Accumulation of PCB Congeners in Nestling Tree Swallows (*Tachycineta bicolor*) on the Hudson River, New York

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Tree swallows (*Tachycineta bicolor*) were used as a sentinel species to monitor the contamination and bioavailability of polychlorinated biphenyls (PCBs) in the Hudson River watershed. Several tree swallow nest box colonies around and downstream from Hudson Falls, NY, were studied. Tree swallow eggs, adults, and 5-, 10-, and 15-day-old nestlings were collected and analyzed for 103 PCB congeners. Emergent insects collected by net (primarily *Odonata*) or as a food bolus (primarily *Diptera*) taken from the mouths of adult tree swallows returning to the nest were analyzed in the same manner. Total PCB concentrations (wet weight) in eggs from two contaminated sites ranged from 9000 to 25 000 ng/g and accumulated to 32 000 and 96 000 ng/g in 15-day-old nestling at two contaminated sites. The congener patterns of PCBs in eggs, nestlings, and adults were compared to those found in emergent insects (*Odonata* and *Diptera*) using principal components analysis. The PCB patterns of the biota differed from that of Aroclor technical mixtures. PCB patterns in adult tree swallows were similar to those in eggs, while the patterns in dietary insects were similar to nestling tree swallows. Uptake rate constants were determined for tree swallow nestlings and compared between the two contaminated sites. The estimated PCB congener uptake rate constants were 0.008−0.02 d^{-1} based on uptake in nestlings until day 15 post-hatch. The rate constants were comparable between the two study areas and may be used to predict nestling contamination at other locations. Our studies confirm the utility of nestling tree swallows to evaluate localized PCB contamination.

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Introduction

Tree swallows (*Tachycineta bicolor*) are passerine insectivores that have been used to evaluate sediment-to-bird transport and biomagnification of PCBs throughout North America (*1*−*8*). The tree swallow has been used as a monitoring tool because of the species' abundance across the North American continent and because breeding colonies in nest boxes can be readily established in most open habitats in their range. Tree swallow nestlings are preferred to adults or eggs to assess contaminant exposure because they feed on emergent benthic invertebrates and reflect contaminated sediments near the vicinity of the nest box (*1*−*8*). Adult tree swallows are migratory and subsequently have a more varied contaminant history, both from longer exposures and multiple sources, while eggs are likely to reflect the exposure history of the laying adult females as well as the extent of sediment contamination in the area around the nest box. Attempts to quantitatively link contaminants in nestlings and sediments have been complicated by differences in the extent of site contamination; bioavailability of contaminants at specific sites; relationship between inherited and acquired contaminant loads; and variability in tree swallows' foraging behavior, range, and prey selection.

Tree swallows have been used at several sites on the Hudson River, NY, to assess PCB contamination and to evaluate the potential for adverse impacts on other avian species living in these areas (*9*−*13*). This paper examines the relationships of PCB congener patterns among tree swallow adults, eggs, and nestlings as well as their insect prey collected from four sites along the Hudson River. Temporal sampling of tree swallow nestlings was conducted to evaluate rates of PCB accumulation and growth over the first 15 days post-hatch. Rate constants for uptake of PCB congeners into nestling swallows were determine using empirical data from the study. Our study did not evaluate sediment PCB concentrations; however, previous studies have evaluated PCB uptake in insect larvae (*Chironomus tentans*) from Hudson River sediments (*14*). Novak et al. (*14*) found that PCB homologue patterns of the sediments, benthic insects, and tree swallows from a specific area were similar. In a companion paper (*15*), a bioenergetics-based model of contaminant uptake in swallows (*4*) was evaluated to develop quantitative linkages between dietary PCBs and concentrations found in nestlings.

Materials and Methods

Sites. In 1995, nest boxes for breeding were provided to tree swallows at four sites in the upper Hudson River watershed (Figure 1). Two sites were established along the Hudson River at known areas of high PCB contamination, downstream of Hudson Falls: Remnant Deposit 4 (REMN) and Special Area 13 (SA13), which are capped PCB disposal sites. A third site was established downstream at Saratoga National Historical Park (SARA), while an upstream site was located along the Champlain Canal, at Lock 8 (CHAM), NE of Hudson Falls.

Sample Collection. Tree swallow eggs and nestlings were collected in May and June 1995. Eggs were weighed, marked within 1 d of laying, and collected within 1−2 d of the start of incubation. Tree swallow nestlings were collected on days 5, 10, and 15 post-hatch at the two contaminated sites (REMN and SA13). Additional nestlings were collected on day 10 post-hatch at the other two sites (SARA downstream and CHAM upstream). Four adult tree swallows (2 females and 2 males) were collected at the end of the breeding season at the SA13 and CHAM sites.

