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First Report of Organochlorine Pesticides and Heavy Metals in a Stranded Bottlenose Dolphin Off the Central Coast of Veracruz State: A Warning to Assess Pollution in a Reef Marine Ecosystem from the Gulf of Mexico?

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Abstract

Live-strandings of cetaceans are uncommon in the southwestern Gulf of Mexico. However, an adult female bottlenose dolphin (*Tursiops truncatus*) with normal body condition was recorded at Pelicano's Beach on the coast of Veracruz State. Health assessment showed multiple external injuries, possibly caused by the stranding event, as well as potential bacterial infection, and, thus, the individual was held in temporary facilities for rehabilitation. Blood samples were taken to assess the health status of the individual and were also analyzed for concentrations of 20 pollutants (14 organochlorine pesticides [OCPs] and six heavy metals [HMs]). The animal was released and found dead within a few days. The concentration of OCPs and HMs were close or above the government limits. Although these were lower than those reported in other living, free-ranging bottlenose dolphins, there are well-known negative effects for health. Low OCP values were attributed to an offloading process through lactation or mobility of the lipophilic OCPs that pass from blood to fat. Whereas HM concentrations (mainly non-essential metals: mercury [Hg], lead [Pb], and cadmium [Cd]—2.73, 21.13, and 12.67 µg L^{-1}, respectively) were probably linked to the diet and the possible distribution of the specimen (possibly offshore). This is the first report on pollutants from anthropogenic origin in the area where uncontrolled activities are of major concern within a protected national reef park. Since marine ecosystems are under continuous pressure, several health issues for top predators are being noticed; therefore, this study underlines the relevance of studying health status of marine mammals in the Mexican waters of the Gulf of Mexico.

Key Words: persistent pollutants, toxicology, marine mammals, health

Introduction

The common bottlenose dolphin (*Tursiops truncatus*) is a worldwide distributed cetacean species that is adapted to several habitat types (e.g., oceanic, continental shelf, coastal; Reynolds et al., 2000). Due to this wide distribution range, this species presents several threats that are derived from its chronic exposure to a variety of anthropogenic hazards. The most concerning of these is marine pollution, mainly due to the industrial and urban discharges from the coasts to the environment (Dos Santos & Lacerda, 1987; Houde et al., 2005; Reijnders et al., 2009). Within the Mexican waters of the Gulf of Mexico (GoM), bottlenose dolphins are the most common marine mammal near the coast and the most extensively studied, specifically in the central portion where two different populations have been described (Morteo et al., 2017; Bolaños-Jiménez et al., 2021). This region has been qualified as relevant for the species since the dolphins are commonly found displaying several activities such as feeding (predatory and depredatory strategies), socializing (i.e., sexual segregation), playing (i.e., using objects), traveling, resting, mating, and calving (Morteo et al., 2012, 2014; Morales-Rincón et al., 2019; García-Aguilar, 2020).

Located in the central portion of the GoM, the State of Veracruz occupies a large southwestern coastal region (≈745 km) influenced by lands at different altitudes (i.e., ~1,800 m above sea level [asl]); its central coast is linked by four large rivers—La Antigua, Cotaxtla, Jamapa, and Papaloapan Rivers (Fuentes-Mariles et al., 2014). The runoff of this system leads to the dissemination of several natural and synthetic compounds in the environment, which consequently end up at sea, mainly in the Veracruz Reef System National Park (VRSNP). This area is one of the most important reef complexes in Mexico, although humans have severely impacted the coastal zone since colonial times (i.e., the 16th century; Ortiz Lozano et al., 2015). It is now influenced by the largest and most populated metropolitan zones in the state (in 2020, both Veracruz and Boca del Río cities had 751,759 inhabitants combined) and is one of the main commercial ports in the GoM and Latin America (in 2021 alone, there were 2,012 containers moved weekly; Aguilar Sánchez & Ortiz Escamilla, 2011; Official Journal of the Federation [DOF], 2012; Administración Portuaria Integral de Veracruz S. A. de C. V. [APIVER], 2022; Secretaría de Comunicaciones y Transportes [SCT], 2023).

This area is also affected by the Alvarado lagoon system, located 70 km to the southeast (influenced by the population of the Alvarado municipality consisting of 57,035 inhabitants by 2020), and the Papaloapan River, which is formed by the confluence of several rivers that collects the discharges from sugar refineries, as well as large agriculture and cattle farms (Thiébaut, 2018; Comisión Nacional del Agua [CONAGUA], 2020; Instituto Nacional de Estadística y Geografía [INEGI], 2021). All these chemical assemblages throughout the systems promote changes in the coastal zone as a reservoir of pollutants (Iwata et al., 1995). In particular, the VRSNP area has undergone drastic changes due to the impact of urban development, marine traffic, sediment removal, and runoff from industrial areas, carrying pollutants like heavy metals (HMs), hydrocarbons, and pesticides produced by anthropic activities (e.g., agriculture, urban, and industrial sources) near coastal and adjacent areas (Montessoro-Méndez, 2007; Castañeda-Chávez et al., 2020; Mapel-Hernández et al., 2021). The exact flux of water from the rivers to the GoM is currently unknown, and the same applies to the quantity of nutrients, elements, and chemical compounds, especially in the VRSNP area, which certainly could affect the biogeochemical cycles. Thus, the concentration of pollutants in marine ecosystems has become an important concern due to their presumed variety, persistence, availability, bioaccumulation, biomagnification, and impact on ecosystem health (Das et al., 2003; Murphy et al., 2018).

