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Organochlorines Contaminants in Eggs of Hawksbill (*Eretmochelys imbricata*) and Green Sea Turtles (*Chelonia mydas*) from Mexico coast

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Abstract

The investigation of organochlorine pesticides (OCPs) levels in sea turtles is an important issue in conservation research, due to the harmful effects of these chemicals. In the present study, OCPs concentrations were determined in the eggs of two sea turtle species (*Eretmochelys imbricata* and *Chelonia mydas*) collected from the Punta Xen and Isla Aguada (Mexican coast) in 2014 and 2015. Concentrations of 20 OCPs were analysed, including isomers of hexachlorocyclohexane, aldrin, chlordanes, endosulfans, methoxychlor, DDTs, and heptachlor. From the group of contaminants considered (analysed as families), the results revealed higher concentrations of ΣHCH and ΣDienes on both selected species. We analysed the relationship between turtle size and the OCPs concentrations; no correlation was found between the size of the female and concentrations in the eggs. In addition, principal component analysis indicated pattern differences between species and years, in good agreement with concentrations differences.

Global anthropogenic pollution of the marine environment by organic contaminants, including persistent organic pollutants (POPs), is an issue of great concern. Their presence in aquatic systems around the world is a result of its widespread use and long-distance transport (Hamann et al. 2010). Environmental contaminants of chemical origin can resist chemical, photolytic, and biological degradation (Clark 1992). Due to their lipophilic properties, resistance to breakdown, and biomagnification potential, these chemicals are extremely persistent in the environment and can have many harmful effects on the development and functioning of sea animals (Clark and Krynitsky 1980; Mckenzie et al. 1999; Alava et al. 2006). The bioaccumulation of these toxic substances has become a major cause for concern on several wildlife species (Marcotrigiano and Storelli 2003; Keller et al. 2004b; Ogata et al. 2009) and for the marine turtles communities worldwide (Lake et al. 1994; Storelli and Marcotrigiano 2003; Alava et al. 2006; de Andréa 2008; Alava et al. 2011; Marcovecchio and Freije 2013; da Silva et al. 2014; Guerranti et al. 2014).

Sea turtles have recently been considered as suitable environmental indicators to improve the effectiveness of conservation strategies (Parliament 2008) due to their long life, their trophic position, and their mobility, which allow for the integration of pollutants from extensive areas. Taking into account those characteristics, several studies have reported the worldwide accumulation of pollutant substances in the marine turtles during the past decade (Alam and Brim 2000; Gardner et al. 2003; Lam et al. 2004; Andreani et al. 2008; Monagas et al. 2008; Oros et al. 2009; Jerez et al. 2010; Alava et al. 2011; D'Ilio et al. 2011). Because marine turtles allow the integration of pollutants from extensive areas, they can offer a comprehensive contamination profile within that energy flow ecosystem. The contamination of the marine system is one of the research priorities in the topic of turtle biology and conservation (Hamann et al. 2006).

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Some persistent organic pollutants can mimic hormones and may cause adverse health effects in wildlife populations, namely on the fecundity and reproductive competence. According to Camacho et al. (2013a), the bioaccumulation of POPs, such as OCPs, polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and polycyclic aromatic hydrocarbon (PAHs), in the tissues and organs of these animals can influence sea turtle natural populations' growth and development, ultimately causing mortality in the various stages of development. Many sea turtle populations are declining worldwide at alarming rates (Pritchard and Cox 2002) and are considered globally threatened or endangered. (MTSG 1995). Populations of marine turtles suffer greatly by environmental stress and anthropogenic activities being most of the impact on these populations caused by increased commercial and industrial exploitation in the coastal regions. According to the Marine Turtle Specialist Group (MTSG), the main threats to marine turtles currently causing of these species population collapse are coastal development, the incidental capture by fisheries, habitat loss (spawning and feeding) (Derraik 2002), direct use for human consumption and egg poaching (López-Mendilaharsu et al. 2007), climate change, pollution, and pathogens (Shigenaka and Milton 2003).