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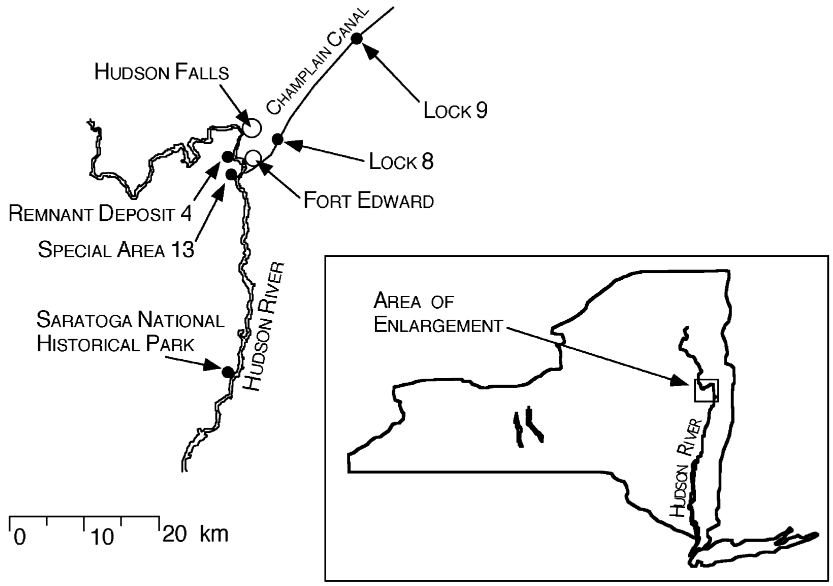

FIGURE 1. Map of sampling sites on the Hudson River, NY.

Dietary insects were collected as adults returned to the nest to feed nestlings. Adult tree swallows typically bring a "bolus" of insects carried in their mouths to dependent young. When adults are captured at the nest box, this bolus can be removed from their mouths before the parent feeds its young (*10*). Upon collection, food bolus weights averaged 0.22 ± 0.027 g wet mass. The food boli were frozen and composited before analysis as needed to meet analytical requirements. Parents deliver food to their young an average of 18 times per hour, so the removal of a single sample represents a small portion of the daily food supply for a nestling and would not have been expected to impact growth or reproduction (*11*). Newly emerged or teneral odonates were collected from the river shore adjacent to nest boxes in the morning before first flights. Caddis flies were also collected directly from the river shore after large hatches, presumably within hours of emergence. Collections occurred during the tree swallow nestling period in mid- to late-June. On days with significant emergence of insects, an average of 1.46 g fresh mass (SE = 0.12) was collected from each site and immediately frozen. These samples were also composited for chemical analysis

Chemical Analysis. All samples were analyzed for PCB congeners. Nestlings and adult birds were ground whole after removal of the beak, feet, and stomach contents. Eggs contents were analyzed minus the shells. Sample tissues were combined with anhydrous sodium sulfate, mixed, and column extracted with dichloromethane. The lipid extracts were taken through a two-stage reactive cleanup on acid- and base-treated silica gels followed by high-performance gel permeation chromatography (*16*, *17*). HPLC carbon chromatography was used to separate the PCB congeners into fractions based on ortho-substitution patterns (*16*, *17*). PCBs congeners (82 single congener peaks and 17 combined congener peaks) were analyzed by high-resolution capillary gas chromatograph/electron capture detection (GC/ECD) and quantified against mixed Aroclor standards (*18*). Total PCBs were reported as a sum of the congeners (Table 1, ng/g all wet weight concentrations). Gas chromatography with high-resolution mass spectrometry and electron ionization (EI) was used to analyze the four non-*ortho*-substituted PCB congeners following the method of Peterman et al. (*17*).

Data Analysis. Principal components analysis (PCA) was used to evaluate PCB congener patterns among Aroclors, insects, and tree swallow eggs, nestlings, and adults. The variable (loading) contributions to the differential patterns were evaluated by PCB congener degree of chlorination, *o*-chlorine substitution pattern, and metabolic class according to the scheme of Boon et al. (*19*) as modified by Kannan et al. (*20*). Throughout the text, PCB congeners are referred to by their International Union of Pure and Applied Chemists (IUPAC) number designations. The classification of congeners

TABLE 1. Total PCBs (ng/g, wet weight) in Tree Swallow Eggs, Nestlings, Adults, and Their Food Items Collected from Sites on the Hudson River, NY 1995[a]

site/samples	lipid (%)	total PCBs[b] (ng/g)
Remnant Site 4 (REMN)		
insects[c] (*Odonata*)	3.6	1 200
insects[d] (*Diptera*)	3.9	18 000
egg	7.5 (0.4)	24 000 (1 400)
day 5 nestling	3.5 (0.8)	14 000 (3 000)
day 10 nestling	7.4 (0.4)	48 000 (11 000)
day 15 nestling	10 (0.8)	96 000 (3 000)
Special Area 13 (SA13)		
insects[c] (*Odonata*)	5.6	560
insects[d] (*Diptera*)	3.1	6 700
egg	5.7 (1.4)	13 000 (3 400)
day 5 nestling	4.4 (1.1)	8 700 (1 400)
day 10 nestling	5.7	19 000
day 15 nestling	8.0 (1.4)	32 000 (8 300)
adult	5.7 (2.0)	152 000 (53 000)
Saratoga NHP (SARA): Downstream		
insects[c] (*Odonata*)	4.0	290
insects[d] (*Diptera*)	–	<MDL (10 ng/g)
egg	7.9 (0.4)	5 300 (2 800)
day 10 nestling	6.9 (0.6)	2 700 (340)
Lock 8, Champlain Canal (CHAM): Upstream		
insects[d] (*Diptera*)	–	630
egg	8.9	4 600
day 10 nestling	5.3	1 500
adult	6.3 (2.8)	53 000 (43 000)

