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SPATIAL, TEMPORAL, AND DIETARY DETERMINANTS OF ORGANIC CONTAMINANTS IN NESTLING TREE SWALLOWS IN POINT PELEE NATIONAL PARK, ONTARIO, CANADA

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Abstract—Point Pelee National Park of Canada in southwestern Ontario, an important migratory route and vital breeding area for many birds, has localized areas of organochlorine (OC) pesticide contamination from agricultural production during the 1950s and 1960s. During 2001 and 2002, we investigated movement of persistent contaminants through the food web with the insectivorous tree swallow (*Tachycineta bicolor*) as a sentinel. The a priori site classifications, contaminated or reference, were based on soil residues of dichlorodiphenyltrichloroethane (DDT) and its breakdown products (ΣDDT), dieldrin, and other OC pesticides. In 2001, all nestling tissue samples were pooled by site, and residue levels did not reflect the soil contaminant status. To improve sampling accuracy in 2002, tissue residues were determined from birds in individual nests. This showed OC pesticides to be higher in samples from contaminated sites compared with reference sites ($p = 0.031$). Polychlorinated biphenyls (PCBs), which were not detected in soil samples, were present in the nestlings and were not related to site of origin ($p = 0.422$). In 2002, dietary samples were collected from nestlings and identified to taxon, and representative insects collected from nesting sites were analyzed for PCBs and other OCs. Consumption of terrestrial prey was positively correlated with tissue residues of ΣDDT ($p = 0.006$), whereas PCBs came from aquatic prey, *Hexagenia* mayflies ($p = 0.003$). Dietary details proved valuable in this study of contaminant transfer in insectivorous vertebrates.

Keywords—Contaminant transfer Food web transfer Tree swallows Biomonitoring Organochlorine contaminants

INTRODUCTION

Across Canada, localized areas have been contaminated with organic pollutants from the historic use of persistent industrial or agricultural chemicals [1]. Point Pelee National Park of Canada (PPNP) in southwestern Ontario is one such area, with contamination from historical use of chlorinated organochlorine pesticides (principally DDT and its degradation products and dieldrin) during the 1950s and 1960s (O'Connor Associates Environmental, 2001, Oakville, ON, Canada) [2]. Point Pelee National Park is one of Canada's smallest national parks, consisting of 15 km^2 of wetlands, Carolinian forest, beach habitats, and old fields (former farms and orchards) within a highly fragmented landscape. It is internationally known as an important staging area for migratory birds during spring and fall migration and is a vital breeding area for many species of birds, especially passerines.

This study was launched because of the recent discovery that highly localized areas within the park boundaries had high soil levels of persistent contaminants stemming from previous agricultural practices. Specifically, dichlorodiphenyldichloroethylene (DDE), DDT, and dieldrin exceeded Canadian Council of Ministers of the Environment guidelines, which are the conventional reference criteria for assessments of federally owned sites, as well as the provincial criteria as established by the Ministry of the Environment (MOE) for near surface soil samples (O'Connor Associates Environmental, 2001). Because of the ubiquitous nature of this class of contaminants on a global scale and because tree swallows are increasingly playing the role of sentinel species for other avian wildlife exposed to environmental pollutants, the current investigation into risks to wildlife was launched.

The insectivorous tree swallow (*Tachycineta bicolor*) feeds primarily on flying insects. This species has been widely studied to document biological effects of anthropogenically imposed environmental stress [3–7]. They are passerines that forage within approximately 100 m of their nest site during the breeding season [8,9]. Tree swallows are effective integrative biomonitors of local organochlorine contamination because of their position high in the food web [10,11]. Birds living in habitats with contaminated soils or sediments are thought to feed almost exclusively on insects whose immature stages have developed locally and therefore would accumulate persistent compounds from these food items [10]. Female birds can pass contaminants stored in their body tissues on to their eggs and thus affect embryos during development [11,12]. However, nestlings receive additional dietary contaminants while the parents raise them on locally captured prey items. Thus, offspring are variably exposed to any xenobiotic compounds that exist in, or have bioaccumulated through, the local food chain. The biomass of tree swallow nestlings increases by an order of magnitude between the time that they hatch and the time that they fledge 15 to 20 d later. Therefore, we expected that the body burden of contaminants would predominantly reflect their diet rather than maternally derived xenobiotic compounds.