It is noteworthy that at least 34 banned and 13 restricted pesticides are still illegally used in Mexico (Ruiz-Gamboa et al., 2018) despite their high toxicity, persistence, and severe associated problems such as immune system depression, reproductive implications, hormonal disruption (e.g., endometriosis and/or infertility), neurotoxic potential, tumerogenic effect, liver and kidney damage, among others (Busbee et al., 1999; Sang & Petrovic, 1999; Gourounti et al., 2008; Jayaraj et al., 2016; Murphy et al., 2018; Kang et al., 2022; Reckendorf et al., 2023). These affect organisms in every link in the trophic web in several ecosystems on the planet (Sitaramaraju et al., 2014). On the other hand, HMs (also denominated trace metals; Libes, 2009) naturally occur in the earth's crust and consequently in the environment (e.g., copper [Cu], zinc [Zn], manganese [Mn], iron [Fe], molybdenum [Mo], cobalt [Co]), and some are considered essential for cellular biochemical reactions. In high concentrations, these may also be highly toxic (Jakimska et al., 2011; Li et al., 2017; Ruiz et al., 2021).

The distribution routes for both types of pollutants, organochlorine pesticides (OCPs) and HMs, may include spraying, farming, and industrial waste (Centers for Disease Control and Prevention [CDC], 2017), which will dissolve in water and air afterward, and subsequently enter organisms at all trophic levels (Islam et al., 2022) by contact and absorption through mucosa/skin. However, ingestion represents the primary exposure mechanism, as well as direct water-skin contact; also, indirect exposure may occur *in utero* or by feeding on the mother's milk (Honda et al., 1987; Pardío et al., 1998; Gourounti et al., 2008; Loseto & Ross, 2011).

In marine mammals, OCPs are recognized for acting as hormonal disruptors, leading to reproductive failure, as well as metabolic and neurological disorders (Das et al., 2003; Rosales-Ledezma et al., 2011). In marine mammals, bioaccumulation of these compounds is related to endocrine system dysfunction and changes in reproductive behavior (O'Shea et al., 1998; Das et al, 2003), as well as immunosuppression and susceptibility to infectious disease (Litz et al., 2014; Dron et al., 2022), and even to cancer development, like urogenital carcinoma in the California sea lion (*Zalophus californianus*) (Gulland et al., 2020).

Furthermore, non-essential HMs (e.g., mercury [Hg], lead [Pb], and cadmium [Cd]) have great relevance due to the lack of metabolic routes for their elimination; these pollutants can disrupt cellular events (e.g., proliferation, differentiation, apoptosis, damage-repairing process; Balali-Mood et al., 2021), and their unusual amounts in marine fauna, such as marine mammals, may be associated with dermatitis as well as liver and kidney damage (Friberg et al., 1992; Das et al., 2003; Sorensen et al., 2008; EPA, 2023a). In humans, HMs present neuro-, nephron-, hepato-, cardiovascular-, and geno-toxicity, as well as skin damage, leading to reproductive problems, but they can also affect the immune system, causing an autoinflammatory response that results in a decrease in immune defense (Mishra, 2009; Guo et al., 2010; Anka et al., 2022), and play a role in cancer development (e.g., intestine; Engwa et al., 2008; Tchounwou et al., 2012; Kim et al., 2015).

As long-living apex predators that inhabit estuarine, coastal, and offshore waters, marine mammals often occupy high trophic levels; their large storages of fatty tissue can accumulate high concentrations of organic and inorganic pollutants such as OCPs and HMs (Aguilar, 1985; Veinott & Sjare, 2006; Reif et al., 2015). Therefore, marine mammals are considered integrative indicators of the aquatic environment quality and, thus, of the components that generate a potential risk for public health (Bossart, 2006; Nogueira, 2007; Reif et al., 2015).

Marine mammal strandings usually occur due to natural causes (e.g., age, disease, predation), but these may also have anthropogenic origins (e.g., bycatch, toxicosis by petroleum) (Caurant et al., 1994; Das et al., 2003; Arbelo et al., 2013; Moore, 2018; Seguel et al., 2020). Therefore, analyses of stranded marine mammal tissues are considered useful resources to assess environmental health and potential risks to megafauna and human health such as the impact of persistent chemical pollutants that may lead to quantifying the cause-and-effect and evidence of adverse effects in ecosystem health.