The Mexican coast represents an area of vital importance for the survival of marine turtles to growth and reproduce. Six of the seven existing species in the world visit the Mexican coasts: *Caretta caretta, Chelonia mydas, Dermochelys coriacea, Eretmochelys imbricata, Lepidochelys olivacea, Natator depressus, Lepidochelys kempii*, except for *Natator depressus*, all are listed as vulnerable, endangered, and critically endangered in the IUCN Red List (International Union for Conservation of Nature) (IUCN 2016). The green turtle (*Chelonia mydas*) can be found in all tropical and subtropical seas, and nesting populations are generally comprised of individuals that have migrated from a wide range of foraging grounds (Godley et al. 2002; Seminoff et al. 2008), and it is the species of sea turtle that presents more coastal habits (de Pádua Almeida et al. 2011). Hawksbill turtles (*Eretmochelys imbricata*) are circumtropically distributed in coastal waters (Meylan and Donnelly 1999). This species can be found in larger numbers in tropical coastal areas than in subtropical seas (Marcovaldi et al. 2011). Sea turtles are highly migratory, and they undertake complex movements and migrations through geographically disparate habitats. Their movements within the marine environment are less understood, but it is believed that hawksbills turtles in 108 countries and green turtles inhabit coastal waters of more than 140 countries (Groombridge and Luxmoore 1989; IUCN 2016).

During their reproductive years, *C. mydas* and *E. imbricata* show strong fidelity to their foraging and breeding sites, which can be up to thousands of kilometers apart (Carr 1964; Carr and Carr 1972; Limpus et al. 1992; Lohmann et al. 1997). Using satellite telemetry, scientists can track the movements of sea turtles between areas and even across entire oceans (Gaos et al. 2012); however, information on the migrations of sea turtles is currently sparse (Limpus et al. 1992). Marcovaldi and Marcovaldi (1985) describe these species' general feeding characteristics, indicating that *E. imbricata* prefer corals and sponges and *C. mydas* feed on small molluscs and sponges during the first year of life, preferentially feeding on macroalgae and phanerogams after this period; during this foraging time, local environmental nutritional resources are deposited into follicles (which become the yolk of the egg) for the next nesting season.

Most studies focusing on the concentrations of pollutants in sea turtles were based on tissues collected from dead animals. Levels and distribution of various chemical compounds were reported for liver (Malarvannan et al. 2011; Guerranti et al. 2014; Storelli and Zizzo 2014), adipose tissue (Lazar et al. 2011; Yogui 2002), or for more than one organ and tissue (Lake et al. 1994; Corsolini et al. 2000; Miao et al. 2001; Gardner et al. 2003; da Silva 2009; Oros et al. 2009; D'Ilio et al. 2011). Blood samples were successfully used to measure the concentrations of organochlorine pollutants, which is considered to be a non-lethal collection technique (Keller et al. 2004a; Hamann et al. 2006; Swarthout et al. 2010; Camacho et al. 2013b, 2014). Assessments from POP concentrations in eggs and the extent to which contaminants affect these developmental stages of sea turtles has been insufficiently researched, including the embryonic abnormality rates, relationships to hatching success, the timing of reproductive maturation, hatchling growth rates, and hatchling survival rates. Contaminant levels in eggs may offer information for two different life stages—the embryo and the adult females—because contaminants are transferred to the egg from the mother during vitellogenesis (Pagano et al. 1999). Maternal transfer of POPs into eggs has been documented in some turtle species, including sea turtles (Russell et al. 1999; Stewart et al. 2011; Guirlet et al. 2008, 2010).

The OCPs concentrations in sea turtle eggs are of high concern and their potential impact on embryonic and hatchling development is poorly understood. In addition, sea turtle nesting populations are of high interest to determine the range of exposure among different species and locations (Alava et al. 2011). Because nesting females do not feed during migration or nesting periods (Bjorndal et al. 1997), their POPs concentrations are likely to reflect the contamination in their foraging areas and their feeding habits (Bjorndal et al. 1985, 1997; Alava et al. 2006, 2011). Consequently, the POPs concentrations in eggs may represent the contamination levels received on the adult female foraging grounds. Females nesting on the same beach but foraging in different locations would likely produce eggs containing different POPs concentrations. Alternatively, if females

from one nesting beach forage in similar locations, then their egg POPs concentrations would be similar and indicative of their foraging regions. Adult females accumulate POPs from their prey as well as from incidentally ingested sediments, which then are deposited, along with lipids, into the follicles. According to Aguirre et al. (2006), the consumption of sea turtle products (tissues, eggs, and blood) poses a number of public health concerns because of the high lipid content and the presence of bacteria, parasites, and environmental contaminants. Thereby, the World Health Organization (WHO) and other regional organizations have provided a guide for consumption of foods containing environmental contaminants and acceptable daily intakes (ADIs) (FAO/WHO 2007). The ADIs are based on human and animal experiments, which investigate the nonobservable adverse effect levels of these chemicals and are generally presented as micrograms per kilogram of body weight per day (Van Oostdam et al. 2005).