The developmental history and ecological requirements of the larvae of insect prey greatly influence the types of contaminants that they can accumulate and pass on to predators

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[13–15]. Adult terrestrial insects in which larval stages are aquatic tend not to feed as adults [16]. Thus, their entire body burden of contaminants is derived from the sediments, food, or water in the location in which the immatures developed. Insects that have terrestrial larvae might acquire different suites of contaminants during their development in soil or on plants and additional persistent chemicals through their feeding and dispersal behavior as adults.

Swallows are opportunistic feeders, catching the most abundant insects available at the times of day and season during which they are active [17,18]. Aquatic insects often dominate the diet (midges, mayflies, caddisflies) [7,9–11], but terrestrial insects can be an important component of the diet during emergence periods [18–20]. The purpose of this study was to determine whether tree swallows breeding in PPNP were being exposed to persistent organic contaminants known to exist in soil in specific areas within the park and to determine the degree to which exposure in tree swallows was explained by focal soil environmental contamination. These were the questions posed to us by Parks Canada, Point Pelee National Park, Ontario, who supported the study. The role of dietary composition in explaining contaminant transfer in nestling tree swallows was also investigated.

MATERIALS AND METHODS

Study sites

Within the boundaries of PPNP, former orchards are contaminated with organochlorine (OC) pesticides such as DDT, its degradation products (DDD, DDE), and dieldrin. In 2001, 10 soil samples (top 5 cm of earth) were collected from four different locations that were suspected of being contaminated on the basis of historic land use. These were analyzed for a suite of organochlorine pesticides (principally DDE, DDT, and dieldrin; O'Connor Associates Environmental, 2001). Concentrations of dieldrin, DDE, and DDT exceeded MOE guidelines (1996) and the Canadian Council of Ministers of the Environment Environmental Quality Guidelines [21] on three sites.

The reference and contaminated sites within PPNP were identified by the federal agency Parks Canada, who wanted us to determine whether birds breeding on the contaminated sites were being exposed to the soil contaminants through the food web. Because of the small size of the park, suitable nesting areas were limited. The two areas defined as contaminated for our study were those at which OC levels exceeded MOE guidelines (e.g., DDE up to 33.31 μg/g [9 of 10 soil samples exceeded MOE], DDT up to 22.14 μg/g [8 of 10 exceeded MOE], and dieldrin up to 1.56 μg/g [7 of 10 exceeded MOE]). One reference site (4-R) within 4 km of the park was at the administration building of PPNP, which is surrounded by a natural area of willow shrubs, forbs, and grasses.

In March 2002, we erected 50 standard nest boxes for tree swallows apportioned among two nominally contaminated sites and two reference sites on the basis of previously described a priori classifications from a soil residue report (O'Connor Associates Environmental, 2001) and historic land use (i.e., orchards) because the soil samples were taken from point locations chosen to represent more extensive areas. All sites were within 100 m of small bodies of water and within 400 m of Lake Erie, Ontario, Canada. The two contaminated sites (1-C: 600 × 300 m; 2-C: 300 × 100 m) were 1 km apart at the nearest points; one reference site (3-R: 400 × 150 m) was 400 m from the nearest contaminated site and 4 km from the second reference site (4-R: 40 × 40 m).

Boxes were placed in open areas with scattered shrubs and trees. The two areas designated reference sites had a land use history similar to that of other locations around the park that were known to have OC levels in the surface soil below detection limits of 0.004 μg/g (Table 1). A total of 15 boxes on reference sites and 20 boxes on contaminated sites supported successful nests (those with breeding pairs of tree swallows that raised nestlings).