[a] Standard deviation of values in parentheses. MDL, method detection limit for total PCBs; –, lipid value not determined because sample size was insufficient. [b] Sum of all PCB congeners analyzed. [c] Odonates collected with hand nets along the shoreline. [d] Prey items (primarily *Diptera*) collected and composited from the mouths of adults returning to the nest to feed their young.

into one of four metabolic groups was based upon chlorine substitution pattern and metabolism by P450 isozymes: group I congeners have no meta−para and ortho−meta vicinal hydrogen atoms and are not metabolized; group II congeners have only meta−para vicinal hydrogen atoms and are metabolized by CYP2B isozymes; group III congeners have only ortho−meta vicinal hydrogen atoms and are metabolized by CYP1A isozymes; and group IV congeners have both meta−para and ortho−meta vicinal hydrogen atoms and are metabolized by both 2B and 1A isozymes. While this scheme was developed from mammalian studies, studies in birds have found similar enzymatic behavior toward PCB congeners (*21*−*26*).

PCA was performed using SIMCA-P (Umetri, NJ; version 7.0) software. PCA is a multivariate statistical method that reduces the dimensionality of the data (in this case, $n = 42$ samples with 103 PCB variables) and allows projection onto a small number of principal components (usually 2−3) that are linear combinations of the original variables. Patterns in the data were evaluated qualitatively from plots of the resultant principal component scores (*18*, *27*, *28*).

Congener-specific uptake rate constants (k_{ui}) were estimated for 25 individual PCB congeners in tree swallow nestlings from the REMN and SA13 sites. Rate constants were calculated from the congener-specific rates of PCB uptake (U_i) in the nestlings that occurred between day 5 and day 15 post-hatch and dietary concentrations of the selected PCB congeners measured in food boli (C_{id}) according to

$$k_{ui} = U_i / C_{id} \tag{1}$$

PCB uptake rates (log(pg g^{-1}) d^{-1}) were calculated from linear regressions of log-transformed PCB concentrations in the nestlings over time (5−15 d). C_{id} values were log-transformed concentrations of the selected PCB congeners (pg g^{-1}) in food boli collected at the same site as the nestlings. The uptake rate constants (d^{-1}) were estimated under the assumptions that feeding rates, growth, metabolism, assimilation efficiencies, and elimination rates were constants. In addition to the selected congeners evaluated in this study, uptake rate constants for all of the PCB congeners measured in our analysis are available from the authors.

Results and Discussion

Concentrations. Concentrations of PCBs were among the greatest ever measured in tree swallow nestlings in North America (*1*−*8*). Total PCB concentrations in day 15 nestlings at the contaminated REMN and SA13 sites were 96 000 and 32 000 ng/g, respectively. Nestlings collected at the upstream and downstream reference sites (CHAM and SARA, respectively) had smaller concentrations of total PCBs as compared to nestlings from the two main study sites. Nestlings from the CHAM upstream site contained total PCB concentrations of 1500 ng/g by day 10, while nestlings from the SARA downstream site contained 2700 ng/g by day 10. Eggs from the REMN and SA13 sites contained total PCB concentrations of 24 000 and 13 000 ng/g, respectively. The concentrations of total PCBs in eggs collected at CHAM and SARA sites were 2−6 times lower than eggs from the REMN and SA13 sites (Table 1). Adult swallows were only collected from two locations, SA13 and CHAM. Concentrations of total PCBs were approximately 3-fold greater in adults from SA13 as compared to CHAM (152 000 and 53 000 ng/g, respectively). There was also approximately a 3-fold difference in concentrations of total PCBs in eggs from SA13 and CHAM (13 000 and 4600 ng/g, respectively). It is uncertain how much of the PCB load in these adult tree swallows was accumulated while the birds were living in the Hudson River area. However, it is known that locally derived diets can influence contaminant burdens in adult tree swallow.

Concentrations of PCB in nestling tree swallows reflected the extent of PCB contamination at each of the study sites through exposure to emergent insects (Table 1). Congener data for all PCB congeners, representing the range of chlorination and structure and the various metabolic groups, is presented as Supporting Information. Predominant PCB congeners (given in descending order of mass) observed in nestling swallows were the lower to moderately chlorinated tri- (028, 031, 016, 032), tetra- (049, 052, 042, 074, 047, 044, 070, 076, 066, 048, 064, 041), and pentachlorobiphenyl (101, 095, 099, 110, 118, 087, 097) congeners. These congeners comprise approximately 80−85% of the total PCB mass measured in 15-day nestlings collected at the REMN or SA13 sites. These PCB congeners are largely from the metabolic groups III and IV (see Supporting Information). The major hexachlorinated congener measured in the nestlings was PCB 138, which only ranked 30th in mass and represented <1% of the mass of total PCB. Thus, it is clear from the PCB congener profiles that the lower chlorinated PCB congeners (tri-, tetra-, and to a lesser extent pentachlorinated biphenyls) dominate the total PCB content of nestling tree swallows at the REMN and SA13 sites. The same pattern of relative importance for PCB congeners was not evident in nestling swallows from the upstream and downstream sites (SARA and CHAM, see Supporting Information).

