult. Exact age of the specimens or a reliable estimation should be known and differences between the growth curve of populations must be taken into account. Besides, ideally the analyses should be done in the same laboratory in order to reduce inaccurate results and facilitate comparison.

Studies carried out in liver, kidney and muscles on striped dolphins in the Mediterranean Area have been considered (Bellante et al., 2012a, b; Borrell et al., 2014; Cardellicchio et al., 2000, 2002a and 2002b; Decataldo et al., 2004; Rojo-Nieto and Fernández-Maldonado, 2017; Shoham-Frider et al., 2016).

With respect to Hg concentrations, our results are similar to those described by other authors in internal tissues of striped dolphin in other areas of the Mediterranean in the same period (Bellante et al., 2012a, b; Borrell et al., 2014 (samples 2007–2009); Shoham-Frider et al., 2016; Rojo-Nieto and Fernández-Maldonado, 2017). However, Hg concentrations in our study are below those found in dolphins stranded before th eyear 2000 (Borrell et al., 2014; samples 1990–1993). This fact could indicate, as Borrell et al. (2014) commented, an overall decreasing trend in Hg concentration in the ecosystem. As stated above, the liver of marine mammals is the preferential organ for Hg accumulation, so it appears to be the best indicator of long-term changes in Hg deposition. However, we must be cautious about Hg level interpretation among geographical areas, andhabitat depth has been pointed out as a relevant factor, together with feeding habits and age in the Hg presence in tissues (Borrell et al., 2014; Monaci et al., 1998). For a given age, similar Hg levels could be detected in dolphins which feed from mesopelagic prey in low pollution areas, and those which feed at lesser depths in more polluted areas (Perrin et al., 2002). Se concentrations in adults (20–205 $\mu g\,g^{-1}$ in the liver, 4.86–16.90 $\mu g\,g^{-1}$ in the kidney and 1.19–10.10 $\mu g\,g^{-1}$ in the muscle, Table 2) were similar to other observations from the Mediterranean Sea (Cardellicchio et al., 2002a, b; Capelli et al., 2008; Shoham-Frider et al., 2016) and Gibratar coastline (transitional region; Rojo-Nieto and Fernández-Maldonado, 2017) but higher than those reported from the Northeastern Atlantic (Méndez-Fernandez et al., 2014).

Cd concentrations in liver and kidney were similar to those reported by Bellante et al. (2009, 2012a and 2012b), Cardellicchio et al. (2000,2002a,b) and Capelli et al. (2008) at several points of the Italian coastline. However, our results were lower than those measured in individuals from the Israeli Mediterranean coast (Roditi-Elasar et al., 2003; Shoham-Frider et al., 2016) and others measured in *S. coeruleoalba* from Northeastern Atlantic, UK and Japan (Méndez-Fernandez et al., 2014; Law, 1996; Agusa et al., 2008; respectively). Differences observed for Cd concentrations in tissues could be justified mainly by diet pattern, highly specialized in cephalopods (Roditi-Elasar et al., 2003) whose availability could change with the seasons and geographic areas (Capelli et al., 2008). Habitat characteristics, with special relevance of depth and distance from the coast, seem to be the secondary factors, taking into account that Cd presence its inversely proportional to them. The smaller number of samples of some these studies, together with no age segregation, mean that this comparison should be treated with caution.

Data on As in striped dolphins are sparse (Becker et al., 1995; Hansen et al., 2015; Meador et al., 1999; Stavros et al., 2011). We found a couple of studies evaluating this metal in tissues of *S.coeruleoalba* from the Mediterranean Sea. In these studies, As ranges of <0.2–2.9 μug g^{-1} in liver, <0.2–2.5 μug g^{-1} in kidney and <0.2–1.3 μug g-1 in muscle were detected (Bellante et al., 2012a; Shoham-Frider et al., 2016). These results are similar to those detected in our study in adult individuals (Table 2; nd-2.83 l $\mu g\,g^{-1}$ liver, nd-1.3 $\mu g\,g^{-1}$ kidney and nd-0.60 $\mu g\,g^{-1}$ in muscle). Concentrations of As in livers of *S. coeruleoalba* specimens from the Pacific Islands (Hansen et al., 2015) were similar as well.