Dietary studies in 2002

To investigate the link between specific food items consumed by the nestlings and potential sources of persistent contaminants in year 2 only, dietary samples were collected from selected 7- to 10-d-old individuals from each site. We placed collars on nestlings to prevent them from swallowing the insects provided by their parents. Sampling took place in the early morning or evening when the air temperature was moderate (15–25°C) to minimize stress to the nestlings and to correspond with times of maximal parental foraging activity. An elastic band was placed around the base of the throat of each nestling. The band was secured by sliding a 3-mm section of a latex number 8 French feeding tube (Benlan, Oakville, ON, Canada) along its length, tightening the band enough to prevent passage of the food bolus into the esophagus, but not enough to inhibit normal gaping behavior and breathing (J. Smits, unpublished data). Chicks were immediately returned to the nest box. The provisioning behavior of the parents was watched from a distance of 50 to 100 m. After 30 to 45 min, or after the parents had made four to six trips to feed the young, chicks were taken out and any food bolus was removed from their crops with a curved hemostat. The nest and environs within nest boxes were also examined for any boluses that might have been regurgitated. The boluses from all the chicks in one nest were pooled and preserved in a single jar with 95% ethanol.

In the laboratory, the boluses were gently teased apart with fine forceps beneath a dissection microscope, and the insects were separated, identified, and quantified. The insects were in good condition, so almost all could be identified to at least the order level. Diptera were identified to family.

Diet per nest box was described by number and by biomass per insect taxon. Because ethanol preservation of the boluses resulted in loss of an indeterminate amount of body fluids, insect biomass could not be determined directly by weighing. Instead, the length of each insect was measured to the nearest 0.1 mm by an image analysis system. Lengths were converted to biomass (dry mass) according to conversion equations reported by Benke [22].

Contaminant analyses

Tree swallow collection and preparation. Two nestlings from each nest were randomly selected at 12 d of age, when they reached maximum body mass (J. Smits, unpublished data). They were anesthetized with an inhalation anesthetic (Halothane®; Halocarbon Laboratories, River Edge, NJ, USA), euthanized by exsanguination, and examined post mortem. Stomach contents, bursa of Fabricius, spleen, thyroid glands, plus a section of liver were removed and preserved for other analyses. The remainder of the carcass was skinned, wrapped in xylene-rinsed foil, and frozen at −20°C for OC residue analyses.

Table 1. Residues of polychlorinated biphenyls (PCBs) and organochlorine (OC) pesticides in soil samples as well as in tissues of nestling tree swallows in 2001 and 2002 in Point Pelee National Park, Ontario, Canada[a]

Site	A priori designation (*n*)	Contaminant	Soil residue (μg/g dry wt)	2001 Tissue residue (ng/g wet wt)[b]	2002 Tissue residue (ng/g wet wt)[b]; 0 ± SE
1-C	Contaminated (6)	ΣPCBs	ND	87	429 ± 97.4
		DDT	7.8	1	16 ± 7.7
		DDE	13.8	7	309 ± 111
		DDD	0.2	8	5 ± 1.0
		Dieldrin	0.5	3	18 ± 5.9
		Σ Other OCs	<0.5	4	13 ± 1.7
2-C	Contaminated (6)	ΣPCBs	ND	365	510 ± 41.6
		DDT	9.5	2	11 ± 2.4
		DDE	12.2	93	281 ± 48.3
		DDD	0.2	4	4 ± 1.1
		Dieldrin	0.5	14	9 ± 1.8
		Σ Other OCs	<0.5	20	12 ± 1.4
3-R	Reference (3)	ΣPCBs	NS	109	786 ± 294
		DDT	NS	1	1 ± 0.5
		DDE	NS	3	85 ± 17.3
		DDD	NS	1	3 ± 1.8
		Dieldrin	NS	3	6 ± 2.0
		Σ Other OCs	NS	2	15 ± 4.5
4-R	Reference (5)	ΣPCBs	NS	141	515 ± 103.7
		DDT	NS	1	4 ± 1.6
		DDE	NS	15	125 ± 22.5
		DDD	NS	7	3 ± 0.6
		Dieldrin	NS	5	9 ± 1.1
		Σ Other OCs	NS	5	17 ± 3.8

[a] ND = not detected; DDE = dichlorodiphenyldichloroethylene; NS = not sampled.
[b] From pooled samples of 34 individual birds in the area.