Since 2014, all personnel involved in marine mammal stranding events in Mexico have been compelled to follow a federal protocol (DOF, 2014) wherein samples are taken from necropsies; these are a source of data that can provide valuable information about the risk to which organisms are exposed. These samples have shown presence of pollutants mainly in the blubber of stranded dolphins, but instances still are very limited (Ruelas-Inzunza et al., 2003; Delgado-Estrella et al., 2015; Flores-Sánchez et al., 2018; Ruiz-Hernández et al., 2022). Studies on the concentration of OCPs and HMs in marine mammal tissues and organs conducted in the GoM are generally concentrated in the northern portion involving only the United States (Kuehl & Haebler, 1995; Meador et al., 1999; Balmer et al., 2011, 2015). Conversely, the report of these pollutants in the VRSNP has been focused on sediments, water, and fish (Rosales-Hoz et al., 2007, 2009; Montoya-Mendoza et al., 2023). Despite the incidence of several dolphin strandings documented since the early 1990s, there are no reports on pollutants for marine mammals such as the bottlenose dolphin in this area. Therefore, this study aimed to detect and quantify OCP and HM concentrations in a live-stranded bottlenose dolphin in the VRSNP, providing basic information in toxicology with implications for conservation of small odontocetes in the southern GoM.

Methods

Three blood samples were collected (~1 ml) during clinical management from the periarterial venous in the caudal fin. These samples were conserved in ethylenediaminetetraacetic acid (EDTA) tubes, following standardized protocols for medical standard procedures and toxicology (see Bossart et al., 2001). Morphometric data was collected using a measuring tape, and general health was assessed according to the body condition scoring system (Body Condition Score [BCS]) proposed by Joblon et al. (2014).

Determination of Persistent Pollutants (OCPs and HMs)

The presence and concentration of 14 organochlorines (hexachlorobenzene [HCB], hexachlorocyclohexane [α-HCH], β-HCH, δ-HCH, lindane, heptachlor, heptachlor-epoxic, endosulfan, endosulfan-sulfate, p,p'-DDE, o,p'-DDT, p,p'-DDD, endri-aldehyde, and dieldrin) and six heavy metals (chromium [Cr], nickel [Ni], Zn, Cd, Pb, and Hg) were evaluated for the individual. Blood samples were refrigerated until toxicological analysis at the Laboratory of Toxicology of the Veterinary Medicine Faculty (Universidad Veracruzana) and Laboratorio de Investigaciones Acuáticas (LIRA) at Instituto Tecnológico de Boca del Río (ITBOCA). OCPs were measured using gas chromatography electron capture detection (Agilent 6890; Agilent Technologies, Santa Clara, CA, USA) according to Murphy (1972) and determined on a $\mu g\ kg^{-1}$ lipid weight (Lw) basis. For HMs, the sample was analyzed by flame atomic absorption spectrophotometry with a Thermo Scientific Model Ice 3500 AA System (Thermo Fisher Scientific Inc., Waltham, MA, USA) and expressed in $\mu g\ L^{-1}$. If concentrations fell below the limit of quantification, these were set at half the detection limit. Since toxicity guideline levels for marine mammals have not been proposed for potential health effects of contaminants that may be of concern, we used common laboratory rats (*Rattus norvegicus*) as reference for toxicity, expressed as Reference Dose (RfD) (EPA, 2023b).

