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Organochlorine Pollutants and Stable Isotopes in Resident and Migrant Passerine Birds from Northwest Michoacán, Mexico

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Abstract Although concentrations of organochlorine compounds (OCs) in birds from most of the United States and Canada have decreased over the last 30 years, there is still concern that migrant birds might be exposed to elevated concentrations of OCs during migration in Latin America. The Lerma-Chapala Basin in west-central Mexico is an important migration corridor and wintering area for many species. The objectives of this study were to assess if resident and migrant birds wintering in western Michoacán, Mexico accumulated elevated concentrations of OCs during fall and spring and to determine if the stable isotopes δ^{15}N, δ^{13}C, and δD could be used to predict burdens and origins of DDE accumulation. Resident and migrant passerine insectivorous birds were collected during fall and spring (2001–2002) in northwest Michoacán, near Chapala Lake, Mexico. The carcasses were analyzed for OCs and tail feathers were analyzed for stable isotopes δ^{15}N, δ^{13}C, and δD. The OCs detected in more than 50% of the samples were: oxychlordane (79%), *p,p*'-DDE (100%), *p*,p′-DDT (57%), and total PCBs (100%). *p,p*′-DDE was the OC detected at the highest concentrations, whereas residues of other OCs were near or below detection limits. Overall, there were no significant differences in concentrations of OCs between seasons or between resident and migrant birds. Concentrations of DDE and oxychlordane were somewhat higher in migrant and resident birds during spring than in fall; however, concentrations were significantly different only for oxychlordane. Two resident birds collected in fall and spring had DDE residues >10 μg/g wet weight in carcass. There were no significant differences in δ^{13}C and δ^{15}N values among species, between seasons, or between migrant and resident birds. However, δD values were clearly different between species and helped differentiate migrant from resident birds. δD values also were negatively and significantly correlated with DDE concentrations in carcass. Birds with more depleted δD values in feathers tended to have higher DDE concentrations than those with less depleted δD values, suggesting a potential latitudinal accumulation of DDE. Overall, our results suggest that during fall and spring, there is not a significant buildup of persistent OCs in migrant and resident passerine insectivorous birds in northwest Michoacán, Mexico.

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Neotropical North American migratory birds travel south every year to winter in Mexico, Central America, and South America, where they spend 6–7 months (Norris et al. 2004). Although concentrations of organochlorine compounds (OCs) in birds from most of the United States and Canada have decreased over the last 30 years, there is still concern that migrant birds might be exposed to elevated concentrations of persistent organochlorine pollutants (POPs) in Latin America. DDT [1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane] was banned in the United States in 1972 and shortly thereafter in Canada (Harris et al. 2000). Agricultural use of DDT in Mexico was discontinued around 1978 (Fertilizantes Mexicanos 1981); however, DDT use for malaria control and other public health campaigns continued until around 2000 (Chanon et al. 2003; http://www.cofepris.gob.mx/bv/libros.htm, December 4, 2006). Because of the continued, although restricted, use of DDT in Mexico until 2000 and possible continued use in other parts of Latin America, one hypothesis is that *p,p'*-DDE [1,1-dichloro-2,2-bis (*p*-chlorophenyl)ethylene], a metabolite of DDT, is accumulated by migrant birds during the winter in Latin America.

The Lerma-Chapala Basin in west-central Mexico is an important migration corridor and wintering area for many species (Hutto 1986). Parts of the basin are suspected contaminant hot spots because of agricultural use of pesticides and contaminant discharges from the Lerma River into Chapala Lake (Lind and Dávalos-Lind 2002). Until around 2000, DDT was manufactured in Mexico in the city of Salamanca, ~180 km upstream from the mouth of the Lerma River and Chapala Lake (http://www.panna.org/resources/gpc/gpc_200112.11.3.10.dv.html, January 15, 2007).