In 2001, of 10 samples of swallow carcasses pooled by site, five were from DDT-contaminated sites and five were from nominal reference sites. Because there was poor concordance between tissue residue levels of persistent OC and the site designations (Table 1), in 2002 we analyzed 20 samples of nestlings from individual nests. Eight samples were from reference area nests and 12 were from contaminated area nests. Some of these nestlings had been used for the dietary collections, but there was incomplete concordance between nests sampled for tissue residues and those from which dietary samples had been collected.

Insect collection and preparation. Several collection methods were used to acquire sufficient insect biomass for contaminant analysis. Modified Pennsylvania-style light traps [23] were operated for 2-h periods beginning at dusk on one evening when parents were provisioning for their young in 2002. To obtain enough biomass for contaminant analysis, insect collections had to be conducted again during the same season in 2003 to augment quantities of terrestrial insects in particular. Pairs of traps, operated at each of sites 3-R and 1-C, collected large quantities of adults of aquatic insects but relatively little biomass of terrestrial insects except for Lepidoptera. Daytime sweep netting and hand-collecting individual terrestrial insects from vegetation was subsequently used to augment quantities of these taxa. Insect collections were frozen en masse in hexane-rinsed glass jars. In the laboratory, they were thawed, sorted into taxonomic groups, weighed, and stored refrozen in hexane-rinsed foil until analyzed. Sufficient biomass was collected to permit analysis of a sample of each of three taxa from each of the two sampling sites.

Analytical procedures. Contaminant analyses were performed by the Great Lakes Institute of Environmental Research Analytical Laboratory, University of Windsor (Windsor, ON, Canada) according to standard analytical procedures with a Hewlett-Packard (Orangeville, ON, Canada) 5890 gas chromatograph equipped with an HP-5972 mass selective detector and HP-7673 autosampler [24]. Tissues from nestling swallows and insect samples were analyzed for 85 polychlorinated biphenyl (PCB) congeners, DDT, DDE, DDD, dieldrin, *cis*-nonachlor, hexachlorocyclohexane, mirex, and others. Throughout this paper, OC comprises the compounds listed above, excluding PCBs, which are presented separately.

Statistical analysis

Contaminant concentrations in nestling tissues among sites were compared with one-way analysis of variance (ANOVA) of log-transformed data. Planned comparisons were used to determine whether contaminant concentrations differed between the two reference and the two contaminated locations. Separate, Bonferroni-corrected univariate analyses were performed for the sum of DDT and its degradation products (ΣDDT), total PCBs (ΣPCB), and the sum of other organochlorine pesticides (ΣOCs).

Correlations between tissue concentrations of nestlings per nest box and the absolute or relative biomass of the dominant dietary items of aquatic and terrestrial origin were determined by Spearman's rank correlation coefficient.

RESULTS

Swallow tissue residues

2001 samples. Tissue body burdens of major OC and ΣPCBs in nestling tree swallows are presented from the four sites: 1-C and 2-C are the a priori contaminated sites on the basis of soil contaminant residues of OCs, whereas 3-R and 4-R are reference sites (Table 1). In 2001, nestlings from contaminated site 1-C had OC and ΣPCB levels similar to those at the reference sites, which were lower than those in the other con-