Because marine turtles are an endangered species, it is important to understand the responses to long-term impact and conservation measures. Therefore, knowing the species exposure level to these compounds is of paramount importance to make informed management decisions and to perform response measures in order to improve the effectiveness of long-term conservation strategies in developing populations' recovery (Lam et al. 2004; Casale et al. 2004; Jakimska et al. 2011). The purpose of this study was to determine the POPs and OCPs concentrations in eggs from two species of sea turtles, *C. mydas* and *E. imbricata*, nesting on the coasts of Mexico during two consecutive years (2014 and 2015). Understanding chemical contamination, and ultimately the potential risks to the development and reproduction, are crucial elements to the management and conservation of sea turtles.

Materials and methods

Sample collection

Eggs of two sea turtles species with spawning areas from Campeche were collected to analyse the concentration of organochlorine contaminants. Campeche is located in southeastern Mexico in the Yucatan Peninsula (Fig. 1).

Two species were analysed in the study: green turtles (*C. mydas*) were sampled in Isla Aguada field (18°47′15.5″N, 91°29′56.5″W), and hawksbill turtles (*E. imbricata*) were sampled in the Punta Xen field (19°12′39″N, 90°52′09.7″W) (Fig. 1). Sixty eggs for 60 individual sea turtles were collected (1 egg per nest), for each species during the breeding season of 2014 and 2015 (30 eggs per year/species). The curved carapace length (CCL) and curved carapace width (CCW) of the carapace were measured with a flexible tape (Bolten 1999). Sea turtle eggs were collected and wrapped in aluminium foil, stored in Ziploc bags, stored on ice and frozen at − 20 °C. All analyses were performed at the Institute of Ecology, Fishery and Oceanography of the Gulf of Mexico (EPOMEX, Campeche, Mexico).