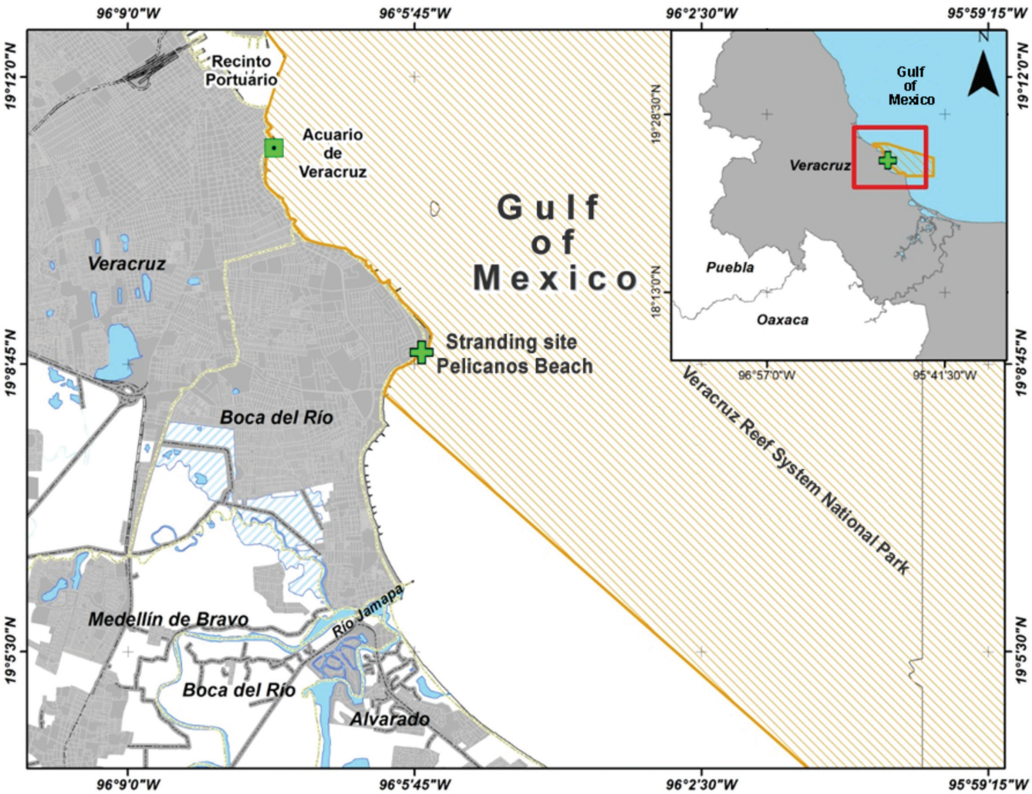

Figure 1. Location of the adult female bottlenose dolphin (*Tursiops truncatus*) stranding in Boca del Río, Veracruz (green cross)

Results

The experimental subject was found live-stranded at Pelicano's Beach in Boca del Río, Veracruz, on 3 February 2010 (Figure 1) and was classified as an adult female bottlenose dolphin. A local stranding protocol was activated, where federal authorities coordinated staff from the Veracruz Aquarium and the Marine Mammal Laboratory (LabMMar, IIB-UV) at Universidad Veracruzana.

Standard photo-identification of the dorsal fin was used to search for the identity of the individual using previous data from the area (VRSNP, unpub. data, 2005-2007), as well as adjacent sites (Alvarado and Nautla, unpub. data, 2002-2003 and 2002-2010, respectively); however, no match was found within over 400 different coastal individuals from the catalogs by LabMMar, IIB-ICIMAP-UV (see Morteo et al., 2014; Hernández-Candelario et al., 2015). The total length of the dolphin was 323 cm, and it weighed roughly 200 kg. During the clinical and behavioral examination, the animal reacted actively and exhibited a fair body condition (BCS = 3). On the same day, we performed two attempts of release in shallow (15 m) waters, and the individual was loosely followed upon liberation by staff aboard a boat and a jet ski to verify its swimming speed and direction, as well as its breathing rate and general behavior; however, it moved erratically towards the coast, exhibiting fatigue and a tendency to float on her left side. Approximately 20 min later, this individual was sighted alive on shore at ~350 m to the southwest and was consequently translocated for rehabilitation at the Veracruz Aquarium. At these indoor aquarium facilities, the age of the individual was roughly estimated (> 25 y) according to teeth wear (Figure 2a; Townsend et al., 2018), comparing the teeth wear with local stranded and aged individuals through growth layer groups of dentine (Mendoza-Martínez, 2019).

Gross Pathologic Findings in the Bottlenose Dolphin

Multiple external injuries were found such as recent abrasions in the tip of the rostrum and the anterior part of the eye (~4 cm; Figure 2a). Ocular lesions were found such as unilateral ulcerative keratitis with axial corneal opacities

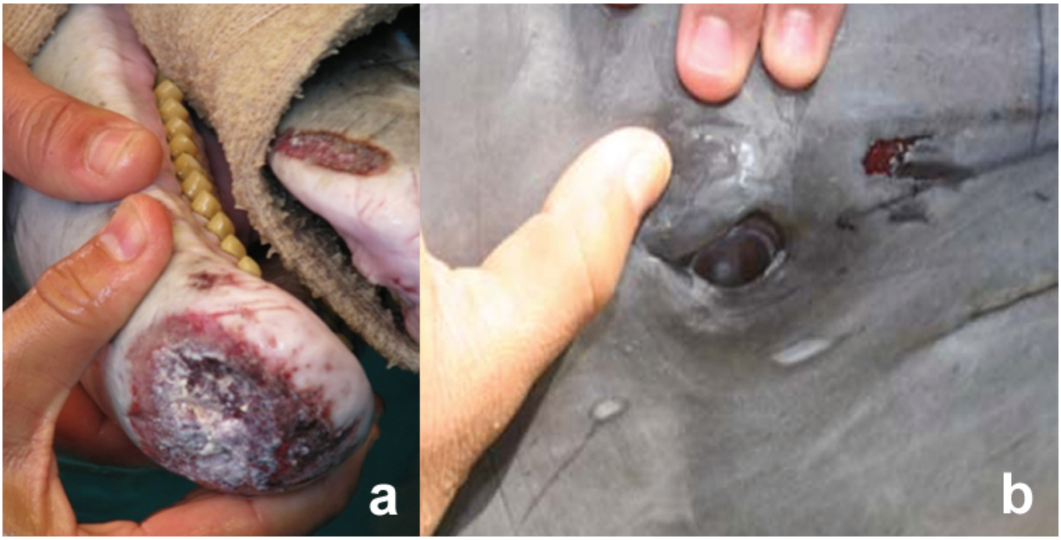

Figure 2. External lesions found in the female bottlenose dolphin stranded at Boca del Río, Veracruz: (a) epidermal rounded and reddish areas (4 cm) in lower and upper jaw with proliferative tissue in ulcerative areas; and (b) right eye, with unilateral ulcerative keratitis, conjunctival and palpebral irritation, swelling, edema, and a recent laceration at the upper eyelid.