On the other hand, our results about Pb concentrations under detection limit (0.30 $\mu g\,g^{-1}$ ww, less in one case with a value of 0.33 $\mu g\,g^{-1}$, Table 2) were similar to those described in striped dolphins from Adriatic and Ionian seas whose means were lower than our detection limit ($n = 10$, Cardellicchio et al., 2002a, b; 0.22 $\mu g\,g^{-1}$ in liver, 0.17 $\mu g\,g^{-1}$ in kidney, 0,12 $\mu g\,g^{-1}$ in brain, 0,21 $\mu g\,g^{-1}$ in lung and 0.12 $\mu g\,g^{-1}$ in muscle).

3.5. Risk assessment

Although cetaceans are known as the highest accumulators of heavy metals among marine mammals, there is a lack of knowledge about the precise effects of these xenobiotic and toxicological benchmarks. References of concentrations in critical organs at which effects occur could be useful in assessing potential toxicological risks and impacts in free-ranging wildlife.

Heavy metals such as Hg and Cd, typically accumulate and might exert toxic effects on vital organs (e.g liver, kidney, brain). Liver damage has been associated with Hg concentrations in liver above 61 $\mu g\,g^{-1}$ ww in Stranded Atlantic Bottlenosed Dolphins (Rawson et al., 1993). In marine mammals, liver effects have been described for a range of 100–400 $\mu g\,g^{-1}$ ww (Wagemann and Muir, 1984; Rawson et al., 1993). According to this, liver Hg concentrations observed in striped dolphins from the Murcia region with maximum Hg liver concentrations of 498 μg g-1 ww and adults median of 180 $\mu g\,g^{1}$ ww could be in the range for which liver damage has been describe and, in consequence, may suppose compromised health for this specimens. However, as highlighted by Monteiro et al. (2016) and Rojo-Nieto and Fernández-Maldonado (2017), the Hg potential toxic effects may have been mitigated through detoxification strategies (developed by marine mammals due to their long-term exposure to non-essential elements) such as the protective actions of metallotioneins and the formation of methylmercury and selenium complexes (HgSe) in the liver. As previously mentioned, the ratio Hg:Se found in our study was close to 1 in several cases corroborating this fact. However, Se mean levels found in tissues of striped dolphins in our study exceed the limit of Se homeostatic control suggested for marine mammals (range reported for liver 0.4–40 μg g-1 dw; Mackey et al., 1996 or 0.1–10 μg g-1 ww according to converter factor by Becker et al., 1995). The anomalously high hepatic levels of Se are typically observed in cases in which levels of other toxic metals like Hg are also relatively high, due to the key role of Se in detoxification processes or from eating Se-rich fish, which could become toxic at high levels (O'Hara et al., 2003).

Regarding Cd, Fujise et al. (1988) indicated that renal dysfunction attributable to Cd can occur in marine mammals with Cd liver concentrations > 20 μg g −1 w.w. As aforementioned, none of the dolphins analyzed in our study exhibited these concentrations.

4. Conclusions

Trace metal concentrations of Hg, Cd, Pb, As and Se detected in 72 striped dolphins from the Murcia Region are within the range of other studies carried out in the Mediterranean Sea in most cases. However, detected concentrations of Hg in liver of some adult specimens were within the range which provoke organ damage in cetaceans. Besides, in most adult and sub-adult specimens, the ratio Hg:Se in liver were close to 1, which would indicate an overload of the Hg-Se detoxify function and compromised health. In this way, further research in areas with high Hg pollution such as the Mediterranean Sea will be necessary in order to assess the potential effects on overall health of cetaceans and the impact on population levels, with special emphasis on correlation of health status and trace metal concentration. Finally, it is considered that cetaceans are usually exposed to a mixture of different pollutants whose effects may be synergistic and difficult to assess, these conclusions must not lead to an underestimation of the toxicological risk of other trace metals and persistent pollutants. This is the first study of these characteristics in the Murcia coastline (SW Mediterranean Sea).

Acknowledgements

The authors are greatly indebted to the Seneca Foundation for financing the MASCA 2014 project (19481/PI/14), to the staff of “El Valle” Wildlife Recovery Center for the careful sampling work and, to the LAYSA Laboratory for the accurate analysis of the samples. Thanks to Eddie Benson to revise the English grammar.

References

Aguilar, A., Gaspari, S., 2012. Stenella coeruleoalba (Mediterranean Subpopulation). The IUCN Red List of Threatened Species 2012.

Agusa, T., Nomura, K., Kunito, T., Anan, Y., Iwata, H., Miyazaki, N., Tatsukawa, R., Tanabe, S., 2008. Interelement relationships and age-related variation of trace element concentrations in liver of striped dolphins (Stenella coeruleoalba) from Japanese coastal waters. Mar. Pollut. Bull. 57, 807–815. https://doi.org/10.1016/j.marpolbul.2008.01.039.