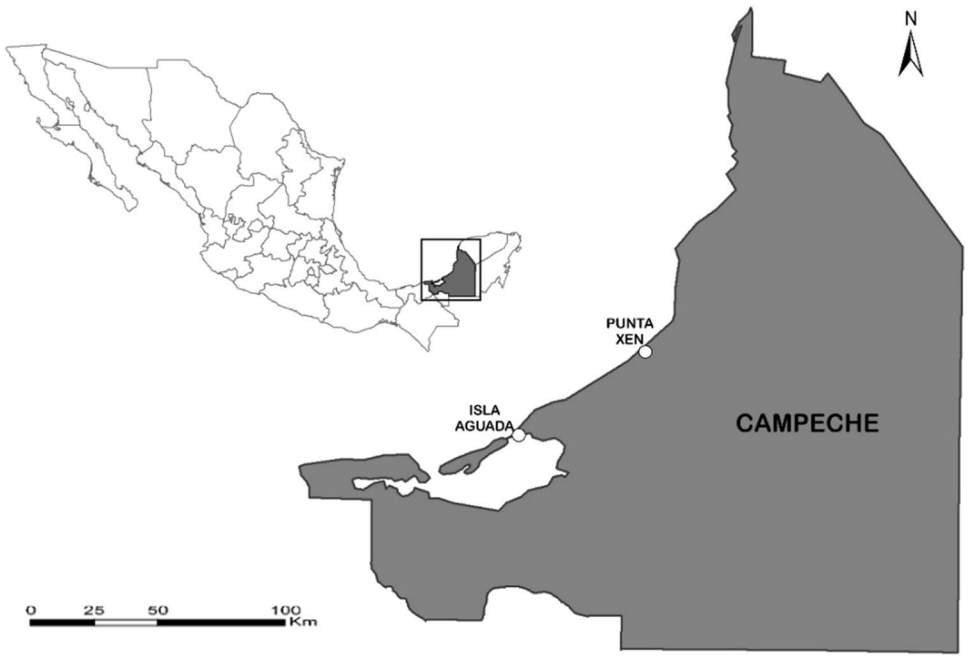

Fig. 1 Map of the study area and sampling locations in Mexico

Pollutants analysed in this study

A total of 20 organochlorine pesticides compounds were investigated in sea turtle eggs, including isomers of hexachlorocyclohexane (alpha, beta, gamma, delta-HCH), aldrin, dieldrin, endrin, endrin aldehyde, ketone endrin, trans chlordane, cis chlordane, endosulfan I, endosulfan II, endosulfan sulfate, methoxychlor, *p,p′* DDE, *p,p′* DDD, *p,p′* DDT, heptachlor, heptachlor epoxide). OCPs were analysed using a mix of standards (SUPELCO 47426-U CLP Organochlorine Pesticide Mix), contaminant concentrations were organized as families: ΣDDT was defined as the sum of *p,p′* DDE, *p,p′* DDT, and *p,p′* DDD; ΣChlordanes as the sum of cis-chlordane and trans-chlordane; ΣHCH as the sum of alpha, beta, gamma, delta; ΣHeptachlor as the sum of heptachlor and heptachlor epoxide; ΣDienes as the sum of aldrin, dieldrin, endrin, endrin aldehyde, and ketone endrin; ΣEndosulfans as the sum of endosulfan I, endosulfan II, and endosulfan sulfate. Limit of detection for each family of compounds in μg g^{-1} (HCHs—0.007; Aldrin—0.0018; DDTs—0.01; Chlordanes—0.009; Endosulfans—0.007; Heptachlors—0.013; Methoxychlor—0.01).

Contaminant analysis

All the solvents used in the laboratory procedures were of 98% of purity grade (HPLC). Silica gel, alumina, Florisil, and sodium sulfate were purified following the protocol NMX-AA-071-1981 (1981). The glassware was washed with Extran, dried in the oven for 4 h at 200 °C, and washed with acetone and hexane. POP analysis of the eggs followed the method described by Zhang et al. (2007). Fertile eggs were rinsed with distilled water, and the contents were extracted and homogenized thoroughly. The homogenized mix was dried in an oven at 40 °C. Three extractions were performed in an ultrasonic bath. For the first extraction, 50 ml of ethyl acetate-hexane (1:1) was added, and the sample was sonicated for 1 h. The organic layer was transferred to a glass tube, and the extraction was repeated twice with 40 mL of hexane for 1 h. Samples were purified by column chromatography. The column was packed with silica gel (2 g), alumina (2 g), florisil (2 g), and sodium sulfate (2 g). First, 20 ml of methylene chloride was added, followed by 20 ml acetone, and finally 20 ml of hexane. The mobile phase, 35-ml mixture of ethyl acetate: hexane (1: 9) was added. The cleaned extracts were diluted to 5 ml for analysis. The final volume of the solvent used was 0.5 ml.

Instrumental analysis

The contaminants were quantified using a Varian 3800 gas chromatograph equipped with an Ni^{63} electron capture detector and HT8 capillary column (60 m × 0.25 mm; 25-μm film thickness) (SGE Analytical Science, USA). The temperatures of the injector and detector were 150 and 300 °C, respectively. The oven temperature was maintained at 60 °C min^{-1} and then increased to 320 °C at a rate of 2 °C min^{-1} for 5 min. The nitrogen flow into the column was 2 ml/min and a composition of 30 ml/min. Qualitative data were obtained by calculating the area under the curve with the star Chromatography Workstation software version 6 and the calibration patter. The quality of the standard is 99%, and the stock solutions, to make the calibration curve were: 1, 10, 50, 100, and 150 μg/ml.

Quality assurance

Laboratory blanks were analysed for quality assurance. Chicken egg samples were used in triplicate. One milliliter of a 200 ng/ml Decachlorobiphenyl surrogate spike (SK011 Sigma-Aldrich) was added to the samples before the extraction, and they were subsequently refrigerated for 48 h. One of the subsamples was not spiked with the standard as a positive blank. Afterward, the contaminants were extracted and processed in an identical manner to the rest of the samples. Percentages of recovery was > 85%.