PCB concentrations in the two different types of insect composites differed substantially at all of the sites. The hand-collected insects were primarily *Odonata*, and the food boli were comprised mostly of *Diptera* (*29*). Previously, Johnson and Lombardo (*30*) conducted a taxonomic analysis of food boli from tree swallows and concluded that *Diptera* were the predominant prey item for this species, consistent with our findings. Concentrations of total PCBs in food boli collected from adults at the REMN and SA13 sites were about 10−15 times greater than those of *Odonata* collected from the same sites (Table 1). Insects collected at the upstream and downstream reference areas, SARA and CHAM, did not contain appreciable levels of total PCBs (Table 1).

PCA of PCB Congener Profiles. The PCB patterns in all biota collected along the Hudson River (tree swallows and co-collected insects) were similar to one another, when modeled with the technical Aroclor mixtures (Figure 2A). The PCB congener profiles of the biota did not resemble any one Aroclor technical standard but had the greatest similarity to a combination of Aroclors 1248 and 1254 (Figure 2A). The first two principal components of the PCA plot described 53% of the total variance. The biota samples fall within space defined by the Aroclors, based on their similarity to the source technical Aroclor mixtures (*18*, *28*). The U.S. EPA has reported that General Electric scientists believe that 80% of the total PCBs discharged to the river were Aroclor 1242, with lesser quantities of Aroclors 1254, 1221, and 1016 (*31*). Aroclor 1260 falls outside the 95% confidence ellipse of the PC model. This is not unexpected given that Aroclor 1260 was not a technical mixture that was reported to be discharged by General Electric into the Hudson River.

Closer inspection of the PCB congener patterns observed in biota collected along the Hudson River revealed significant differences among the patterns found in various life stages of the tree swallows (Figure 2B). A second PCA (biota samples modeled without the technical Aroclors, $n = 36$, vars. = 103), produced four significant PCs describing 72% of the variance. The score plot of the first two PCs of this model described 55% of the variance. In this PCA plot, the adult tree swallows (male and female) cluster with the egg samples, while the nestlings form a cluster with the food boli samples (Figure 2B). The odonates did not cluster with either the adult/eggs or the nestlings. The odonates collected at the REMN and SA13 sites were within the 95% confidence ellipse ($p = 0.05$) of the PCA model, but the odonates from the CHAM