Andre, J., Boudou, A., Ribeyre, F., Bernhard, M., 1991. Comparative study of mercury accumulation in dolphins (*Stenella coeruleoalba*) from French Atlantic and Mediterranean coasts. Sci. Total Environ. 104 (3), 191–209. https://doi.org/10.1016/0048-9697(91)90072-m.

Bacci, E., 1989. Mercury in the mediterranean. Mar. Pollut. Bull. 20 (2), 59–63. https://doi.org/10.1016/0025-326x(89)90227-0.

Becker, P., Mackey, E., Demiralp, R., Suydam, R., Early, G., Koster, B., Wise, S., 1995. Relationship of silver with selenium and mercury in the liver of two species of toothed whales (odontocetes). Mar. Pollut. Bull. 30 (4), 262–271. https://doi.org/10.1016/0025-326x(94)00176-a.

Becker, P., Mackey, E., Demiralp, R., Schantz, M., Koster, B., Wise, S., 1997. Concentrations of chlorinated hydrocarbons and trace elements in marine mammal tissues archived in the U.S. national biomonitoring specimen bank. Chemosphere 34 (9–10), 2067–2098. https://doi.org/10.1016/s0045-6535(97)00069-6.

Bellante, A., Sprovieri, M., Buscaino, G., Manta, D.S., Buffa, G., Di Stefano, V., Bonanno, A., Barra, M., Patti, B., Giacoma, C., 2009. Trace elements and vanadium in tissues and organs of five species of cetaceans from Italian coasts. Chem. Ecol. 25, 311–323. https://doi.org/10.1080/02757540903193155.

Bellante, A., Sprovieri, M., Buscaino, G., Buffa, G., Di Stefano, V., Manta, D.S., Barra, M., Filiciotto, F., Bonanno, A., Mazzola, S., 2012a. Distribution of Cd and as in organs and tissues of four marine mammal species stranded along the Italian coasts. J. Environ. Monit. 14, 2382–2391. https://doi.org/10.1039/c2em30161j.

Bellante, A., Sprovieri, M., Buscaino, G., Buffa, G., Di Stefano, V., Manta, D.S., Barra, M., Filiciotto, F., Bonanno, A., Giacoma, C., Mazzola, S., 2012b. Stranded cetaceans as indicators of mercury pollution in the Mediterranean Sea. Ital. J. Zool. 79, 151–160. https://doi.org/10.1080/11250003.2011.621072.

Bennett, P., Jepson, P., Law, R., Jones, B., Kuiken, T., Baker, J., et al., 2001. Exposure to heavy metals and infectious disease mortality in harbour porpoises from England and Wales. Environ. Pollut. 112 (1), 33–40. https://doi.org/10.1016/s0269-7491(00)00105-6.

Borrell, A., Aguilar, A., Tornero, V., Drago, M., 2014. Concentrations of mercury in tissues of striped dolphins suggest decline of pollution in Mediterranean open waters. Chemosphere 107, 319–323. https://doi.org/10.1016/j.chemosphere.2013.12.076.

Borrell, A., Clusa, M., Aguilar, A., Drago, M., 2015. Use of epidermis for the monitoring of tissular trace elements in Mediterranean striped dolphins (*Stenella coeruleoalba*). Chemosphere 122, 288–294. https://doi.org/10.1016/j.chemosphere.2014.10.080.

Braune, B., 2007. Temporal trends of organochlorines and mercury in seabird eggs from the Canadian Arctic, 1975–2003. Environ. Pollut. 148 (2), 599–613. https://doi.org/10.1016/j.envpol.2006.11.024.

Campbell, L., Norstrom, R., Hobson, K., Muir, D., Backus, S., Fisk, A., 2005. Mercury and other trace elements in a pelagic Arctic marine food web (Northwater Polynya, Baffin Bay). Sci. Total Environ. 351–352, 247–263. https://doi.org/10.1016/j.scitotenv.2005.02.043.

Capelli, R., Drava, G., De Pellegrini, R., Minganti, V., Poggi, R., 2000. Study of trace elements in organs and tissues of striped dolphins (*Stenella coeruleoalba*) found dead along the Ligurian coasts (Italy). Adv. Environ. Res. 4 (1), 31–42. https://doi.org/10.1016/s1093-0191(00)00005-8.