In the early 1980s, Mora et al. (1987) documented that northern pintails (*Anas acuta*) wintering in western and central Mexico had lower levels of OCs, particularly DDE, than those wintering in the Salton Sea in southern California. Thereafter, other studies also suggested that OCs are as likely to accumulate in birds during the summer as well as during migration or in the winter (Bartuszevige et al. 2002; Capparella et al. 2003; Elliott et al. 2007; Harper et al. 1996; Klemens et al. 2000, 2003; Mora 1997). Most evidence indicates that OCs have decreased for the last 30 years in birds from the United States and Canada, although some localized hot spots still exist (Harris et al. 2000; Mora 1997; Mora and Wainwright 1998; Mora et al. 2006). Recently, elevated concentrations of *p,p'*-DDE, up to 25 µg/g wet weight (ww) in carcass, were reported in swallows (*Petrochelidon* spp.) nesting along the Rio Grande in the United States–Mexico border region (Mora et al. 2006). Stable isotopes suggested that the DDE sources were likely from the border region (Mora et al. 2005), thereby renewing the concern for the existence of contaminant hotspots along the United States–Mexico border that could affect resident and migratory birds.

Stable isotope ratios of nitrogen ($^{15}N/^{14}N$, expressed as $\delta^{15}N$) and carbon ($^{13}C/^{12}C$, expressed as $\delta^{13}C$) in consumer tissues have been used to determine trophic relationships within food webs and whether a food chain or food web is based on C_3 plants ($\delta^{13}C \approx -23‰$ to $-32‰$), C_4 plants ($\delta^{13}C \approx -16‰$ to $-9‰$), or a mixture of the two groups (De Niro and Epstein 1978; Tieszen et al. 1983). Similarly, stable isotopes of hydrogen in bird feathers (δD_f) have been positively correlated with stable isotopes of hydrogen in rain (δD_p; Chamberlain et al. 1997; Hobson and Wassenaar 1997). Deuterium maps of precipitation have been established for North America showing a latitudinal gradient, with δD_p more depleted toward the north from the equator and at higher altitudes within the same region (Hobson and Wassenaar 1997; Meehan et al. 2004). Accordingly, δD_f values reflect the δD_p patterns from the region where the feathers were grown (Chamberlain et al. 1997; Hobson and Wassenaar 1997; Meehan et al. 2004).

Organochlorine compounds in birds are primarily accumulated through the food chain. In birds, it has been shown that the δD of tissues during the time of growth is significantly and positively correlated with the δD of food or the local δD_p. It has been revealed that some OCs, particularly the most volatile, can be found at higher concentrations at northern latitudes in North America due to a global distillation effect (Simonich and Hites 1995). If the use of DDT has been discontinued in North America for nearly 35 years, except for restricted use in Mexico until 2000 (Chanon et al. 2003), then it could be hypothesized that the accumulation of DDE during the breeding season in small passerine birds is correlated with a latitudinal gradient, with birds breeding in more northern latitudes having greater concentrations of DDE than birds from regions closer to the equator. The objectives of this study were to (1) assess if resident and migrant birds wintering in western Michoacán, Mexico accumulated elevated concentrations of OCs during the fall and spring and (2) determine if the stable isotopes $\delta^{15}N$, $\delta^{13}C$, and δD could be used to predict burdens and origins of DDE accumulation.

Methods

Resident and migrant passerine birds were collected during March 2001 ($n = 18$) and October 2002 ($n = 21$) in northwest Michoacán (19°58′ N, 102°40′ W), ~15 km southeast of Chapala Lake (Fig. 1). The collection sites were located around agricultural fields, primarily corn, wheat, and vegetable crops. The following species were captured with the use of mist nets: least flycatcher (*Empidonax minimus*), dusky flycatcher (*Empidonax oberholseri*), vermilion flycatcher (*Pyrocephalus rubinus*), brown-crested flycatcher (*Myiarchus tyrannulus*), Bell's vireo (*Vireo bellii*), Northern rough-winged swallow (*Stelgidopteryx serripennis*), blue-gray gnatcatcher (*Polioptila caerulea*), orange-crowned warbler (*Vermivora celata*), yellow-rumped warbler (*Dendroica coronata*), common yellowthroat (*Geothlypis trichas*), and yellow-breasted chat (*Icteria virens*). Immediately after collection, birds were weighed with a pesola spring scale and then euthanized by cervical dislocation. Carcasses were wrapped in aluminum foil and stored on ice in individual plastic bags until taken to the laboratory, where they were stored at −80°C until chemical analyses were conducted. Birds