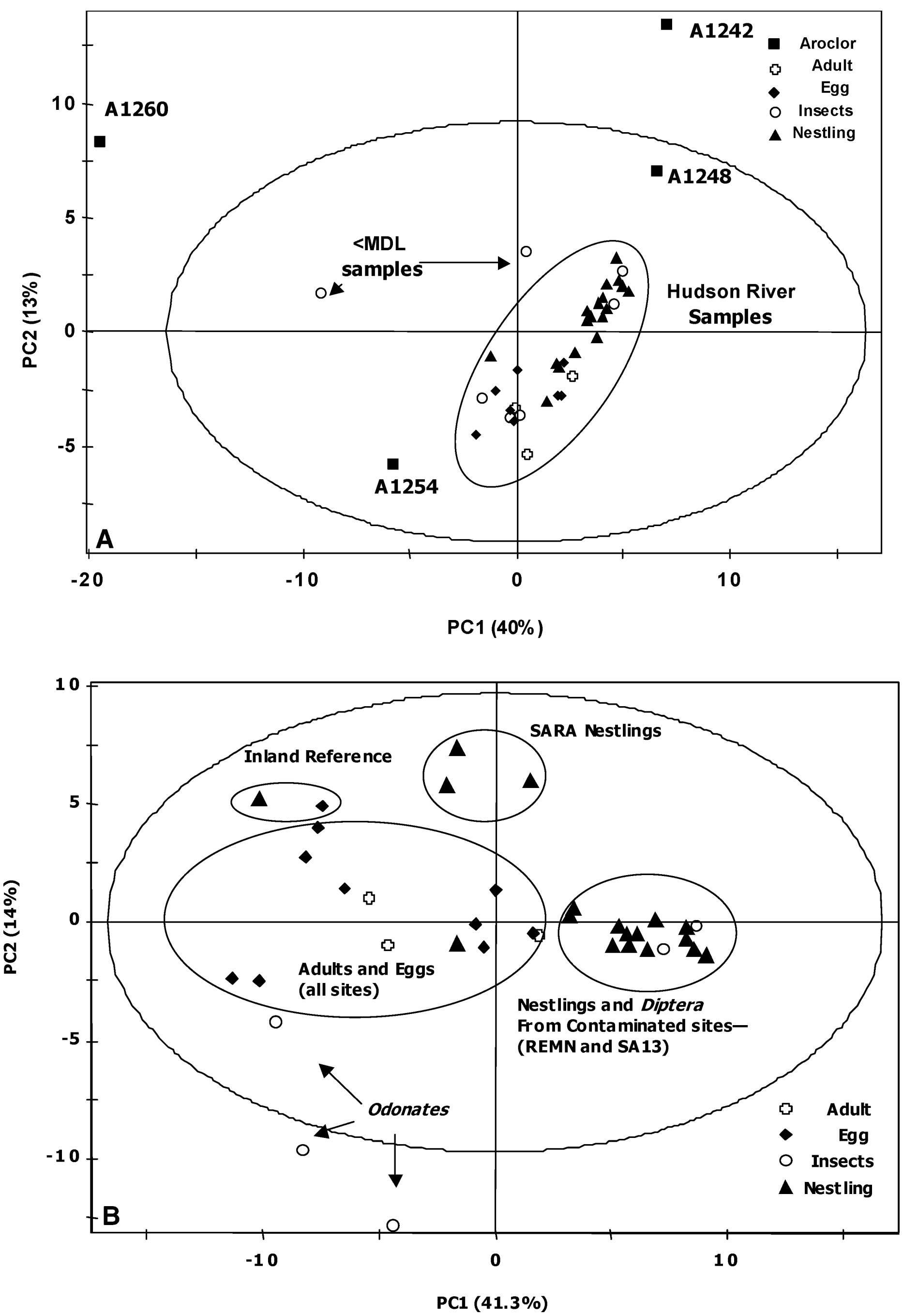

FIGURE 2. PCA score plots of the PCB congener patterns in tree swallows and dietary insects collected from site on the Hudson River, NY. (A) Model containing PCB congener patterns of technical Aroclors standards and all biota samples from the study. (B) Model of only the PCB congener patterns in biota. Ellipses designate the 95% confidence interval for each of the PCA models.

(upstream) and SARA (downstream) sites fell outside the confidence ellipse. Tree swallows select prey items for their nestlings by size and type, with the greater percentages of the prey taxa belonging to *Diptera* (*30*, *32*).

Comparison of PCB patterns in tree swallow adults, eggs, nestlings, and the food boli in this study suggest that metabolism is relatively unimportant with regard to the disposition of these contaminants in early life-stage nestlings. PCB congener profiles of the *Diptera* (food boli) and nestlings feeding on these insects were similar, suggesting that differential metabolism of PCBs was not very significant in the nestlings; whereas the PCB profiles of the adult tree swallows were more similar to the eggs (Figure 2B). Studies of embryonic and neonatal chickens as well as other species of birds show that MFO activity in these early life-stages can be comparable to that of adult birds (*33*, *34*). However, the metabolic capacity of neonatal tree swallows has not been evaluated. Recent studies with ring doves suggest that the PCB burdens are transferred to eggs from maternal lipid pools and not directly from their diets (*35*). Thus, PCB congener patterns in adult birds and the eggs they lay are expected to be more similar to one another. Different sources of PCBs and exposures experienced by migratory birds are reflected in the PCB patterns of their eggs. The PCB patterns of eggs, and therefore the adults, would only exactly match the local environment (i.e., the food source) if the adult females had reached a steady state with the source of PCBs at the breeding site (*35*). The adults at these sites, while present long enough

TABLE 2. Congener-Specific Rate of PCB Uptake and Rate Constants for Tree Swallow Nestlings from Two Sites on the Hudson River, NY[a]

				Remnant Site 4				Special Area 13			
IUPAC congener	structure	metabolic group	log K_{ow}	C_{id} (log (pg/g))	U_i (log (pg/g) d^{-1})	k_{ui} (d^{-1})	CV (%)	C_{id} (log (pg/g))	U_i (log (pg/g) d^{-1})	k_{ui} (d^{-1})	CV (%)
006	2−3	IV	5.06	3.73	0.0975	0.02614	46	3.53	0.0431	0.01223	57
019	26−2	IV	5.02	4.36	0.0625	0.01433	15	4.39	0.0400	0.00910	54
026	25−3	IV	5.66	5.08	0.0896	0.01765	11	4.52	0.0513	0.01136	24
028	24−4	III	5.67	6.08	0.0998	0.01642	12	5.73	0.0710	0.01239	19
042	23−24	IV	5.76	5.97	0.0896	0.01500	13	5.61	0.0513	0.00914	28
044	23−25	IV	5.75	5.80	0.0828	0.01427	8	5.43	0.0525	0.00966	24
049	24−25	IV	5.85	6.15	0.0949	0.01545	9	5.75	0.0570	0.00991	14
052	25−25	II	5.84	6.11	0.0875	0.01431	7	5.64	0.0564	0.01001	13
074	245−4	III	6.2	5.91	0.0856	0.01449	9	5.58	0.0589	0.01056	14
077	34−34	III	6.36	4.97	0.0668	0.01345	12	4.55	0.0453	0.00997	10
084	236−23	IV	6.04	4.83	0.0688	0.01423	19	4.37	0.0361	0.00827	24
110	236−34	IV	6.48	5.52	0.0804	0.01457	16	5.20	0.0583	0.01119	14
114	2345−4	III	6.65	4.26	0.0642	0.01507	20	4.10	0.0387	0.00944	28
118	245−34	III	6.74	5.30	0.0814	0.01536	16	5.28	0.0573	0.01085	18
126	345−34	III	6.89	3.10	0.0568	0.01833	13	2.63	0.0449	0.01704	16
138	234−245	III	6.83	5.15	0.0643	0.01250	18	4.85	0.0465	0.00959	8
151	2356−25	II	6.64	4.31	0.0663	0.01538	9	3.91	0.0569	0.01456	13
153	245−245	I	6.92	4.86	0.0624	0.01283	16	4.56	0.0464	0.01016	8
156	2345−34	III	7.18	4.27	*		*	3.97	0.0322	0.00813	29
174	2345−236	II	7.11	4.02	0.0675	0.01679	15	3.42	0.0547	0.01600	16
180	2345−245	I	7.36	4.40	0.0421	0.00957	18	4.19	0.0254	0.00606	24
189	2345−345	I	7.71	2.61	0.0591	0.02260	13	2.34	0.0425	0.01815	17
194	2345−2345	I	7.8	3.48	0.0453	0.01303	23	3.29	0.0319	0.00972	18
199	2345−2356	II	7.62	3.68	0.0434	0.01178	24	3.36	0.0390	0.01158	17
207	23456-2346	I	7.74	2.26	0.0355	0.01574	66	2.00	0.0347	0.01736	37
total PCBs	−	−	−	7.25	0.0851	0.01173	11	6.83	0.0551	0.00807	15