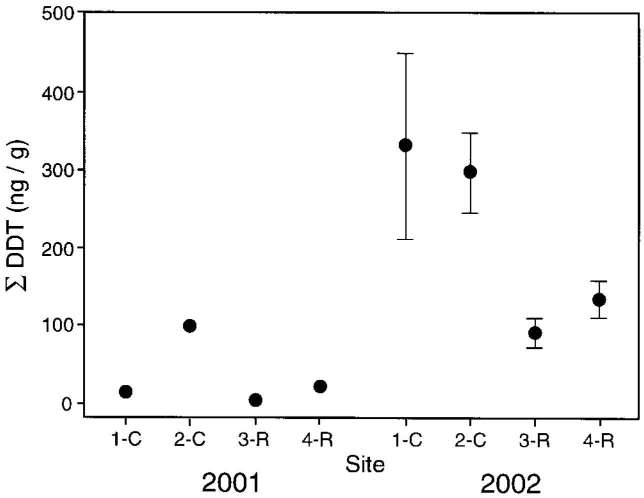

Fig. 1. Tissue concentrations of dichlorodiphenyltrichloroethane (DDT) and its degradation products in 13-d-old nestling tree swallows from contaminated (1-C, 2-C, on the basis of soil residue analysis) or reference (3-R, 4-R) sites in 2001 and 2002.

taminated area (2-C, Table 1). Polychlorinated biphenyls were detected in all pooled tissue samples of tree swallows but were below detectable levels in the soil samples collected throughout the park (O'Connor Associates Environmental, 2001).

2002 samples. Tissue concentrations of persistent contaminants were determined from the nestlings of individual nests within the different sites. Tissue residues were, on average, much higher in 2002 than in 2001 (Table 1 and Fig. 1). In 2002, soil and tissue OC levels were in better agreement than had been observed in 2001. Overall, the concentration of ΣDDT was significantly higher in the tree swallows collected from the contaminated areas than in nestlings from the reference areas (ANOVA $F = 11.31$; $df = 1, 18$; $p < 0.01$). Mean nestling concentration of ΣDDT varied significantly among sites ($F = 3.80$; $df = 3, 16$; $p < 0.05$; Fig. 1). Concentrations in nestlings from the two contaminated sites were significantly greater than concentrations in tissues from the reference sites (planned comparison $F = 11.26$; $df = 1, 16$; $p < 0.005$). In birds from the two contaminated sites (1-C and 2-C) and the two reference sites (3-R and 4-R), tissue contaminants were not different from each other ($F = 0.10$ and 0.76, respectively; $df = 1, 16$). The pattern was the same for an analysis of the total concentrations of ΣDDTs plus dieldrin and other pesticides. In contrast, for PCB residues in tissues of nestlings, there were no significant differences between nests in contaminated and reference areas ($F = 1.14$; $df = 1, 16$; $p > 0.05$), or among the four sites ($F = 0.99$; $df = 3, 16$; $p > 0.05$; Fig. 1b).

Diet

Aquatic insects in the diet were represented primarily by two aquatic taxa (Chironomidae [midges] and Ephemeroptera [mayflies, almost entirely *Hexagenia*]) and two terrestrial taxa (Formicidae [ants] and Asilidae [robber flies]). These four taxa typically (13 of 17 nest boxes) accounted for over 90% of the biomass of food boluses, and they represented at least 68% of the diet collected from any nest box. Chironomids were numerically most abundant, but *Hexagenia* made up most of the biomass (Table 2). Diet varied much more from nest box to nest box than among sites. We observed considerable variation in tissue contaminant levels and dietary items of nestlings both within and among the sites and between years. Consequently, the composition of the diet was investigated as a possible explanation. Insect prey items recovered from food boluses were classified as aquatic (having at least the larval stage spent in water—Chironomidae and *Hexagenia*), or terrestrial (all life stages spent on land). The few semiaquatic invertebrates collected (those whose larvae develop in saturated soil) were included in the terrestrial category. The proportion of prey items of terrestrial origin in the diet of the nestlings (on a biomass basis) was positively correlated with the nestlings' tissue residue levels of ΣDDT (Spearman rank order correlation, $r_s = 0.60$; $p < 0.05$; $n = 13$). However, when the biomass (weight of insects delivered per nest) was considered, the association was weaker and not statistically significant ($r_s = 0.38$; $p > 0.05$; $n = 13$). Almost identical correlations to ΣDDT were found between tissue concentrations of ΣOCs and the proportions of total biomass of the various insect groups ($r_s = 0.07$ [Chironomidae] $p > 0.05$; $r_s = -0.45$ [*Hexagenia*] $p > 0.05$; $r_s = 0.57$ [terrestrial insects] $p < 0.05$). Tissue burdens of ΣPCBs were highly significantly correlated with the biomass of *Hexagenia* mayflies whether determined on the basis of total weight ($r_s = 0.71$; $p < 0.01$; $n = 13$) or as a percentage of the total biomass ($r_s = 0.82$; $p < 0.001$; $n = 13$; Fig. 2). Concentrations of ΣPCBs were not correlated with either absolute or relative biomass of Chironomidae ($r_s = 0.01$ and -0.04, respectively; $p > 0.05$; $n = 13$). The relative number and biomass of insects of terrestrial or aquatic origins were independent of the date that the prey were collected from the nestlings ($p > 0.2$). However, the biomass of mayflies, which was so strongly associated with PCB tissue levels, was highly negatively correlated with the date of clutch initiation for the nest (Pearson correlation $r = -0.91$; $p < 0.001$; $n = 17$; Fig. 3).