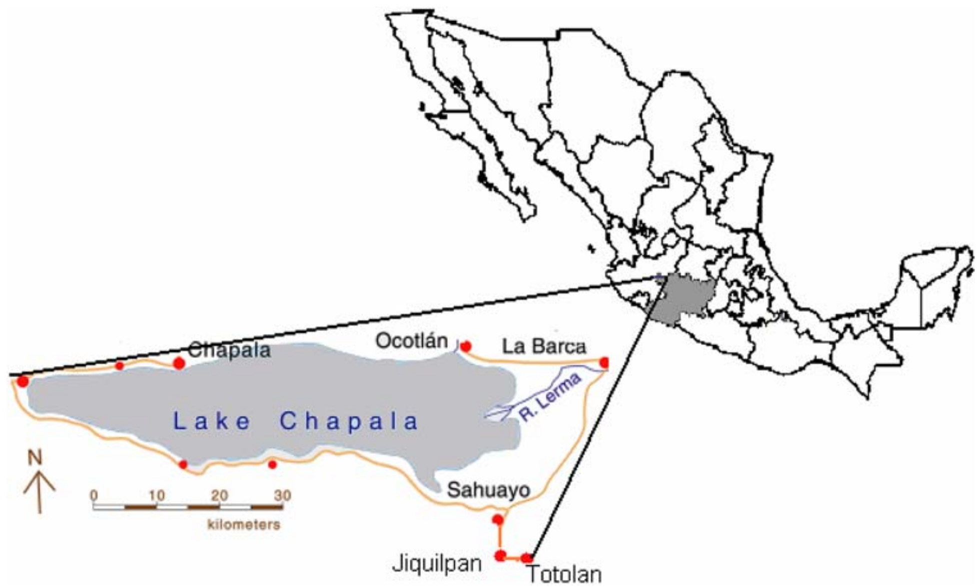

Fig. 1 Map of Mexico showing the collection location in northwest Michoacán, Mexico

were classified as residents or migrants based on distribution maps, with additional support from δD values from tail feathers (Howell and Webb 1995; Lott and Smith 2006; Meehan et al. 2004; Pérez and Hobson 2007). The resident species had δD values in feathers ≥ -56‰, except for one northern rough-winged swallow, and included the vermilion flycatcher, brown-crested flycatcher, blue-gray gnatcatcher, and yellow-breasted chat. The migrant species had δD values in feathers < -60‰, except for least flycatchers collected during the fall, and included the dusky flycatcher, Bell's vireo, orange-crowned warbler, yellow-rumped warbler, and common yellowthroat.

Organochlorine Analysis

The bird carcasses were prepared for analyses by removing the feathers, head, beak, wings, legs, tail, and stomach contents and then homogenizing the rest of the body with a Teckmar tissumizer (Pro Scientific, Oxford, CTt, USA). Two to five grams of homogenate was used for each analysis. The carcass homogenates were analyzed for persistent OCs, including polychlorinated biphenyls (PCBs), at the Geochemical and Environmental Research Group, Texas A&M University, under procedures described previously (Brooks et al. 1989; Mora et al. 2007; Sericano et al. 1990). Carcass homogenates were mixed with sodium sulfate and extracted with hexane. The extracts were further purified by silica/alumina column chromatography and with high-performance liquid chromatography (HPLC). Residues were quantitated by gas chromatography and electron capture detector (GC-ECD) (^{63}Ni) in splitless mode (Hewlett Packard 5890A, Palo Alto, CA, USA), with a DB-5 (30×0.25 mm inner diameter) fused-silica capillary column (Agilent/J&W Scientific, Folsom, CA, USA). Confirmation was performed by GC-MS (mass spectrometry). Percent recoveries of OCs in reference and spiked samples were greater than 80%, and variation between duplicates was below 10%. The lowest detection limit for OCs was $\sim$1 ng/g ww.

Stable Isotope Analysis

Stable isotopes (δ^{15}N, δ^{13}C, and δD) in tail feathers (first and second rectrices) were analyzed at the Colorado Plateau Stable Isotope Laboratory, Northern Arizona University (Flagstaff, AZ, USA). Feathers were prepared by washing with detergent, rinsing with deionized water, and air-drying at room temperature. Approximately 1.0 mg of feather material was placed into tin capsules for δ^{15}N and δ^{13}C analyses. δ^{15}N and δ^{13}C were analyzed in continuous-flow mode using a Thermo-Finnigan Delta^{plus} Advantage gas isotope-ratio mass spectrometer (Thermo Fisher Scientific, Waltham, MA, USA) interfaced with a Costech Analytical ECS4010 elemental analyzer. Helium flow rate was set at 110–130 mL/min and oxygen flow rate at 80 mL/min. A standard 3-m GC column was used (set at 55°C) for peak separation, in combination with one quartz (combustion) tube filled with chromium oxide and silvered cobaltous/cobaltic oxide (set at 1020°C) and one quartz (reduction) tube filled with reduced copper (set at 650°C). Data were normalized using four internationally accepted isotope standards (IAEA CH6, CH7, N1, and N2). External precision on these standards was ± 0.10‰ or better for δ^{13}C and ± 0.20‰ or better for δ^{15}N. δ^{15}N and δ^{13}C data were expressed relative to the Vienna PeeDee Belemnite International Reference Standard (VPDB) for carbon and to the