Statistical analysis

All obtained data were checked for distribution, normality and homogeneity of variances using the Kolmogorov–Smirnov and Levene's tests, respectively (Zar 1996). A logarithmic transformation (log $(x+1)$) was used when data did not fulfil the assumptions of normality or homogeneity of variances. Differences in concentrations among eggs within species and years were determined using a one-way Analysis of Variance (ANOVA) and the interactions using a two-way ANOVA. For these analysis, the IBM SPSS Statistics package, version 22, was used, and the significance level was 0.05. The variation of contaminants was, also, tested by a Permutational multivariate analysis of variance (PERMANOVA) test, including a multifactorial temporal and spatial design (sampling locations, years and interactions). The Principal Coordinates Analysis (PCA) was used visualise the temporal and spatial variation of selected contaminants, with vector overlays (Pearson correlations), indicating correlations between these variables and ordination axes (Anderson et al. 2008). Both PERMANOVA and PCA analysis were based on Euclidian distances between samples, after data transformation Log $(x+1)$. Multivariate PERMANOVA tests were performed using PRIMER with PERMANOVA software (PRIMER v6 & PERMANOVA v1, PRIMER-E Ltd.).

Table 1 Selected contaminant concentrations (mean ± SD) for each family of compounds (ng/g dw) in the eggs of green turtles and hawksbill turtles, during two spawning seasons

2727OCPs	*E. imbricata*				One-way ANOVA		*C. mydas*				One-way ANOVA	
	N	2014	*N*	2015	*F*	*P*	*N*	2014	*N*	2015	*F*	*P*
ΣHCHs	32	0.504 ± 0.371	27	0.695 ± 1.229	0.673	0.415	28	0.484 ± 0.404	27	4.934 ± 16.834	5.581	0.022
ΣDienes	32	0.329 ± 0.452	27	0.289 ± 0.691	0.071	0.791	28	0.506 ± 0.508	27	2.635 ± 6.049	7.480	0.008
ΣChlordane	32	0.201 ± 0.290	27	0.193 ± 0.439	0.007	0.935	28	0.337 ± 0.319	27	2.417 ± 6.096	7.406	0.009
ΣDDTs	32	0.192 ± 0.337	27	0.318 ± 0.615	0.953	0.333	28	0.308 ± 0.389	27	0.965 ± 6.001	2.444	0.124
ΣHeptachlor	32	0.100 ± 0.151	27	0.155 ± 0.418	0.452	0.504	28	0.189 ± 0.194	27	2.460 ± 4.777	11.611	0.001
ΣEndolsufans	32	0.191 ± 0.337	27	0.185 ± 0.379	0.004	0.949	28	0.330 ± 0.348	27	0.941 ± 2.161	5.595	0.022
Methoxychlor	32	0.073 ± 0.141	27	0.059 ± 0.209	0.087	0.769	28	0.165 ± 0.167	27	1.060 ± 1.787	12.359	0.001

The one-way ANOVA, comparing both years, within each species also are presented ($p < 0.05$)

Results

A total of 120 eggs were sampled for contaminant analysis; data from 6 of these were excluded because of problems during analysis. We identified POPs as ΣChlordane, ΣHCHs, ΣDienes, ΣDDTs, ΣHeptachlor, ΣEndosulfans, and methoxychlor in all 114 of the eggs analysed. Compounds most commonly identified in Punta Xen were ΣDienes, ΣHCHs, and ΣDDT, and in Isla Aguada were ΣDienes, ΣHCHs, ΣChlordane, and ΣHeptachlor (Table 1).

Contaminants concentration in the eggs of hawksbill turtles

In Punta Xen, ΣChlordane, ΣDienes, ΣEndosulfans, and methoxychlor were found to be higher in eggs collected in 2014 than from 2015, whereas ΣDDTs, ΣHCHs, and ΣHeptachlor were found at higher levels in 2015 compared with 2014 (Table 1). For the hawksbill turtles, no significant differences were found for OCPs in eggs between years ($p > 0.05$). No correlation was found between the CCL and OCP concentrations in eggs ($p > 0.05$).

Contaminants concentration in the eggs of green turtles

In Isla Aguada, ΣChlordane, ΣHCHs, ΣDienes, ΣEndosulfans, ΣHeptachlor, ΣDDTs, and methoxychlor were the most highly concentrated compounds in 2015 compared with 2014 (Table 1). Significant differences were found between years for OCPs, except DDT, in eggs of green turtles ($p = 0.124$). No correlation was found between the CCL and OCP concentrations in eggs ($p > 0.05$).