Table 2. Geometric mean (SE) biomass (mg) of insects collected from boluses (*n* per site) of tree swallow nestlings in four areas of Point Pelee National Park, Ontario, Canada

	Biomass			
Aquatic	3-R ($n = 4$)	4-R ($n = 3$)	1-C ($n = 4$)	2-C ($n = 6$)
Aquatic				
Chironomidae	60.7 (4.0)	122 (1.1)	25.9 (3.0)	11.6 (1.7)
Hexagenia	14.8 (5.0)	96.7 (1.9)	51.5 (6.6)	4.75 (2.3)
Terrestrial				
Asilidae	0.00 (0.00)	0.00 (0.00)	2.00 (3.00)	22.4 (2.1)
Formicidae	1.34 (1.91)	1.0 (2.0)	16.8 (3.1)	1.75 (1.78)
Other taxa	5.92 (1.32)	10.5 (2.3)	11.0 (2.5)	20.9 (1.3)

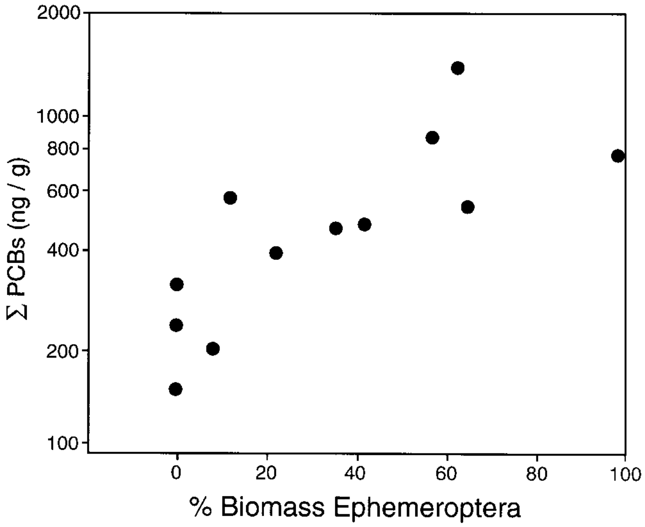

Fig. 2. Tissue concentrations of the sum of all PCB congeners (ΣPCB) in 13-d-old nestling tree swallows in 2002, relative to the percentage of their diets made up of ephemeroptera (mayflies).

DISCUSSION

In this study, we examined whether persistent organic contaminants known to exist in areas within PPNP were bioaccumulating in tree swallows breeding there. For the two years of this study, tree swallows were breeding throughout PPNP, regardless of the status of the soil contaminant levels. Because many of the OC compounds that are still being detected at unacceptably high levels in park soils are insecticides, one might expect this to have a detrimental effect on food supply of insectivorous birds. This ought to result in decreased numbers of breeding pairs choosing these sites for nesting. Furthermore, the bioaccumulative potential of chlorinated pesticides would lead to increased body burdens and possible negative biological effects in birds breeding on these sites. Our data present evidence that persistent environmental contaminants are accumulating in the nestling tree swallows and that chlorinated pesticide burdens in particular are higher in nestlings raised in the contaminated areas than in those raised in reference areas.