Figure 3. Oral cavity inspection of the female bottlenose dolphin stranded at Boca del Río, Veracruz: oropharyngeal area with severe erythema and serous-purulent plaque with bilateral lymph node hypertrophy.

and conjunctival and palpebral irritation as well as swelling (Figure 2b). Inspection of the oral cavity revealed redness and erythema in pharyngeal mucosa with the presence of serous-purulent material; this suggests an active infectious disease (Figure 3). Epidermal chronic lesions were identified in the lower and upper jaw as well as the anterior portion of the eye, corresponding to ulcerative areas with proliferative tissue. Also, a 40-cm "V" shaped scar at the left flank was identified, suggesting a possible interaction with fisheries; and a parasite barnacle (*Xenobalanus* sp.) was found at the right pectoral flipper.

After 21 d under veterinary care (fed with local fish) and treatment (i.e., wound care and broad range antibiotics), federal authorities mandated the animal to be released in shallow waters (~15 m). At this point, the animal had not finished its antibiotic treatment but was already eating live local fish provided at the tank. She also swam and breathed normally. Unfortunately, 5 d after the release (on 27 February), her dead body was identified southwest of the first stranding site, confirmed by both the dorsal fin and molecular analyses (PCR; see Montano-Frías, 2009).

Determination of Persistent Pollutants (OCPs and HMs)

The concentration of OCPs in blood samples of the bottlenose dolphin was compared with the concentration observed in other tissues in the same species (Table 1). The results showed the presence of all pesticides analyzed and, except for HCB and endosulfan I, all were above RfD values. The concentration of OCPs in blood ranged between 1.63 and 3.26 $\mu g\ kg^{-1}$ for HCH isomers (α-, β-, δ-HCH) and between 3.51 and 4.62 $\mu g\ kg^{-1}$ for dichloro-diphenyl-trichloroethane (DDT) and its metabolites (p,p'-DDD and p,p'-DDE). The results of essential HMs (Cr, Ni, and Zn) presented concentrations within the range or even lower than the permissible limit for humans (Table 2); furthermore, these concentrations were lower than those reported in dolphins from other areas of the GoM (Sorensen et al., 2008). The non-essential metals, such as cadmium (Cd) and lead (Pb) (21.13 and 12.67 $\mu g\ L^{-1}$, respectively), also showed a similar trend compared to the concentration of essential metals previously mentioned, which were above those reported for human blood but below those reported for bottlenose dolphins from other sites within the GoM (Sorensen et al., 2008). The concentration of Hg (2.73 $\mu g\ L^{-1}$) was within the range for human blood (0.32 to 10 $\mu g\ L^{-1}$; Agency for Toxic Substances and Disease Registry [ATSDR], 1999; McKelvey et al., 2007; Wodzebeyew, 2014), although lower than that reported for the species.

Discussion

Strandings of cetaceans are uncommon in the southwestern GoM since these are rarely reported and barely documented, and because live-stranded individuals are extremely rare. For instance, from the 47 bottlenose dolphin strandings reported along the coast of Veracruz State since 1992, only one was alive (LabMMar, unpub. data; Table 3). Due to the type of sample reported in this study, limited information was available. The only other study that reported concentrations in blood found low HCB values in stranded bottlenose dolphins from Sarasota Bay, Florida (Yordy et al., 2010b). Exposure leading to concentrations above the identifiable threshold (which is the case for the individual) has been linked to increased liver weight, progressive glomerulonephrosis, and blood vessel aneurysms. Different factors may affect the relationship between lipids and OCPs in the blood, such as their mobility towards other tissues by their lipophilic nature (Kleivane et al., 1995; Yordy et al., 2010a, 2010b, 2010c; Damseaux et al., 2017); thus, OCP concentrations vary depending on the analyzed tissue. Given that the concentration of contaminants in the fat layer of the stranded female bottlenose dolphin is in fact unknown, these may actually be present considering the body condition of this female, notwithstanding the low concentration of all OCPs in the blood detected.

On the other hand, it must be noted that β-HCH, α-HCH, and δ-HCH concentrations are typically lower in females than in males, and this is related to the elimination of these compounds from their body via maternal offloading (i.e., lactation). Conversely, reproductive status, infectious disease processes, stress periods, and starvation may cause the concentration of these compounds to increase (Thomas & Colborn, 1992; Reddy et al., 1998; Debier et al., 2006; Yordy et al., 2010c; Hayes et al., 2022).