Air International Reference Standard (AIR) for nitrogen. For δD analysis, samples were weighed into silver capsules (0.330–0.370 mg per sample) and were analyzed on a Thermo-Finnigan TC/EA coupled to a Thermo-Finnigan Delta Plus mass spectrometer via a CONFLO II interface. The TC/EA furnace was set to 1400°C, with GC separation occurring in a molecular sieve column at 100°C. The helium flow rate was 118 mL/min. δD values were normalized as stated in Wassenaar and Hobson (2003). δ^{13}C, δ^{15}N, and δD values are reported in per mil units (‰) according to the formula $\delta(\mathrm{D}, {}^{13}\mathrm{C}, {}^{15}\mathrm{N})_{\mathrm{sample}}$ ‰ $= [(R_{\mathrm{sample}}/R_{\mathrm{Standard}}) - 1] \times 1000$, relative to each standard.

Statistical Analysis

The contaminant data for all resident and migratory birds collected during each season were combined to compare contaminant concentrations between migrant and resident bird species. All of the species collected during the fall and spring were insectivorous and I assumed that they were feeding on insects from the same agricultural areas and that the residue intake was presumably similar. The data were log-transformed to meet the assumptions of normality. Comparisons between seasons and between migratory status were conducted for oxychlordane, *p,p′*-DDE, and total PCBs with a two-way factorial GLM procedure of log-transformed data. To determine if the accumulation of DDE in carcass could be predicted with δD, δ^{15}N, or δ^{13}C values in tail feathers, I performed an analysis of covariance with the GLM method, using species as a class variable and the isotopes δD, δ^{15}N, or δ^{13}C as covariates in each particular case. Type III sum of squares and *F*-statistics were used to determine the significance of each variable. If the species did not have an effect on the interaction, then a simple linear regression model was used. All statistical analyses were performed with the use of SAS software (SAS 9.1 for Windows; SAS Institute, Inc., Cary, NC, USA). The significance level was established at $p < 0.05$.

Results

Only a few OCs were detected in more than 50% of the samples and included oxychlordane (79%), *p,p′*-DDE (100%), *p,p′*-DDT (57%), and total PCBs (100%) (Table 1). Other OCs were detected in fewer than 50% of the samples at concentrations near or below detection limits and included hexachlorocyclohexane (α, β, γ, and δ isomers), heptachlor, heptachlor epoxide, chlordane (α and γ isomers), *cis*-nonachlor, *trans*-nonachlor, aldrin, dieldrin, endrin, endosulfan, and mirex. Overall, concentrations of OCs in carcasses of migrant and resident birds were fairly low, except for two samples (one vermilion flycatcher and one northern rough-winged swallow), which had DDE concentrations >10 µg/g ww, about two orders of magnitude greater than the other birds tested. Concentrations of oxychlordane ranged from 1 to 80 ng/g ww, *p,p′*-DDE from 12 to 12,103 ng/g ww, *p,p′*-DDT from 0.1 to 4 ng/g ww, and PCBs from 1 to 281 ng/g ww. Concentrations of *p,p′*-DDE and total PCBs were not significantly different within or between seasons between migrant and resident birds (Tables 1 and 2). Concentrations of oxychlordane also were not different between migrant and residents during each season; however, there was a significant increase from fall to spring (Tables 1 and 2). Concentrations of *p,p′*-DDT were not compared because they were near detection limits and were detected only in 57% of the samples.