Capelli, R., Das, K., Pellegrini, R., Drava, G., Lepoint, G., Miglio, C., et al., 2008. Distribution of trace elements in organs of six species of cetaceans from the Ligurian Sea (Mediterranean), and the relationship with carbon and nitrogen ratios. Sci. Total Environ. 390 (2–3), 569–578. https://doi.org/10.1016/j.scitotenv.2007.10.036.

Cardellicchio, N., Giandomenico, S., Ragone, P., Di Leo, A., 2000. Tissue distribution of metals in striped dolphins (*Stenella coeruleoalba*) from the Apulian coasts, Southern Italy. Mar. Environ. Res. 49 (1), 55–66. https://doi.org/10.1016/s0141-1136(99)00048-3.

Cardellicchio, N., Decataldo, A., Di Leo, A., Giandomenico, S., 2002a. Trace elements in organs and tissues of striped dolphins (*Stenella coeruleoalba*) from the Mediterranean Sea (Southern Italy). Chemosphere 49 (1), 85–90. https://doi.org/10.1016/s0045-6535(02)00170-4.

Cardellicchio, N., Decataldo, A., Di Leo, A., Misino, A., 2002b. Accumulation and tissue distribution of mercury and selenium in striped dolphins (*Stenella coeruleoalba)* from the Mediterranean Sea (southern Italy). Environ. Pollut. 116, 265–271. https://doi.org/10.1016/S0269-7491(01)00127-0.

Caurant, F., Navarro, M., Amiard, J., 1996. Mercury in pilot whales: possible limits to the detoxification process. Sci. Total Environ. 186 (1–2), 95–104. https://doi.org/10.1016/0048-9697(96)05087-5.

Caurant, F., Aubail, A., Lahaye, V., Van Canneyt, O., Rogan, E., López, A., et al., 2006. Lead contamination of small cetaceans in European waters – the use of isotopes for identifying the sources of lead exposure. Mar. Environ. Res. 62 (2), 131–148. https://doi.org/10.1016/j.marenvres.2006.03.007.

Chan, D.K.P., Tsui, H.C.L., Kot, B.C.W., 2017. Database documentation of marine mammal stranding and mortality: current status review and future prospects. Dis. Aquat. Org. 126, 247–256. https://doi.org/10.3354/dao03179.

Das, K., Beans, C., Holsbeek, L., Mauger, G., Berrow, S., Rogan, E., Bouquegneau, J., 2003. Marine mammals from northeast atlantic: relationship between their trophic status as determined by δ13C and δ15N measurements and their trace metal concentrations. Mar. Environ. Res. 56 (3), 349–365. https://doi.org/10.1016/s0141-1136(02)00308-2.

Decataldo, A., Di Leo, A., Giandomenico, S., Cardellicchio, N., 2004. Association of metals (mercury, cadmium and zinc) with metallothionein-like proteins in storage organs of stranded dolphins from the Mediterranean Sea (Southern Italy). J. Environ. Monit. 6, 361–367. https://doi.org/1039/b315685k.

Dietz, R., Riget, F., Born, E., 2000. An assessment of selenium to mercury in Greenland marine animals. Sci. Total Environ. 245 (1–3), 15–24. https://doi.org/10.1016/s0048-9697(99)00430-1.

Endo, T., Haraguchi, K., Sakata, M., 2002. Mercury and selenium concentrations in the internal organs of toothed whales and dolphins marketed for human consumption in Japan. Sci. Total Environ. 300 (1–3), 15–22. https://doi.org/10.1016/s0048-9697(02)00137-7.

Fernandes, C., Fontaínhas-Fernandes, A., Peixoto, F., Salgado, M., 2007. Bioaccumulation of heavy metals in Liza saliens from the Esmoriz–Paramos coastal lagoon, Portugal. Ecotoxicol. Environ. Saf. 66 (3), 426–443. https://doi.org/10.1016/j.ecoenv.2006.02.007.

Fujise, Y., Honda, K., Tatsukawa, R., Mishima, S., 1988. Tissue distribution of heavy metals in Dall's porpoise in the northwestern Pacific. Mar. Pollut. Bull. 19 (5), 226–230. https://doi.org/10.1016/0025-326x(88)90236-6.

Gajdosechova, Z., Lawan, M., Urgast, D., Raab, A., Scheckel, K., Lombi, E., Kopittke, P., Loeschner, K., Larsen, E., Woods, G., Brownlow, A., Read, F., Feldmann, J., Krupp, E., 2016. In vivo formation of natural HgSe nanoparticles in the liver and brain of pilot whales. Sci. Rep. 6 (1) https://doi.org/10.1038/srep34361.