Table 2 Summary results of two-way ANOVA

	Two-way ANOVA		
	F	*P*	
Location	19.210	0.000	$p < 0.001$
Year	11.062	0.001	$p < 0.05$
Year × location	11.161	0.001	$p < 0.05$

Table 3 Summary results of permutational multivariate analysis of variance (PERMANOVA) main test

Source	*df*	SS	Pseudo-*F*	*P*(perm)
Location	1	25,230	14.04	0.001
Year	1	17,311	9.6333	0.001
Location × year	1	5927.3	3.2985	0.015
Res	118	2.1205E5		
Total	121	2.6037E5		

Interyear and intersite comparisons

The concentrations of OCPs in eggs were significantly differed between green and hawksbill turtles ($p < 0.05$) in nearly every family of compounds, except for ΣDDT. When analysing the data of two-way ANOVA, according to the year and the sampling location, it was found that the interaction between factors was significant ($p < 0.05$). Additionally, location and year separately showed differences ($p < 0.05$; Table 2). The Permutational multivariate analysis of variance (PERMANOVA) test allowed to verify that all the locations were different from each other and showed a significant correlation between location and year ($p = 0.015$; Table 3). The first Principal Coordinate Analysis (PCA) showed a clear separation between the years and between both sampled locations: Isla Aguada e Punta Xen (Fig. 2). In both

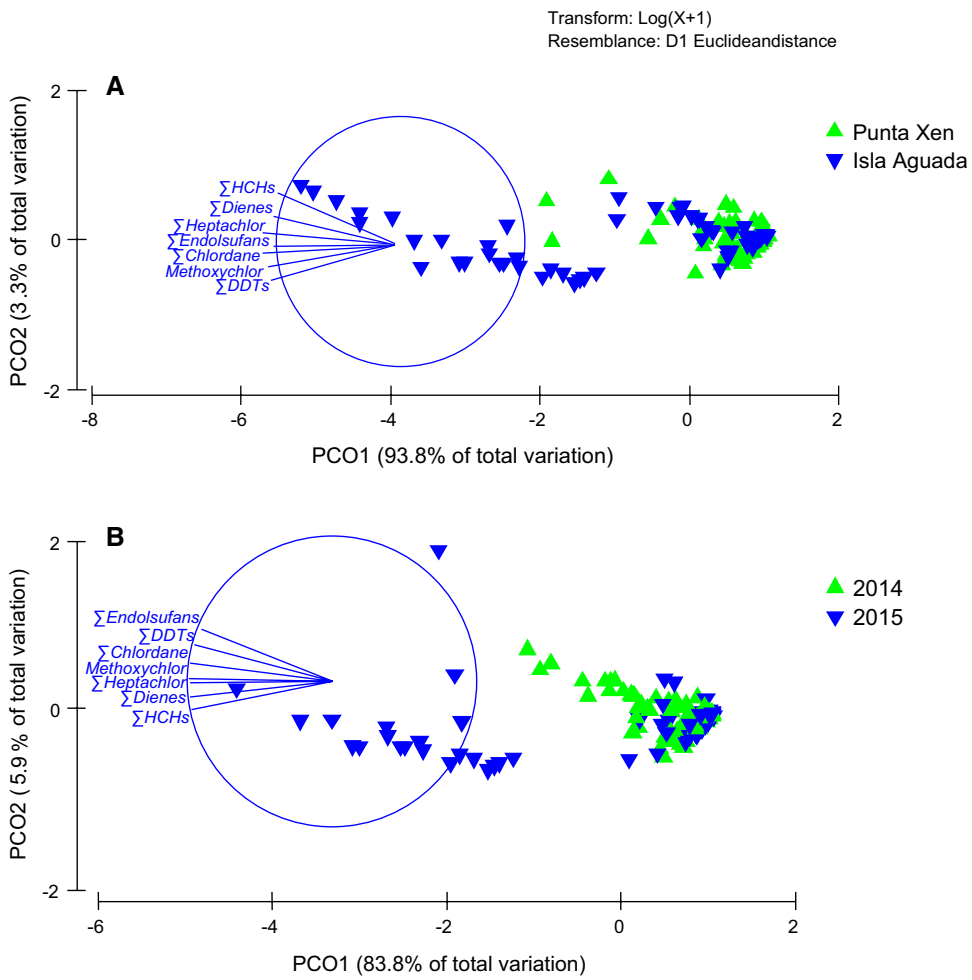

Fig. 2 Principal coordinate analysis (PCA) scaling plot of the analysed contaminants in both sites (**a**) and years (**b**). In both analysis, vectors are also overlapping the scaling plot with Pearson correlations

PCA analysis, all analysed contaminants were clearly associated with Isla Aguada and the 2015 sampling.