The proximity of the VRSNP to intensive human activity led us to hypothesize high concentrations of pollutants, based on data from sediments (ΣDDTs from < 0.01 to 34.11 $\mu g\ kg^{-1}$, and ΣHCHs from 22.10 to 102.80 $\mu g\ kg^{-1}$; Briones-Venegas et al., 2023) and those obtained from other southeastern regions of the GoM (e.g., p,p'-DDD, p,p'-DDE, o,p'-DDT, α-HCH, β-HCH, δ-HCH, heptachlor, endosulfan; Delgado-Estrella et al., 2015; Flores-Sánchez et al., 2018; Table 1), but this was not the case for the blood sample. As the VRSNP possesses high human activity, with large inflow from important rivers (Ortiz-Lozano et al., 2005; Gutiérrez-Ruíz et al., 2011), concentrations of HCB reported herein are relatively low compared to other sites like Sarasota Bay, which also has a large human population and is influenced by a large river (i.e., the Mississippi River)

Table 1. Organochlorines pesticides (OCPs; µg kg^{-1} Lw) in different tissues of bottlenose dolphins (*Tursiops truncatus*)

	Studies	This study	Flores-Sánchez et al., 2018	Delgado-Estrella et al., 2015	Romanić et al., 2014						Wafo et al., 2012	Yordy et al., 2010b		Fair et al., 2010		
	Location	Veracruz-Boca del Río	Campeche	Campeche	Adriatic Sea						French Mediterranean coast	Sarasota Bay, FL		Florida	South Carolina	
	Samples type	Bl	B	B	B	L	K	Lu	M	H	B	B	Bl	B	B	RfD* (µg/kg/d)
Organochlorines (OCPs)	HCB	0.18	69.54	--	79 ± 87	9 ± 14	3.5 ± 2.1	3.5 ± 1.1	8 ± 13	4 ± 4	--	26.2	22.5	6.2	8.9	0.8
	α-HCH	1.63	24.47	--	23 ± 21	6 ± 3.8	4.6 ± 2.7	5.4 ± 3.7	6.1 ± 3.3	5.5 ± 4.7	--	--	--	0.1	0.3	--
	β-HCH	3.22	6.0	44,984.0	552 ± 1,301	48 ± 34	57 ± 46	50 ± 29	42 ± 37	52 ± 61	--	--	--	--	--	0.06
	δ-HCH	3.26	49.75	11,129.5	--	--	--	--	--	--	--	--	--	--	1.1	--
	Lindane	2.51	--	--	--	--	--	--	--	--	16.6 ± 12.1	--	--	--	--	0.3
	Heptachlor	2.82	--	6,838.0	--	--	--	--	--	--	6.7 ± 4.2	--	--	--	--	0.5
	Heptachlor-epoxide	3.10	--	274,385.0	--	--	--	--	--	--	106.6 ± 107.1	--	--	49.6	57.1	0.013
	Endosulfan I	3.07	--	980.5	--	--	--	--	--	--	46.6 ± 32.8	--	--	2.1	1.3	6.0
	Endosulfan sulfate	4.51	--	16,396.0	--	--	--	--	--	--	--	--	--	1.5	190.0	--
	p,p'-DDE	4.98	2,140.47	8,586.3	8,400 ± 14,382	107 ± 106	146 ± 293	57 ± 69	275 ± 765	136 ± 283	--	--	--	3750.0	1870.0	0.3
	o,p'-DDT	4.62	13,080.0	--	--	--	--	--	--	--	--	--	--	22.0	150.0	--
	p,p'-DDD	3.51	270.6	--	790 ± 757	31 ± 48	16 ± 16	13 ± 7	51 ± 99	14 ± 16	--	--	--	274.0	394.0	0.03
	Endrin aldehyde	1.85	--	3,835.0	--	--	--	--	--	--	207.7 ± 217.5	--	--	--	--	0.3
	Dieldrin	3.40	--	696.0	--	--	--	--	--	--	215.3 ± 290.3	--	--	66.5	160.0	--

Bl = blood; B = blubber; L = liver; K = kidney; Lu = lung; M = muscle; H = heart; HCB = hexachlorobenzene; HCH = hexachlorocyclohexane; DDE = dichloro-diphenyl-dichloroethylene; DDT = dichloro-diphenyl-trichloroethane; and DDD = dichloro-diphenyl-dichloroethane

*Reference Dose for health effects other than cancer and gene mutations in rat chronic chemical feeding study

Table 2. Heavy metal (HM) concentration (µg L^{-1}) in the blood of bottlenose dolphins

	Studies	This study	Bryan et al., 2007	Sorensen et al., 2008	Stavros et al., 2008	Schaefer et al., 2015	Titcomb et al., 2017	
	Location	Veracruz-Boca del Río	Sarasota Bay, FL	Navy Marine Mammal Program (MMP)	Charleston, SC	Indian River Lagoon, FL	Indian River Lagoon, FL	RfD*
	Sample type	Bl	Bl	Bl	Bl	Bl	Bl	Human Bl
Heavy metals (HMs)	Cr	28.19	--	100	--	--	--	20-30[a]
	Ni	5.45	--	--	--	--	--	1[d]
	Zn	3.98	5.27 ± 0.125	7.2 × 10^3	2,370 ± 394	--	--	> 1,000[e]
	Cd	21.13	--	--	--	--	--	50[b]
	Pb	12.67	0.568 ± 0.0236	--	--	--	--	50-100[c]
	Hg	2.73	--	--	147 ± 88	540.54 ± 477.27	199.7 ± 61.8 to 990.5 ± 487.0	0.32-10[e, f, g]

Bl = blood; *Reference Dose for health effects in humans
[a]ATSDR, 2008; [b]ATSDR, 2012; [c]CDC, 2012a; [d]WHO, 1996; [e]ATSDR, 1999; [f]McKelvey et al., 2007; and [g]Wodzebeyew, 2014

discharging organic matter, nutrients, and pollutants from inland, and the oil exploration off the coast of Florida (Yordy et al., 2010b).