[a] An asterisk (*) indicates rate constants were not estimated for this congener as data were outside of quality control limits (CV > 100%). C_{id}, log-normalized PCB concentration (pg/g) in food boli; U_i, rate of PCB uptake in nestlings from regression of log-normalized PCB concentration data from 5-, 10-, and 15-day-old nestlings; k_{ui}, PCB uptake rate constant for tree swallow nestlings; and CV, coefficient of variation (%) as a measure of variance in the estimate.

to accumulate additional PCBs from the local environment, were not at the breeding sites long enough to reach steady state (*8*).

Uptake Rate Constants. Congener-specific uptake rate constants (k_{iu}) were estimated from empirical data on the concentrations for a subset of 25 individual congeners in tree swallow nestlings and their diets. The rate constants were calculated as an initial evaluation of PCB uptake at the REMN and SA13 sites (Table 2). PCB uptake in avian species is a factor of the dietary concentration and the ingestion rate (*4*). These estimates of uptake rate constants assume that ingestion rates, metabolism, assimilation efficiencies, and rates of elimination in nestling swallows remain constant. The rate constants were developed from PCB congener information from nestlings between the ages of 5 and 15 d. The concentration of PCB congeners in the eggs were not used for these calculations because of the differences that were noted in PCB patterns. The congeners present in the eggs reflect contributions of the maternal adult bird, while the PCB burdens in nestlings at age 5, 10, and 15 d post-hatch primarily reflect dietary sources.

A comparison of uptake rate constants (Figure 3A) reveals that estimates from the two study sites were in good agreement with one another and varied by less than a factor of 2. These uptake rate constants might be useful to estimate exposure burdens of PCBs in tree swallow nestlings at other locations. Knowledge of the dietary concentrations of PCBs at a site (i.e., appropriate emergent insects) could be used in conjunction with the uptake rate constants to estimate exposure to nestling tree swallows. Biomagnification factors are often used for this type of estimation (*36*, *37*); however, these nestlings have not attained a steady state at this age. Therefore, the use of biomagnification factors is not warranted for quantitative estimation of exposure in these nestlings, yet exposure of birds at these early stages of development is of critical importance to understand the effects of PCBs. Early life-stages are often the most sensitive toward the toxic effects of PCBs (*33*, *34*). The apparent uptake rate constants measured in tree swallow nestlings were 2−20-fold less than the estimated uptake rate constants measured in adult ring dove (*38*). The studies of ring dove measured PCB uptake into plasma over a 25-h period, and elimination was likely to be insignificant over this period. The estimates of PCB uptake rate constants for tree swallows presented here include the elimination that would occur over this period (10 d), which may account for the significantly lower rate constants we observed.

The congener-specific uptake rates in tree swallow nestlings were not associated with hydrophobicity of the congeners (Figure 3B). The hydrophobicity of the PCB congeners, as measured by the octanol−water partition coefficients (log K_{ow}) (*39*), was not related to the uptake rate constants estimated for tree swallows at either of the sites on the Hudson River. This finding was not unexpected as all the PCBs have been reported to have high rates of dietary absorption. Dietary absorption efficiencies of PCBs, an important factor in the influx of PCBs into a bird, were only slightly associated with hydrophobicity in ring doves (*38*).

Tree swallow nestlings have demonstrated utility as an indicator species for characterization of local sediment contamination. Our study confirms previous work and makes the initial quantitative linkages between dietary concentrations and patterns of PCBs with those concentrations and patterns observed in tree swallow nestlings. On the basis of the similarity in PCB patterns among tree swallow nestlings and food boli collected from adults returning to the nest,