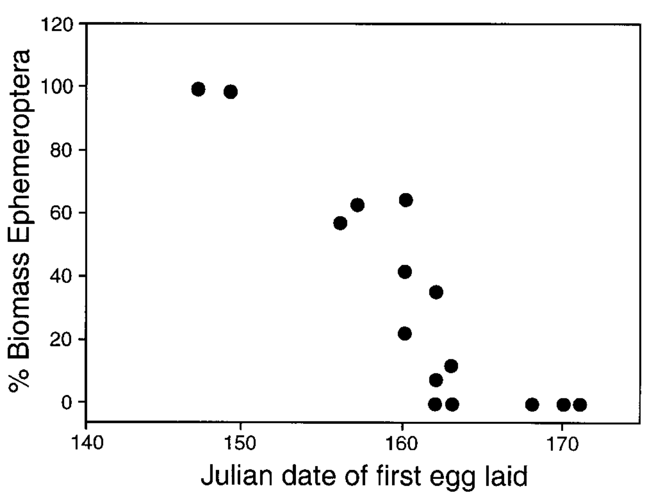

Fig. 3. Percentage of mayflies in the diets of 13-d-old nestling tree swallows relative to the date on which the first egg in their clutch was laid.

Logic would argue that the presence of historically used pesticides in tissues of nestling birds reflects contamination of local food sources because tree swallows generally forage within 100 m of their nests [7,8]. The levels of contaminants in viable embryos weighing 1.7 g, even without considering biotransformation, which is known to occur [12], likely represent a minor proportion of contaminants found once the nestlings have reached their fledging weight of 22 g. Studies of black-crowned night herons (*Nycticorax nycticorax*) [12,25] reported that although concentrations of tissue contaminants decreased over time, the total amount of OC pesticides plus their metabolites in growing chicks was greater than that found in sibling embryos. In other words, the hatchlings continued to accumulate the contaminants throughout their nestling period through their diets. These observations support our rationale that OC accumulation in nestlings reflects local exposure.

Factors determining contaminant loads in birds are complex. The diet, specifically the proportion of mayflies, was variable, even among boxes within the same local sites (Fig. 2), explaining why we failed to observe site-scale differences in PCB contamination. The aerial insect prey of tree swallows are mobile and can be dispersed by wind. When insects from remote areas dominate the diet, local soil residues might provide relatively weak information regarding risk to insectivores. We observed little site-specific consistency in tissue OC residues in nestlings between years, which could be an artifact of the different sampling methods used in the two years (pooled vs nest-specific samples), or it might reflect other differences in the two years, most likely related to diet. In 2002, for which we had both nest-specific residue and dietary data, both the proportion of terrestrial insects in the diet and the insects' contaminant signatures were correlated with the types and amounts of contaminants in tree swallow nestlings, consistent with the bioaccumulation of local contaminants through the food web.

Tissue concentrations of contaminants, especially PCBs, in the nestling tree swallows were more closely tied to the insect prey consumed at specific times during the nestling period than to local soil contamination conditions. The dietary data suggest that the parents of birds from different nests either foraged on different types of insects or that the type of insect available during the nestling period differed dramatically. In 2001, tree swallows reared most of their young during the first 2 weeks of June, and the nestlings had comparatively low levels of both PCBs and other OCs. In 2002, rearing of young was delayed by more than 3 weeks because of various weather- and predator-related reasons. This likely had a major influence on the main types of insect prey items available to the tree swallows, especially *Hexagenia* mayflies. Mass emergences of mayflies from western Lake Erie typically begin in late June [26], when the water temperature reaches 20°C (J.J.H. Ciborowski, University of Windsor, Windsor, ON, Canada, unpublished data). Emergence reaches its peak 1 to 2 weeks after its onset, then gradually tapers off. The park is a thin peninsula extending approximately 10 km into Lake Erie and is thus highly influenced by conditions of the lake. Adult mayfly activity (hence swallow foraging success) is inhibited by strong winds (especially from the north at PPNP), relatively low air temperatures, and heavy precipitation [27,28]. Although we lack detailed information, we expect that the emergence phenology of terrestrial species like ants would be seasonally regulated by the same weather conditions that limit mayfly emergence. In 2001, the *Hexagenia* emergence period began in late

May. Mass emergence did not begin until approximately June 28, 2002 (J.J.H. Ciborowski, personal observation), which followed the coldest month of May on record (Environment Canada, Atmospheric Environment Service, unpublished data).