Gallien, I., Caurant, F., Bordes, M., Bustamante, P., Miramand, P., Fernandez, B., Quellard, N., Babin, P., 2001. Cadmium-containing granules in kidney tissue of the Atlantic white-sided dolphin (*Lagenorhyncus acutus*) off the Faroe Islands. Comp. Biochem. Physiol. C Comp. Pharmacol. 130 (3), 389–395. https://doi.org/10.1016/S1532-0456(01)00265-4.

García-Alix, A., Jimenez-Espejo, F.J., Lozano, J.A., Jiménez-Moreno, G., Martinez-Ruiz, F., García Sanjuán, L., Aranda Jiménez, G., García Alfonso, E., Ruiz-Puertas, G., Scott Anderson, R., 2013. Anthropogenic impact and lead pollution throughout the holocene in southern iberia. Sci. Total Environ. 449, 451–460. https://doi.org/10.1016/j.scitotenv.2013.01.081.

Gaspari, S., 2004. Social and Population Structure of Striped and Risso's Dolphins in the Mediterranean Sea. (PhD Thesis). University of Durham, UK.

Gerpe, M., Rodriguez, D., Moreno, V.J., Aipun, J.E., Bastida, R., 2006. Distribution and dynamics of total mercury, cadmium, zinc and copper in Southern Sea Lions (*Otaria flavescens*) from Argentina. In: Trites, A.W., Atkinson, S.K., DeMaster, D.P., Fritz, L.W., Gelatt, T.S., Rea, L.D., Wynne, K.M. (Eds.), Sea Lions of the World Lowell Wakefield Fisheries Symposium, Alaska Sea Grant, pp. 45–56. AK-SG-06-01.

Gómez-Campos, E., Borrell, A., Aguilar, A., 2011. Assessment of nutritional condition indices across reproductive states in the striped dolphin (Stenella coeruleoalba). J. Exp. Mar. Biol. Ecol. 405 (1–2), 18–24. https://doi.org/10.1016/j.jembe.2011.05.013.

Hammond, P.S., Bearzi, G., Bjørge, A., Forney, K., Karczmarski, L., Kasuya, T., Perrin, W.F., Scott, M.D., Wang, J.Y., Wells, R.S., Wilson, B., 2008. Stenella coeruleoalba. The IUCN Red List of Threatened Species 2008.

Hansen, A.M., Bryan, C.E., West, K., Jensen, B.A., 2015. Trace element concentrations in liver of 16 species of cetaceans stranded on Pacific islands from 1997 through 2013. Arch. Environ. Contam. Toxicol. 1–21. https://doi.org/10.1007/s00244-015-0204-1.

Haraguchi, K., Endo, T., Sakata, M., Masuda, Y., Simmonds, M., 2000. Contamination survey of heavy metals and organochlorine compounds in cetacean products purchased in Japan. J. Food Hyg. Soc. Jpn. 41 (4), 287–296. https://doi.org/10.3358/shokueishi.41.287.

Honda, K., Tatsukawa, R., 1983. Distribution of cadmium and zinc in tissues and organs, and their age-Related changes in striped dolphins, Stenella coeruleoalba. Arch. Environ. Contam. Toxicol. 12 (5), 543–550. https://doi.org/10.1007/bf01056550.

Honda, K., Fujise, Y., Tatsukawa, R., Itano, K., Miyazaki, N., 1986. Age-related accumulation of heavy metals in bone of the striped dolphin, Stenella coeruleoalba. Mar. Environ. Res. 20 (3), 143–160. https://doi.org/10.1016/0141-1136(86)90045-0.

Itano, K., Kawai, S., Miyazaki, N., Tatsukawa, R., Fujiyama, T., 1984. Body burdens and distribution of mercury and selenium in striped dolphins. Agric. Biol. Chem. 48 (5), 1117–1121. https://doi.org/10.1271/bbb1961.48.1117.

Komarnicki, G., 2000. Tissue, sex and age specific accumulation of heavy metals (Zn, Cu, Pb, Cd) by populations of the mole (*Talpa europaea* L.) in a central urban area. Chemosphere 41 (10), 1593–1602. https://doi.org/10.1016/s0045-6535(00)00018-7.

Kubota, R., Kunito, T., Tanabe, S., 2001. Arsenic accumulation in the liver tissue of marine mammals. Environ. Pollut. 115 (2), 303–312. https://doi.org/10.1016/s0269-7491(01)00099-9.