δD, δ^{13}C, and δ^{15}N values in feathers of resident and migrant birds are provided in Table 3. The resident species had δD values between −56‰ and −26‰, whereas the migrants had δD values between −143‰ and −75‰ (Table 3). δ^{13}C values ranged from −24.7‰ in the common yellowthroat to −15.0‰ in the Bell's vireo during the fall and from −22.8‰ in the yellow-rumped warbler to −17.1‰ in the dusky flycatcher during the spring (Table 3). δ^{15}N values ranged from 2.9‰ to 12.7‰ in the yellow-rumped warbler and vermilion flycatcher, respectively, during the fall and from 5.4‰ to 11.8 ‰ in the yellow-rumped warbler and dusky flycatcher, respectively, during the spring (Table 3).

Both δ^{15}N values and log DDE and δ^{13}C values and log DDE covaried with species ($F_{1,10} = 20.8$, $p < 0.0001$ and $F_{1,10} = 22.7$, $p < 0.0001$, respectively). Also, species had a near significant effect on the linear correlation between δD and log DDE ($F_{1,7} = 2.3$, $p = 0.054$). However, species did not affect the correlation between δ^{15}N and δ^{13}C

Table 1 Organochlorine concentrations (ng/g ww, geometric means and range) in passerine birds from Mexico during Spring and Fall 2001–2002

Migratory status	Spring					Fall				
	n	Oxychlordane	*p,p′*-DDE	*p,p′*-DDT	PCBs	n	Oxychlordane	*p,p′*-DDE	*p,p′*-DDT	PCBs
Migrants	11	12 (7–80)	101 (58–161)	0.5 (0.1–2)	46 (33–281)	10	3 (1–13)	49 (12–178)	0.2 (0.1–2)	14 (4–30)
Residents	7	7 (1–29)	116 (12–10677)	2 (0.1–4)	29 (1–78)	11	2 (0.2–3)	65 (24–12103)	2 (0.1–4)	21 (2–47)

Table 2 Probability values for the two way factorial GLM procedure of concentrations of contaminants, by status (migrants vs. residents) and season (fall vs. spring)

	Oxychlordane	DDE	PCBs
Status	0.160	0.640	0.960
Season	0.003	0.160	0.080
Status × Season	0.890	0.860	0.310

($F_{1,10} = 1.4$, $p = 0.24$) nor between δ^{15}N and δD ($F_{1,10} = 2.0$, $p = 0.07$), but it affected the correlation between δ^{13}C and δD ($F_{1,10} = 7.4$, $p < 0.001$). Thus, there was a species-independent positive significant correlation between δ^{15}N and δ^{13}C ($r^2 = 0.43$, $p < 0.0001$; Fig. 2) and a negative significant correlation between log DDE and δD values [$r^2 = 0.36$, $p < 0.001$ (Fig. 3 with two extreme values removed); $r^2 = 0.16$, $p = 0.04$ with the extreme values included}.

Discussion

The results of this study indicate that the accumulation of OCs in neotropical migrants in western Michoacán is very low and is similar to other areas of North America. The negative significant correlation between log DDE and δD also suggests a potential latitudinal accumulation of DDE with slightly greater concentrations of DDE in birds breeding in more northern regions or areas of increased precipitation. Simonich and Hites (1995) reported a latitudinal distribution of OCs in the bark of trees around the globe; pesticides had a tendency to increase at higher latitudes based on a global distillation effect. High concentrations of DDE were reported in parts of the Midwest and the southwestern United States (Simonich and Hites 1995). *p,p′*-DDT was relatively low in all bird samples, suggesting little or no recent bird exposure to this compound. Because DDT was banned in the United States in 1972 and DDT use in agriculture in Mexico was discontinued around 1978 (Fertilizantes Mexicanos SA 1981), then it is possible that the current distribution of DDE in the environment in North America correlates with precipitation patterns and latitude, except for hot spots, particularly in the southwestern United States.