We have convincing evidence (Fig. 2) that the nestling tree swallows with increased body burdens of PCBs were those for which mayflies dominated the diet. Samples of light-trapped *Hexagenia*, collected on the same date as food boluses in 2002, had PCB concentrations six to 10 times higher than locally collected terrestrial insects (Formicidae). However, the concentrations of PCBs, dieldrin, and other organochlorine compounds were typical of adult *Hexagenia* emerging from western Lake Erie [28,29].

Food boluses were collected from 7- to 11-d-old nestlings over a two-week period. The DDT levels in the nestlings were independent of the date they were euthanized, but consumption of terrestrial insects was related to higher tissue contamination with DDT. In 2002, the timing of clutch initiation, and thus the age of the nestlings, corresponded with the period of peak availability of mayflies. Consequently, parents with the oldest nestlings (those hatching earliest in the season) fed their young proportionally more mayflies, which translated into disproportionately higher body burdens of PCBs.

Government agencies in Canada and the United States have derived tissue residue guidelines for the protection of human health and wildlife. These guidelines differ somewhat among jurisdictions, but the level of total DDTs for humans and wildlife that consume aquatic organisms ranges from 0.14 to 1 mg/kg, with 0.4 mg/kg wet weight being considered protective [21]. Protective levels of ΣPCBs for aquatic and terrestrial wildlife are 0.1 mg/kg wet weight [30]. The birds analyzed in this study had tissue residues well below those associated with reproductive impairment (DDE $\geq$ 4 μg/g wet wt [1], PCB mixtures $\geq$ 1 mg/kg wet wt [31]) in a variety of other avian species, although studies of individual congeners of PCBs produced adverse effects at 10× lower concentrations. However, because the concentrations of PCBs in mayflies and DDE in ants in this study are above these guidelines, risks exist for birds consuming high proportions of these insects. Tree swallows are used to represent a wide range of insectivorous birds in contaminant-related research [3,4,7,11], even though, for reproductive endpoints at least, they are less sensitive to PCBs and other chemicals than are other insectivores [17,32]. However, there is evidence that they might be more sensitive when considering other endpoints, such as physiological or immunotoxicological variables [7,33]. It would be valuable to study adult birds, or young of the year, after they have spent longer periods feeding on contaminated prey. Modeling studies could provide another means of determining contaminant behavior in the insect–tree swallow food web in this area.

The organic contaminants found in the nestlings must have proximate sources. The DDT-related products appear to be derived from terrestrial insects emerging from areas fairly close to the boxes, which is indicated by higher tissue DDT levels in birds from boxes on contaminated sites compared with those from reference sites in 2002. As well, these observations provide evidence of the spatial stability of DDTs in the soil of the park. Because PPNP is on a narrow peninsula, where most wind effects would come from Lake Erie over the land, there is probably minimal drift of insects blowing major distances from the mainland to the study sites.

Our findings emphasize the importance and value of dietary details in explaining variability in burdens of bioaccumulative compounds. This study was designed to examine possible effects of OC contaminants, PCBs being undetected in the soil. Had the analysis relied on comparisons of contaminated with reference sites, we would have concluded no site differences in PCB contamination of nestlings and an unpredictable relationship of OCs with soil contamination. Our detailed dietary examination elucidated possible food web routes for ΣDDT from soil to tree swallows and identified the source of body burdens of PCBs, which was independent of the a priori designations of the study sites. The localized OC contamination that was the recognized concern in the park is not the only relevant contaminant problem for local insectivorous birds. The biological consequences of increasing tissue levels of OC and PCB must be evaluated before pollutant-based risks are known. Trophodynamic studies such as this are a critical complement to risk assessment studies of natural populations.

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