Kuiken, T., Hartmann, M.G., 1991. Draft standard protocol for the basic postmortem examination and tissue sampling of small cetaceans. In: Guidelines and Rec. Form. Resulting from the 1st ECS Workshop on Cetacean Pathology: Dissection Techniques and Tissue Sampling, pp. 13–14. Leiden.

Kurzel, R.B., Cetrulo, C.L., 1985. Chemical teratogenesis and reproductive failure. Obstet. Gynecol. Surv 40 (7), 397–424.

Lahaye, V., Bustamante, P., Dabin, W., Van Canneyt, O., Dhermain, F., Cesarini, C., Pierce, G., Caurant, F., 2006. New insights from age determination on toxic element accumulation in striped and bottlenose dolphins from Atlantic and Mediterranean waters. Mar. Pollut. Bull. 52 (10), 1219–1230. https://doi.org/10.1016/j.marpolbul.2006.02.020.

Lahaye, V., Bustamante, P., Law, R., Learmonth, J., Santos, M., Boon, J., et al., 2007. Biological and ecological factors related to trace element levels in harbour porpoises (Phocoena phocoena) from European waters. Mar. Environ. Res. 64 (3), 247–266. https://doi.org/10.1016/j.marenvres.2007.01.005.

Law, R.J., 1996. Metals in marine mammals. In: Beyer, N., Heinz, G., Redmon-Norwood, A.W. (Eds.), Environmental Contaminants inWildlife: Interpreting Tissue Concentrations. Lewis Publishers, Inc, Chelsea, Michigan, pp. 357–376.

Law, R., Jones, B., Baker, J., Kennedy, S., Milne, R., Morris, R., 1992. Trace metals in the livers of marine mammals from the Welsh coast and the Irish Sea. Mar. Pollut. Bull. 24 (6), 296–304. https://doi.org/10.1016/0025-326x(92)90590-3.

Law, R., Barry, J., Barber, J., Bersuder, P., Deaville, R., Reid, R., et al., 2012. Contaminants in cetaceans from UK waters: status as assessed within the cetacean strandings investigation programme from 1990 to 2008. Mar. Pollut. Bull. 64 (7), 1485–1494. https://doi.org/10.1016/j.marpolbul.2012.05.024.

Lindh, U., Danersund, A., Lindvall, A., 1996. Selenium protection against toxicity from cadmium and mercury studied at the cellular level. Cell. Mol. Biol. 42 (1), 39–48. https://doi.org/0163-4984/03/9202–0105.

Martínez-Gomez, C., Fernández, B., Benedicto, J.M., Valdés, J., Campillo, J.A., Leon, V.M., Vethaak, A.D., 2012. Health status of red mullets from polluted areas of the Spanish Mediterranean coast, with special reference to Portman (SE-Spain). Mar. Environ. Res. 77, 50–59. https://doi.org/10.1016/j.marenvres.2012.02.002.

Meador, J., Ernest, D., Hohn, A., Tilbury, K., Gorzelany, J., Worthy, G., Stein, J., 1999. Comparison of elements in bottlenose dolphins stranded on the beaches of Texas and Florida in the gulf of Mexico over a one-year period. Arch. Environ. Contam. Toxicol. 36 (1), 87–98. https://doi.org/10.1007/s002449900446.

Méndez-Fernandez, P., Webster, L., Chouvelon, T., Bustamante, P., Ferreira, M., González, A., López, A., Moffat, C., Pierce, G., Read, F., Russell, M., Santos, M., Spitz, J., Vingada, J., Caurant, F., 2014. An assessment of contaminant concentrations in toothed whale species of the NW Iberian Peninsula: Part II. Trace element concentrations. Sci. Total Environ. 484, 206–217. https://doi.org/10.1016/j.scitotenv.2014.03.001.

Mok, J., Kwon, J., Son, K., Choi, W., Shim, K., Lee, T., Kim, J., 2014. Distribution of heavy metals in muscles and internal organs of Korean cephalopods and Crustaceans: risk assessment for human health. J. Food Prot. 77 (12), 2168–2175. https://doi.org/10.4315/0362-028x.jfp-14-317.

Monaci, F., Borrel, A., Leonzio, C., Marsili, L., Calzada, N., 1998. Trace elements in striped dolphins (*Stenella coeruleoalba*) from the western Mediterranean. Environ. Pollut. 99 (1), 61–68. https://doi.org/10.1016/s0269-7491(97)00174-7.