The fact that several species were collected during both seasons and were combined for the statistical analysis should not influence the results because the concentration values observed for each species were low and numerically very similar (range: 8–242 ng/g ww, $n = 37$, excluding two extreme values). The lack of differences in DDE concentrations between migrant and resident birds are also in agreement with other studies that have pointed out the lack of a clear pattern of DDE accumulation in migrant birds while in Mexico or in their wintering grounds (Elliott et al. 2007; Klemens et al. 2000; Mora 1997; Mora et al. 1987). Capparella et al. (2003) detected low concentrations of DDE in few (3% of 135 individuals) resident passerine birds from South America. It was hypothesized that neotropical migrants wintering in South America probably acquire OC contaminants in their breeding grounds or along the migratory pathway. Morrissey et al. (2004) reported higher concentrations of OCs in resident than in migrant American dippers (*Cinclus mexicanus*), but these

Table 3 Stable isotope values (arithmetic means ± SD‰) in passerine birds from Mexico during Spring and Fall 2001–2002

Species	Status	Spring				Fall			
		n	δD	δ^{13}C	δ^{15}N	n	δD	δ^{13}C	δ^{15}N
Least flycatcher (*E.minimus*)	M	5	−78.5 ± 21.1	−18.8 ± 4.4	9.2 ± 3.5	3	−51.6 ± 35.1	−22.3 ± 0.4	10.8 ± 2.5
Dusky flycatcher (*E. oberholseri*)	M	2	−76.4	−17.1	11.8	3	−74.7 ± 18.3	−19.2 ± 1.9	11.5 ± 0.8
Bell's vireo (*V. bellii*)	M	NC				1	−81.8	−15.0	11.0
Orange-crowned warbler (*V. celata*)	M	NC				1	−143.9	−23.7	5.8
Yellow-rumped warbler (*D. coronata*)	M	4	−114.0 ± 4.4	−22.8 ± 1.7	5.4 ± 1.0	1	−120.9	−21.2	2.9
Common yellowthroat (*G. trichas*)	M	NC				1	−116.6	−24.7	7.2
Vermilion flycatcher (*P. rubinus*)	R	NC				1	−53.3	−18.6	12.7
Brown-crested flycatcher (*M. tyrannulus*)	R	NC				1	−26.6	−17.4	8.8
Northern rough-winged swallow (*S. serripennis*)	R	1	−75.5	−17.3	11.5	NC			
Blue-gray gnatcatcher (*P. caerulea*)	R	5	−55.6 ± 14.5	−21.0 ± 1.5	8.2 ± 3.7	8	−53.2 ± 13.9	−23.1 ± 0.9	8.3 ± 2.4
Yellow-breasted chat (*I. virens*)	R	1	−42.6	−20.7	10.4	1	−44.4	−22.7	7.3

NC = not collected, M = migrant, R = resident

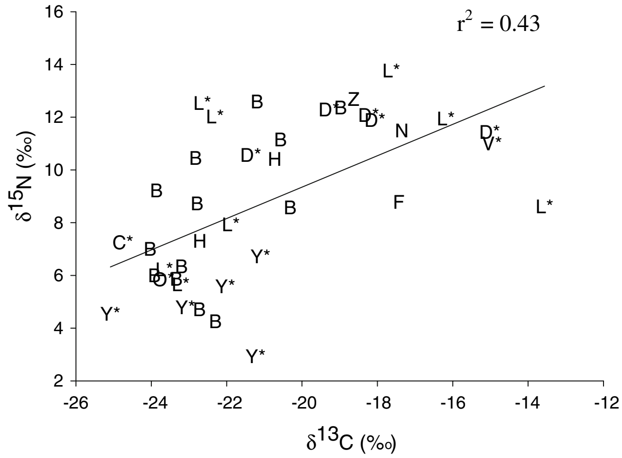

Fig. 2 Correlation between δ^{15}N and δ^{13}C in tail feathers of resident and migrant birds from northwest Michoacán, Mexico. The symbols with an asterisk represent migrants, the others are resident, as follows: L* = least flycatcher *(E. minimus)*, D* = dusky flycatcher (*E. oberholseri*), Z = vermilion flycatcher *(P. rubinus)*, F = brown-crested flycatcher (*M. tyrannulus*), V* = Bell's vireo (*V. bellii*), N = Northern rough-winged swallow (*S. serripennis*), B = blue-gray gnatcatcher (*P. caerulea*), O* = orange-crowned warbler (*V. celata*), Y* = yellow-rumped warbler (*D. coronata*), C* = common yellow-throat (*G. trichas*), and H = yellow-breasted chat (*I. virens*)