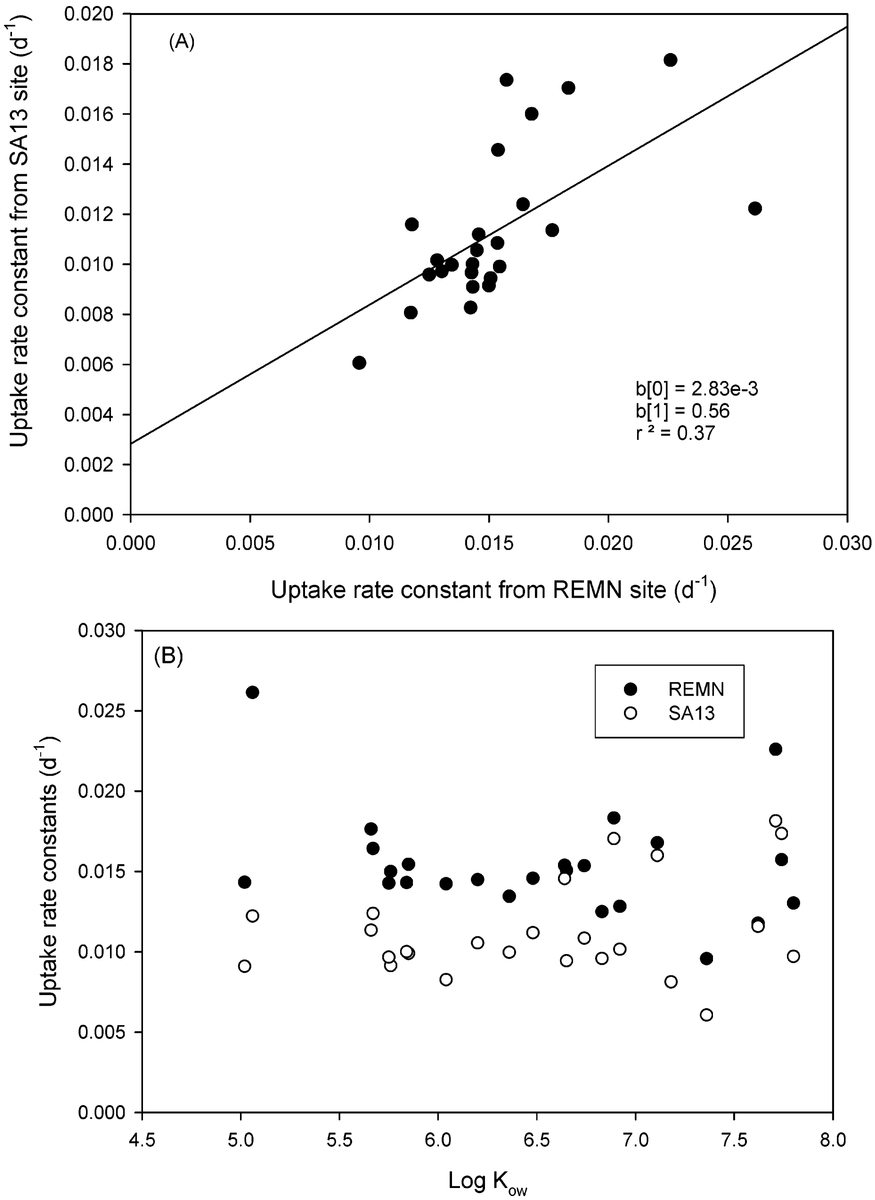

FIGURE 3. (A) Comparison of congener-specific PCB uptake rate constants (d^{-1}) for nestling tree swallows from two sites on the Hudson River, NY. Data taken from Table 2 and regression analysis presented (solid line). (B) Congener-specific PCB uptake rate constants for nestling tree swallows collected at two sites from the Hudson River, NY, as a function of hydrophobicity (log K_{ow}).

quantitative, congener-specific models for uptake may be developed. Initial estimates of congener-specific uptake rates constants for PCBs were comparable between the sites and may be used to estimate PCB contamination in nestling swallows at other locations. A more detailed investigation into the factors which influence PCB uptake and a bioenergetics-based model of PCB uptake into nestling tree swallows in reported in a companion paper in this issue (*15*).

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Supporting Information Available

One table showing PCB congener concentrations in tree swallows and insects. This material is available free of charge via the Internet at http://pubs.acs.org.

Literature Cited

(1) Secord, A. S.; McCarty, J. P.; Echols, K. R.; Meadows, J. C.; Gale, R. W.; Tillitt, D. E. *Environ. Toxicol. Chem.* **1999**, *18*, 2519−2525.

(2) Ankley, G. T.; Niemi, G. J.; Lodge, K. B.; Harris, H. J.; Beaver, D. L.; Tillitt, D. E.; Schwartz, T. R.; Giesy, J. P.; Jones, P. D.; Hagley, C. *Arch. Environ. Contam. Toxicol.* **1993**, *24*, 332−344.

(3) Bishop, C. A.; Koster, M. D.; Chek, A. A.; Hussell, D. J. T.; Jock, K. *Environ. Toxicol. Chem.* **1995**, *14*, 491−501.

(4) Nichols, J. N.; Larsen, C. P.; McDonald, M. E.; Niemi, G. J.; Ankley, G. T. *Environ. Sci. Technol.* **1995**, *29*, 604−612.

(5) Custer, C. M.; Custer, T. W.; Allen, P. D.; Stromborg, K. L.; Melancon, M. J. *Environ. Toxicol. Chem.* **1998**, *17*, 1786−1798.

(6) Froese, K. L.; Verbrugge, D. A.; Ankley, G. T.; Niemi, G. J.; Larsen, C. P.; Giesy, J. P. *Environ. Toxicol. Chem.* **1998**, *17*, 484−492.