Monteiro, S.S., Torres, J., Ferreira, M., Marçalo, A., Nicolau, L., Vingada, J.V., Eira, C., 2016. Ecological variables influencing trace element concentrations in bottlenose dolphins (Tursiops truncatus, Montagu 1821) stranded in continental Portugal. Sci. Total Environ. 544, 837–844. https://doi.org/10.1016/j.scitotenv.2015.12.037.

Palmisano, F., Cardellicchio, N., Zambonin, P., 1995. Speciation of mercury in dolphin liver: a two-stage mechanism for the demethylation accumulation process and role of selenium. Mar. Environ. Res. 40 (2), 109–121. https://doi.org/10.1016/0141-1136(94)00142-C.

O'Hara, T.M., Woshner, V., Bratton, G., 2003. Inorganic pollutants in Arctic marine mammals. In: Vos, J.G., Bossart, G., Fournier, M., O'Shea, T.J. (Eds.), Toxicol Mar Mamm, pp. 206–246.

Pastorelli, A., Baldini, M., Stacchini, P., Baldini, G., Morelli, S., Sagratella, E., et al., 2012. Human exposure to lead, cadmium and mercury through fish and seafood product consumption in Italy: a pilot evaluation. Food Addit. Contam. A 29 (12), 1913–1921. https://doi.org/10.1080/19440049.2012.719644.

Perrin, W., Würsig, B., Thewissen, J., 2002. Encyclopedia of Marine Mammals, first ed. Academic Press, San Diego, p. 895.

Raga, J.A., Banyard, A., Domingo, M., Cortyn, M., Van Bressem, M.F., Fernández, M., Aznar, F.J., Barret, T., 2008. Dolphin morbillivirus epizootic resurgence, Mediterranean Sea. Emerg. Infect. Dis. 14 (2), 471–473. https://doi.org/10.3201/eid1403.071230.

Rawson, A., Patton, G., Hofmann, S., Pietra, G., Johns, L., 1993. Liver abnormalities associated with chronic mercury accumulation in stranded atlantic bottlenosed dolphins. Ecotoxicol. Environ. Saf. 25 (1), 41–47. https://doi.org/10.1006/eesa.1993.1005.

Riget, F., Dietz, R., 2000. Temporal trends of cadmium and mercury in Greenland marine biota. Sci. Total Environ. 245 (1–3), 49–60. https://doi.org/10.1016/s0048-9697(99)00432-5.

Riget, F., Dietz, R., Vorkamp, K., Johansen, P., Muir, D., 2004. Levels and spatial and temporal trends of contaminants in Greenland biota: an updated review. Sci. Total Environ. 331 (1–3), 29–52. https://doi.org/10.1016/j.scitotenv.2004.03.022.

Ringelstein, J., Pusineri, C., Hassani, S., Meynier, L., Nicolas, R., Ridoux, V., 2006. Food and feeding ecology of the striped dolphin, Stenella coeruleoalba, in the oceanic waters of the north-east Atlantic. J. Mar. Biol. Assoc. U. K. 86 (04), 909. https://doi.org/10.1017/s0025315406013865.

Robin, R., Muduli, R., P., Vishnu Vardhan, K., Ganguly, D., R Abhilash, K., Balasubramanian, T., 2012. Heavy metal contamination and risk assessment in the marine environment of arabian sea, along the southwest coast of India. Am. J. Chem. 2 (4), 191–208. https://doi.org/10.5923/j.chemistry.20120204.03.

Robinson, C.D., Webster, L., Martinez-Gómez, C., Burgeot, T., Gubbins, M.J., Thain, J.E., Vethaak, A.D., McInstpsh, A.D., Hylland, K., 2016. Assessment of contaminant concentrations in sediments, fish and mussels sampled from the North Atlantic and European regional seas within the ICON project. Mar. Environ. Res. 1, 11. https://doi.org/10.1016/j.marenvres.2016.04.005.

Roditi-Elasar, M., Kerem, D., Hornung, H., Kress, N., Shoham-Frider, E., Goffman, O., Spanier, E., 2003. Heavy metal levels in bottlenose and striped dolphins off the Mediterranean coast of Israel. Mar. Pollut. Bull. 46 (4), 503–512. https://doi.org/10.1016/s0025-326x(03)00003-1.

Rojo-Nieto, E., Fernández-Maldonado, C., 2017. Assessing trace elements in striped dolphins from the Strait of Gibraltar: Clues to link the bioaccumulation in the westernmost Mediterranean Sea area and nearest Atlantic Ocean. Chemosphere 170, 41–50. https://doi.org/10.1016/j.chemosphere.2016.12.009.