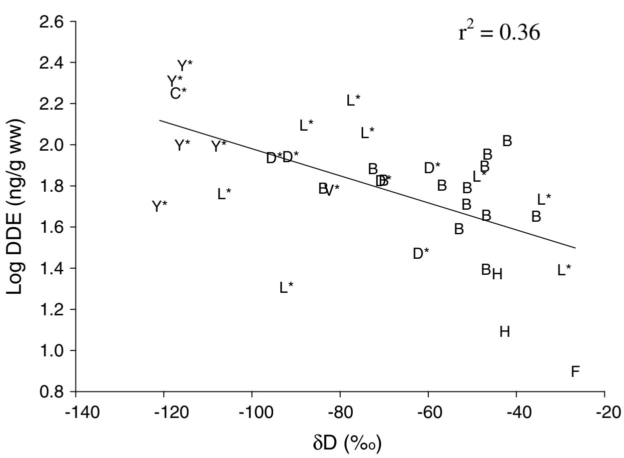

Fig 3 Correlation between log DDE in carcass and δD in tail feathers of resident and migrant birds from northwest Michoacán, Mexico. Symbols are the same as in Figure 2

results were from within one river wathershed east of Vancouver, Canada. The DDE levels observed in least flycatchers during Fall 2002 in Michoacán (mean = 33 ± 18 ng/g ww) were similar to those reported in least flycatchers (mean = 39 ng/g ww) from Illinois during Summer 1996 (Klemens et al. 2000). Furthermore, the DDE values observed in all neotropical migrants from Illinois (Klemens et al. 2000) were within the range of those observed in resident and migrant birds in Michoacán. OCs in resident and migrant birds from Michoacán also were similar to those of insectivorous passerine birds from Arizona (Mora et al. 2003) but were much lower than those observed in passerine birds from the Texas–Mexico border over the last few years (Mora et al. 2002, 2006, 2007, unpublished data).

There are, however, some inconsistencies with the general observed trend of no accumulation of OCs during the winter in Michoacán. There was a significant but moderate increase (from 3 to 12 ng/g ww) of oxychlordane from fall to spring. Also, two resident birds had DDE residues greater than 10 µg/g ww. Both species were captured (one during each season) at about 1.5 km north of Totolán by the Jiquilpan River, which carries agricultural and municipal wastewater in addition to storm water run-off. The high DDE levels in these two species suggest that the DDE residues were probably acquired locally or within the region and that some potential hot spots might occur. Clearly, more data are needed to determine if the observed DDE pattern in birds in this study reflect regional acquisition or other sources along the migratory route or breeding grounds.

The δ^{15}N stable isotope values were useful in establishing that the various insectivorous bird species sampled in this study fed at different trophic levels during the period of feather growth. On average and assuming a δ^{15}N progressive enrichment of 3.0 ‰ with each trophic transfer (McCutchan et al. 2003), the dusky flycatchers and some least flycatchers fed two to three trophic levels above the warbler species, particularly the yellow-rumped warbler at their respective regions of feather growth. Differences in diet between warbler and flycatcher species have been reported (Yard et al. 2004). Hobson et al. (1999) suggested that passerine birds inhabiting agricultural environments had greater δ^{15}N values than those from temperate forests. It is possible that some of the flycatchers in this study came from more agricultural environments, whereas the warblers were from more forested regions.

The δ^{13}C results also supported the observation of potentially different insect food sources among bird species at different feather growth locations. There was an increasing trend in δ^{13}C values in the blue-gray gnatcatcher and least flycatcher from the fall to spring, indicating possible annual variations in food sources or that both species collected during each season grew their tail feathers in different regions or molted their tail feathers between the fall and spring. Blue-gray gnatcatchers occur year- round in northwest Michoacán; however, it is likely that the local populations might intersperse with migrant individuals during the fall and spring. Two least flycatchers also had higher δD values than other individuals, suggesting that they could have been resident birds or that they molted their tail feathers in the wintering grounds.

A systematic decrease of δ^{13}C in bird feathers with increasing latitude has been reported (Marra et al. 1998; Rubenstein et al. 2002). Thus, δ^{13}C values should be more enriched in hotter environments and more depleted in cooler and more humid environments (Marra et al. 1998). In our study, we were able to observe such trend only in the yellow-rumped warbler, as there was greater variability in δ^{13}C values in the other species.

Overall, concentrations of DDE and other OCs in birds were relatively low and are not likely to cause any adverse effects during migration. Future studies with migrant birds in their breeding areas should be helpful for establishing better correlations between DDE and δD_f, to further determine if the DDE body burdens observed during the winter reflect latitudinal distribution gradients or local sources.

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