Accordingly, HM concentrations were also lower than those reported in other regions (in the U.S.) for the same species (Sorensen et al., 2008; Stavros et al., 2008). Our results on essential metals (Zn and Ni; Table 2) also showed low values even when compared with normal values in human blood reported by the World Health Organization (WHO, 1996; Simon-Hettich et al., 2001). It should be noted that the concentration of chromium (Cr) and nickel (Ni) are typically maintained at low levels, and their toxicity has not yet been described (Law, 1996; Das et al., 2003). Even so, the effect of these elements may have important physiological consequences. For instance, low concentrations of Cr tend to affect metabolic efficiency and the activity of the immune system; conversely, in high concentrations, it can cause irritation in the respiratory tract and susceptibility for developing lung cancer (Snitynskyĭ et al., 1999; Sharma et al., 2022). Deficiency of essential trace metals in blood may be caused by fast assimilation in the system and its use in several biochemical reactions in cellular processes (Jomova et al., 2022).

On the other hand, non-essential metals such as mercury (Hg) in the organic form (methylmercury [CH_3Hg^+]) are far more toxic and easily bioaccumulated than in their metal form (Law, 1996). Due to the latter, their concentration would be expected to be high, especially in top predators. In this study, the observed concentration (2.73 µg L^{-1}) is between 190 to 260 times lower compared to bottlenose dolphins in the Indian River Lagoon, Florida (Schaefer et al., 2015), and 54 times lower compared to the same species in South Carolina (Stavros et al., 2008). However, these values are noteworthy given that under chronic exposure such as mining activities, Hg concentrations in human blood are usually lower (0.16 to 0.78 µg L^{-1}) as found by Wodzebeyew (2014) in the region of Ghana.

Furthermore, most studies on cadmium (Cd) concentrations have been performed in organs due to its bioaccumulation capacity (e.g., liver, kidney; Aubail et al., 2013; Monteiro et al., 2016; Page-Karjian et al., 2020). However, blood has also been shown to be a good indicator of metal concentration as it is a transport route (Rafati Rahimzadeh et al., 2017). The high concentration of Cd found in this study (21.13 µg L^{-1}) was 28 times higher than that reported in red blood cells and plasma in species such as the long-finned pilot whale (*Globicephala melas*) (< 10 µg L^{-1}; Caurant & Amiard-Triquet, 1995).

The stranded female bottlenose dolphin in this study showed values for at least two elements (Cd = 21.13 and Hg = 2.73 µg L^{-1}) that far exceed the limits established by the U.S. Environmental Protection Agency (EPA) as the threshold concentration for chronic behavior in marine environments (7.9 and 0.94 µg L^{-1} for Cd and Hg, respectively; EPA, 2016, 2023c). Variations and toxicity levels may occur due to dietary habits; biological characteristics such as age, sex, and reproductive stage; marine mammal species; and the blood residence time as a vehicle for the transfer of such compounds to the organs (Rafati Rahimzadeh

Table 3. Bottlenose dolphin strandings between 1992 to 2023 in Veracruz, Mexico. All reported strandings were of individuals.

Date	Location	
May 1992	Isla Lobos	Tuxpan
March 1993	Tamiahua	Tamiahua
June 1993	Cabo Rojo	Tamiahua
July 1993	Sontecomoapan	Catemaco
July 1993	Cabo Rojo	Tamiahua
Oct 1993	Barra Galindo	Tuxpan
Oct 1993	Alvarado	Alvarado
March 1993	Alvarado	Alvarado
June 1994	Lechuguillas	Vega de la Torre
June 1994	El Raudal	Nautla
June 1994	Sontecomoapan	Catemaco
Oct 1994	Alvarado	Alvarado
June 2009	Boca del Río	Veracruz
Feb 2010	**Boca del Río**	**Veracruz***
April 2012	El Raudal	Nautla
April 2012	Alvarado	Alvarado
May 2012	Santa Anna	Boca del Río
June 2012	Coatzacoalcos	Coatzacoalcos
Nov 2012	Playa Norte	Veracruz
Jan 2013	Malecón Costero	Coatzacoalcos
July 2013	Isla Verde	Veracruz
Sept 2013	Casitas	Tecolutla
Sept 2013	Casitas	Tecolutla
Sept 2013	El Raudal	Nautla
Dec 2013	Playa Norte	Veracruz
Feb 2014	Playa Norte	Veracruz
Dec 2014	Coatzacoalcos	Coatzacoalcos
Dec 2014	Tecolutla	Tecolutla
Dec 2014	La Mancha	Actopan
Jan 2015	Playa Santander	Alto Lucero
Jan 2015	Tuxpan	Tuxpan
April 2015	Playa de San Juan Ángel	Úrsulo Galván
April 2015	Chachalacas	Tonalá
June 2016	Antón Lizardo	Alvarado
July 2016	Alvarado	Alvarado
Feb 2017	Coatzacoalcos	Coatzacoalcos
March 2017	Playa Barra Norte	Tuxpan
May 2017	Barra Galindo	Tuxpan
June 2017	Rancho Playa	Papantla
June 2017	Alvarado	Alvarado
May 2018	Alvarado	Alvarado
May 2018	Alvarado	Alvarado
July 2021	Chachalacas	Tonalá
Feb 2022	Tlacotalpan	Veracruz
April 2022	Las Barrillas	Coatzacoalcos
Aug 2022	Chachalacas	Tonalá
May 2023	Riviera	Veracruz