Rubio-Guerri, C., Melero, M., Esperón, F., Bellière, E.N., Arbelo, M., Crespo, J.L., et al., 2013. Unusual striped dolphin mass mortality episode related to cetacean morbillivirus in the Spanish Mediterranean Sea. BMC Vet. Res. 9, 106. https://doi.org/10.1186/1746-6148-9-106.

Sasakura, C., Suzuki, T., K., 1998. Biological interaction between transition metals (Ag, Cd and Hg), selenide/sulfide and selenoprotein. J. Inorg. Biochem. 71 (3–4), 159–162. https://doi.org/10.1016/s0162-0134(98)10048-x.

Shoham-Frider, E., Goffman, O., Harlavan, Y., Kress, N., Morick, D., Roditi-Elasar, M., et al., 2016. Trace elements in striped dolphins (*Stenella coeruleoalba*) from the Eastern Mediterranean: a 10-years perspective. Mar. Pollut. Bull. 109 (1), 624–632. https://doi.org/10.1016/j.marpolbul.2016.05.021.

Soto, S., Alba, A., Ganges, L., Vidal, E., Raga, J.A., Alegre, F., González, B., Medina, P., Zorrilla, I., et al., 2011a. Post-epizootic chronic dolphin morbillivirus infection in Mediterranean striped dolphins *Stenella coeruleoalba*. Dis. Aquat. Org. 96, 187–194. https://doi.org/10.3354/dao02387.

Soto, S., González, R., Alegre, F., González, B., Medina, P., Raga, J.A., Marco, A., Domingo, M., 2011b. Epizootic of dolphin morbillivirus on the Catalonian Mediterranean coast in 2007. Vet. Rec. 169, 101a. https://doi.org/10.1136/vr.d1686.

Stavros, H., Bossart, G., Hulsey, T., Fair, P., 2008. Trace element concentrations in blood of free-ranging bottlenose dolphins (*Tursiops truncatus*): influence of age, sex and location. Mar. Pollut. Bull. 56 (2), 371–379. https://doi.org/10.1016/j.marpolbul.2007.10.030.

Stavros, H., Stolen, M., Durden, W., McFee, W., Bossart, G., Fair, P., 2011. Correlation and toxicological inference of trace elements in tissues from stranded and free-

ranging bottlenose dolphins (*Tursiops truncatus*). Chemosphere 82 (11), 1649–1661. https://doi.org/10.1016/j.chemosphere.2010.11.019.
Storelli, M., Giacominelli-Stuffler, R., Storelli, A., Marcotrigiano, G., 2005. Accumulation of mercury, cadmium, lead and arsenic in swordfish and bluefin tuna from the Mediterranean Sea: a comparative study. Mar. Pollut. Bull. 50 (9), 1004–1007. https://doi.org/10.1016/j.marpolbul.2005.06.041.
Thompson, D., 1990. Heavy metals in marine vertebrates. In: Furness, R.W., Rainbow, P.S. (Eds.), Heavy Metals in the Marine Environment, first ed. CRC Press, Boca Raton, Florida, pp. 143–182.
Tintoré, J., Gomis, D.D., Alonso, S.S., Wang, D.P., 1988. A theoretical study of large sea-level oscillations in the western Mediterranean. J. Geophys. Res. 93, 10797–10803. https://doi.org/10.1029/JC093iC09p10797.
Vázquez, J.A., Arbelo, M., Martínez-Cedeira, J.A., De la Fuente, J., Fernández, C., Gozalbes, P., López, A., 2015. Documento técnico sobre Protocolo nacional de actuación para varamientos de cetáceos. Informe realizado para el Ministerio de Agricultura, Alimentación y Medio Ambiente, p. 123.
Wagemann, R., Muir, D.C.G., 1984. Concentrations of Heavy Metals and Organochlorines in Marine Mammals of Northern Waters: Overview and Evaluation, vol. 1279. Department of Fisheries and Oceans, Canada: Western Region.
Włodarczyk, B., Minta, M., Biernacki, B., Szkoda, J., Żmudzki, J., 2000. Selenium protection against cadmium toxicity in hamster embryos. Pol. J. Environ. Stud. 9 (4), 323–327.
Yang, J., Kunito, T., Anan, Y., Tanabe, S., Miyazaki, N., 2004. Total and subcellular distribution of trace elements in the liver of a mother–fetus pair of Dall's porpoises (Phocoenoides dalli). Mar. Pollut. Bull. 48 (11–12), 1122–1129. https://doi.org/10.1016/j.marpolbul.2003.12.019.