Discussion

Overall, the present research results may provide an important baseline data on contaminant concentrations in sea turtle eggs from south eastern Mexico. OCPs concentrations (ng/g dw) measured in this study and other research (ng/g dw; lw; ww) are reported in Table 4. In the discussion, where the authors measured the concentrations in ng/g wet mass the values were converted to ng/g dry mass.

The green turtle is a typically a nectonic and solitary animal and may occasionally form aggregations in feeding areas (Márquez 1990). The diet of this species varies considerably during its life cycle and during the first year of life, from an omnivorous diet, mainly consuming food of animal origin, to herbivorous when juvenile and adults, being able to feed themselves eventually of living sponges, propagules of mangrove, molluscs, fish, and crustaceans (Bjorndal et al. 1997). According to Meylan (1988), hawksbill turtles are omnivorous with a specialize diet made of sponges. Differences in feeding preferences, foraging strategies and thus trophic levels could explain the differences in OCPs concentrations observed in these two species of sea turtles.

The average hawksbill turtle ΣHCH concentration (0.59 ng/g dw) measured in the current study were lower to that found in hawksbill and green turtle eggs (1.88; 2.64 ng/g dw respectively) from Caribbean region (Dyc et al. 2015), leatherback eggs (1.64 ng/g dw) from Guiana Francesa (Guirlet et al. 2010), and green turtle eggs (2.76 ng/g dw) from Malasia (van de Merwe et al. 2009a), being lower concentrations were found in green turtle eggs (4.24 ng/g dw) found in the present study.

ΣDienes were the second most abundant OCP class measured in Punta Xen and Isla Aguada. The average ΣDienes concentrations measured in hawksbill eggs (0.31 ng/g dw) and green turtle (2.07 ng/g dw) were lower than levels measured in loggerhead eggs samples in Southern Florida (10.12 ng/g dw) (Alava et al. 2006). Alava and collaborators found that the mean 4,4′-DDE concentration in loggerhead eggs (200.8 ng/g dw) was higher than the concentration found in green turtle eggs, concluding that

Table 4 Mean concentrations for organochlorine contaminant concentrations (ng/g) in eggs collected from sea turtles from different locations

Location	Species	Matrix (*n*)	ΣDDTs	ΣChlordane	ΣHCHs	∑OCPs	References
Merritt Island, Florida	*Cc, Cm*	Eggs (*Cm*-2/*Cc*-9) ww	66[a]				Clark and Krynitsky (1980)
Merritt Island, Florida	*Cc*	Eggs (56) ww	99				Clark and Krynitsky (1985)
Heron Island, Queensland	*Cm*	Eggs (15) ww	1.7 ± 0.3[a]				Podreka et al. (1998)
Southern Florida	*Cc*	Eggs (22) ww	50.2 ± 92.4	25.5 ± 46.7	0.258 ± 0.508		Alava et al. (2006)
Australia	*Cm*	Eggs (10) ww		trans 0.02 ± 0.0004		endolsufan I - 0.20 ± 0.005	van de Merwe et al. (2009b)
Malaysia	*Cm*	Eggs (55) ww	0.083 ± 0.018	0.057 ± 0.009	0.069 ± 0.009	0.39 ± 0.04	van de Merwe et al. (2009a)
French Guiana	*Dc*	Eggs (38)/blood (38) ww	B- 0.31 ± 0.22/E- 1.44 ± 1.26		B- 0.15 ± 0.16/E- 0.41 ± 0.26		Guirlet et al. (2010)
Malaysia	*Cm*	Eggs (33)/blood (11) ww	N.A.		E- 0.17 ± 0.007[b]/ B- 0.50 ± 0.06		van de Merwe et al. (2010)
Eastern, Florida	*Dc*	Eggs (6) ww	1.87 ± 0.4	2.28 ± 1.71	N.A.		Stewart et al. (2011)
Caribe	*Ei, Cm*	Eggs (*Cm*-11/*Ei*-4) ww	*Cm*- 0.17 ± 0.04/*Ei*- 0.19		*Cm*- 0.17 ± 0.007/*Ei*- 0.47		Dyc et al. (2015)
Southeastern United States	*Cc*	Eggs -WF-11/ EF- 24/NC-9 lw	WF- 23.8 ± 7.1/ EF- 136 ± 56/ NC -694 ± 251	WF- 20.8 ± 9.6/ EF- 113 ± 31/ NC- 375 ± 146	WF- 0.449 ± 0.017/ EF- 1.21 ± 0.49/ NC- 3.15 ± 1.39		Alava et al. (2011)
South Carolina	*Cc*	Eggs (10) lw[c]	325 ± 185	94.9 ± 41.2			Keller (2013)
Mexico	*Cm, Ei*	Eggs/blood (30) lw	*Cm*- B- 2.087 ± 3.076/ E- 38.72 ± 0//*Ei*- B -2.078 ± 3.525/ E- 331.1 ± 379.7[a]				García-Besné et al. (2015)
Costa Rica	*Dc*	Eggs (18) lw					De Andrés et al. (2016)
Northwest Florida	*Cc*	Eggs (20) dw	753–800				Alam and Brim (2000)
Mexico	*Cm, Ei*	Eggs (*Cm*-55/*Ei*-59) dw	*Cm*- 1.19 ± 0.58/*Ei*- 0.25 ± 0.05	*Cm*- 1.90 ± 0.61/*Ei*- 0.19 ± 0.04	*Cm*- 4.24 ± 1.67/*Ei*- 0.59 ± 0.11	*Cm*- 1.81 ± 0.62/*Ei*- 0.24 ± 0.5	Present study