*This study

et al., 2017; Fisher & Gupta, 2022); however, the concentration of these elements in blood is considered a good indicator of exposure to pollutants.

Despite HMs being ubiquitous in the environment and that they can be recycled, absorbed, and adsorbed by particulate matter, during the desorption processes (Wafo et al., 2012; Cáceres-Choque et al., 2013), HMs are able to migrate to the sediment-water interface and can subsequently bioaccumulate and biomagnify within marine food webs (Murphy et al., 2018; Fang et al., 2019; Mapel-Hernández et al., 2021).

Considering that high concentrations of OCPs and HMs have been reported in the study area (Celis-Hernández et al., 2017; Briones-Venegas et al., 2023), the low values for the specimen analyzed herein may at least have two alternatives: (1) either the VRSNP ecosystem has contrasting anthropogenic uses and/or different paths, thus buffering the effects into the bottlenose dolphin population; or (2) due to the high mobility of the species, this animal came from a different area (possibly an offshore population). The latter seems to be the case as suggested by the lack of information for the individual, based on intensive photo-identification surveys (i.e., over 70% of adults show permanent marks according to Morteo et al., 2017), but also for the presence of *Xenobalanus* sp., which is uncommon in areas with persistent freshwater runoffs (Hohn et al., 2022) such as the VRSNP.

The oral lesions found in the bottlenose dolphin stranded in Boca del Río, Veracruz, such as erythema in pharyngeal mucosa with serous-purulent material indicative of a respiratory infectious disease process (e.g., bacterial, viral; Nollens et al., 2008; Venn-Watson et al., 2008, 2012), are probably associated with an immunocompromised system linked to exposure to marine pollutants like Hg (Das et al., 2008; Desforges et al., 2016). This is consistent with the concentration found in this study and with those described in the skin of male bottlenose dolphins in Florida as a result of the biochemistry retention of Hg in the region (Damseaux et al., 2017). Also, a recent stranding of bottlenose dolphins on Sanctuary coast (Italy) found a positive relation between immune dysfunction and infectious disease associated with high levels of organochlorine compounds (Grattarola et al., 2023). Moreover, findings by Wunschmann et al. (2001) in harbor porpoises (*Phocoena phocoena*) indicated that contamination of the Baltic environment with OCPs and metals, such as Hg, may be associated with enhanced incidence of bacterial and parasitic infections.

As long-lived organisms and sentinels in the ecosystem (Law et al., 1991; Hansen et al., 2004; Wells et al., 2004; Reif et al., 2015), marine mammals are well-known bioindicators (Law et al., 1991; Marcovecchio et al., 1994; Bossart, 2011). To the best of our knowledge, no other published studies on pollutants (pesticides and heavy metals) are available for cetaceans within the VRSNP; thus, this first approach may serve as a reference for dolphins in the region. The latter would provide insight into the general status and the pathways of pollutants within the ecosystem and beyond (Law et al., 1991; Marcovecchio et al., 1994; Das et al., 2003; Gregory & Cyr, 2003; Bossart, 2006, 2007; Cámara-Pellissó et al., 2008).

Since marine ecosystems are under strong stress by various types of pollutants due to the uncontrolled use of compounds worldwide, several health issues have been exponentiated, resulting in public health concerns. The use of samples from stranded marine mammals plays a relevant role in enhancing our perspective on the conditions of ecosystems and their exposure to pollutant agents. Admittedly, there is still a long way until a comprehensive characterization of the type and level of potentially toxic elements and compounds can be achieved for this marine-protected natural area. As the concentrations found in this study were lower compared to other sites, these values should be taken with caution due to our limited sample size and the lack of certainty on the potential origin of the studied specimen. Additionally, more detailed knowledge of the biogeochemical cycles and the dynamics of this ecosystem is warranted if we aim to determine the possible origin and the potential repercussions of these compounds on the trophic web in the VRSNP, especially those derived from inland and oceanic human activities.

Finally, since marine mammals are proxies of potential risk to ecosystems and human communities, assessing the relationship of bottlenose dolphin strandings with marine pollutants and pathogen exposure has great relevance. Thus, potential ecological risks in aquatic environments and regions like VRSNP may be detected by applying ancillary tests (e.g., molecular) to marine megafauna such as marine mammals, sea turtles, and birds.

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