(7) Yorks, A. L., Melancon, M. J., Hoffman, D. J., Henshel, D. S., Sparks, D. W. *Society of Environmental Toxicology and Chemistry 19th Annual Meeting Abstract Book*; 1998; p 164.
(8) McCarty, J. P. *Rev. Toxicol.* **2002**, *4*, 61−104.
(9) McCarty, J. P.; Secord, A. L. *Environ. Toxicol. Chem.* **1999**, *18*, 1433−1439.
(10) McCarty, J. P.; Winkler, D. W. *Condor* **1999**, *101*, 246−254.
(11) McCarty, J. P. *J. Field Ornithol.* **2002**, *73*, 9−14.
(12) Stapleton, M.; Dunn, P. O.; McCarty, J. P.; Secord, A. L.; Whittingham, L. A. *Environ. Toxicol. Chem.* **2001**, *20*, 2263−2267.
(13) McCarty, J. P.; Secord, A. L. *Auk* **1999**, *116*, 55−63.
(14) Novak, M. A.; Reilly, A. A.; Bush, B.; Shane, L. *Water Res.* **1990**, *24*, 321−327.
(15) Nichols, J. W.; Echols, K. R.; Tillitt, D. E.; Secord, A. S.; McCarty, J. P. *Environ. Sci. Technol.* **2004**, *38*, 6234−6239.
(16) Feltz, K. P.; Tillitt, D. E.; Gale, R. W.; Peterman, P. H. *Environ. Sci. Technol.* **1995**, *29*, 709−718.
(17) Peterman, P. H.; Gale, R. W.; Tillitt, D. E.; Feltz, K. P. In *Techniques in Aquatic Toxicology*; Ostrander, G., Ed.; Lewis Publishers: Boca Raton, FL, 1996; pp 517−553.
(18) Schwartz, T. R.; Stalling, D. L.; Rice, C. L. *Environ. Sci. Technol.* **1987**, *21*, 72−76.
(19) Boon, J. P.; Eijgenraam, F.; Everaarts, J. M.; Duinker, J. C. *Mar. Environ. Res.* **1989**, *27*, 159−176.
(20) Kannan, N.; Reusch, T. B.; Schulz-Bull, D.; Petrick, G.; Duinker, J. C. *Environ. Sci. Technol.* **1995**, *29*, 1851−1859.
(21) Bunyan, P. J.; Page, J. M. J. *Toxicol. Appl. Pharmacol.* **1978**, *43*, 507−518.
(22) Stegeman, J. J.; Hahn, M. E. In *Aquatic Toxicology: Molecular, Biochemical and Cellular Perspectives*; Malins, D. C., Ostrander, G. K., Eds.; CRC Press: Boca Raton, FL, 1994; pp 87−206.
(23) Walker, C. H.; Ronis, M. J. J. *Xenobiotica* **1989**, *19*, 1111−1121.
(24) Borlakoglu, J. T.; Wilkins, J. P. G.; Walker, C. H.; Dils, R. R. *Comp. Biochem. Physiol.* **1990**, *97C*, 151−160.
(25) Borlakoglu J. T.; Wilkins J. P. G.; Walker C. H.; Dils R. R. *Comp. Biochem. Physiol.* **1990**, *97C*, 161−171.
(26) Borlakoglu, J. T.; Wilkins, J. P. G.; Walker, C. H.; Dils, R. R. *Comp. Biochem. Physiol.* **1990**, *97C*, 173−177.
(27) Wold, S.; Albano, C.; Dunn, W. J., III; Edlund, U.; Esbensen, K.; Geladi, P.; Hellberg, S.; Johansson, W. L.; Sjöström, M. In *Chemometrics, Mathematics and Statistics in Chemistry*; Kowalski, B. R., Ed.; D. Reidel Publishing Co.: Boston, MA, 1984; pp 17−95.
(28) Schwartz, T. R.; Stalling, D. L. *Arch. Environ. Contam. Toxicol.* **1991**, *20*, 183−199.
(29) McCarty, J. P. personal communication.
(30) Johnson, M. E.; Lombardo, M. P. *Am. Midl. Nat.* **2000**, *144*, 216−219.
(31) U.S. EPA. Further Site Characterization and Analyses, Volume C−A Low Resolution Sediment Coring Report, Addendum to the Data Evaluation and Interpretation Report, Hudson River PCBs Reassessment RI/FS (Phase 2 Report−Review Copy); 1998.
(32) Quinney, T. E.; Ankney, C. D. *Auk* **1985**, *102*, 245−250.
(33) Hoffman, D. J.; Rice, C. P.; Kubiak, T. J. In *Environmental Contaminants in Wildlife*: *Interpreting Tissue Concentrations*; Beterm, W. N., Heinz, G. H., Redmond-Norwood, A. W., Eds.; CRC Press: New York, 1996; 165−207.
(34) Di Giulio, R. T., Tillitt, D. E., Eds. *Reproductive and Developmental Effects of Contaminants in Oviparous Vertebrates*; SETAC Press: Pensacola, FL, 1999.
(35) Drouillard, K. G.; Norstrom, R J. *Environ. Toxicol. Chem.* **2001**, *20*(3), 561−567.
(36) Bowerman, W. W.; Giesy, J. P.; Best, D. A.; Kramer, V. J. *Environ. Health Perspect.* **1995**, *103* (Suppl. 4), 51−9.
(37) Giesy, J. P.; Kannan, K. *Crit. Rev. Toxicol.* **1998**, *28*, 511−569.
(38) Drouillard, K. G.; Norstrom R. J. *Environ. Toxicol. Chem.* **2001**, *19* (11), 2707−2714.
(39) Hawker, D. W.; Connell, D. W. *Environ. Sci. Technol.* **1988**, *22*, 382−287.

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