Loggerhead (*Cc*), green (*Cm*), leatherback (*Dc*), hawksbill (*Ei*) sea turtles; Mean (SD) in ng/g $^{-1}$

dw dry weight, *lw* lipid weight, *ww* wet weight, *ND* not detected, *B* blood, *E* egg, *WF* Western Florida, *EF* Eastern Florida, *NC* North Carolina

[a]For only *p,p′* -DDE

[b]Only yHCH

[c]Botany Bay Island, South Carolina

green turtles are herbivores, and as such, they do not accumulate POPs to the same level as omnivorous loggerhead turtles (Alava et al. 2006). Nevertheless, average ΣDDTs concentrations found in the present study were higher in green turtle eggs (1.20 ng/g dw) than in hawksbill turtles (0.25 ng/g dw). Extreme caution must be exercised when comparing values with those of other studies' different species because of the differences in feeding grounds.

Green turtle eggs exhibited relatively lower concentrations of ΣChlordane (1.90 ng/g dw) in relation to leatherback eggs (9.12 ng/g dw) from Eastern, Florida (Stewart et al. 2011), and higher concentrations than those found in green turtle eggs (0.24 ng/g dw) from Malaysia (van de Merwe et al. 2009a). Observed results may indicate that different locations in the Gulf of Mexico seem to have a significant influence on OCP concentrations, as well as different years. The average

concentration of ΣHeptachlor, ΣEndosulfans, and methoxychlor in Isla Aguada (1.73; 0.82; 0.76 ng/g dw respectively) was greater than that measured in the Punta Xen (0.12; 0.19; 0.07 ng/g dw respectively).

In fact, in the species *C. mydas* most OCPs concentrations appear to have increased during the two analysed years. The differences in concentrations between species are likely attributable to differing foraging locales, on trophic differences, as well as different metabolic breakdown or elimination of congeners in reptiles inhabiting different climates. For example, leatherback turtles inhabiting waters both much further north and much deeper than the loggerhead.

Future studies should investigate this latter possibility (Alava et al. 2011). In addition, the comparisons between the present and previous studies are limited because of different analytical methodologies, sampling locations, and sample sizes used. Further investigations are necessary to evaluate long-term effects of OCPs and to understand if the concentrations are decreasing or increasing on a temporal scale in green and hawksbill turtles nesting in south eastern Mexico in the Yucatan Peninsula.

Conclusions

The present study provides a foundation for future research and monitoring of sea turtle eggs for contaminant concentrations. Were analysed OCP concentrations in eggs of green and hawksbill turtles, indicated differences between species, which are classified into different trophic levels. The concentration of ΣDDTs was the only OCP group found at similar levels between species. Location and year of sampling were a significant factors influencing OCP concentrations in green turtles. Future studies should evaluate biological effects of contaminants in turtles and relationships with hatchling success, embryonic abnormality rates, hatchling growth rates, and hatchling survival rates.

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Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

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