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MULTIPLE LINES OF EVIDENCE RISK ASSESSMENT OF AMERICAN ROBINS EXPOSED TO POLYCHLORINATED DIBENZOFURANS (PCDFS) AND POLYCHLORINATED DIBENZO-*P*-DIOXINS (PCDDS) IN THE TITTABAWASSEE RIVER FLOODPLAIN, MIDLAND, MICHIGAN, USA

presented by

DUSTIN L TAZELAAR

has been accepted towards fulfillment
of the requirements for the

M.S. degree in Animal Science

Major Professor's Signature

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By

Dustin L Tazelaar

A THESIS

Submitted to
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ABSTRACT

MULTIPLE LINES OF EVIDENCE RISK ASSESSMENT OF AMERICAN ROBINS EXPOSED TO POLYCHLORINATED DIBENZOFURANS (PCDFS) AND POLYCHLORINATED DIBENZO-*P*-DIOXINS (PCDDS) IN THE TITTABAWASSEE RIVER FLOODPLAIN, MIDLAND, MICHIGAN, USA

By

Dustin L Tazelaar

Polychlorinated dibenzofuran (PCDF) and polychlorinated dibenzo-*p*-dioxin (PCDD) concentrations in floodplain soils and biota downstream of Midland, MI, USA are greater than regional background concentrations. A multiple lines of evidence approach was utilized to evaluate the potential for effects of PCDD/DFs to American robins (*Turdus migratorius*; AR) breeding in the floodplains from 2005-2008. A dietary-based hazard assessment indicated there was potential for adverse effects for ARs that were predicted to have the greatest exposures; conversely, a tissue-based exposure assessment based on on-site eggs indicated minimal potential. A reproductive endpoints assessment indicated measures of hatch success for the study areas (SA) were significantly less than those of reference areas (RA), however there was no contaminant dose-response relationship. Given the dietary-based exposure and reproductive endpoint assessments were in accordance, the present study suggests potential for adverse effects to resident ARs exists and effects were observed. However, the tissue-based assessment suggests no potential for adverse effects and is reinforced by the fact the response was not does-related. It is likely the dietary assessment is overly conservative based on the inherent uncertainties of estimating dietary exposure relative to the direct measure of the tissue-based assessment. As such, ARs are not expected to be at risk to potential adverse effects of exposure to PCDD/DFs.

This thesis is dedicated to my loved ones, who have shown their support throughout my life, giving me the opportunity for education from the finest institutions.

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LIST OF ABBREVIATIONS

ADD_{pot} - potential average daily dose

AhR - aryl hydrocarbon receptor

AR - American robin

BSA - biological sampling area

COC - contaminant of concern

DL - dioxin-like

DDT - dichloro-diphenyl-trichloroethane

DDX - dichloro-diphenyl-trichloroethane related metabolites

ED- effective dose

ERA - ecological risk assessment

HpCDD - heptachlorodibenzo-*p*-dioxin

HpCDF - heptachlorodibenzofuran

HRGC/HRMS - high-resolution gas chromatography/high-resolution mass spectroscopy

HxCDD - hexachlorodibenzo-*p*-dioxin

HxCDF - hexachlorodibenzofuran

HQ - hazard quotient

IP - intraperitoneal

LBD - ligand binding domain

LCE50 - lethal concentration for 50%

LOAEC - lowest observed adverse effect concentrations

LOQ - limit of quantification

NOAEC - no observed adverse effect concentrations

OCDD - octachlorodibenzo-*p*-dioxin

OCDF - octachlorodibenzofuran

PCB - polychlorinated biphenyl

PCDD - polychlorinated dibenzo-*p*-dioxin

PCDF - polychlorinated dibenzofuran

PeCDD - pentachlorodibenzo-*p*-dioxin

PeCDF - pentachlorodibenzofuran

RA - reference area

SA - study area

SIM - single ion monitoring

SR - Saginaw River

TCDD - tetrachlorodibenzo-*p*-dioxin

TCDF - tetrachlorodibenzofuran

TEF - toxic 2,3,7,8-tetrachlorodibenzo-*p*-dioxin equivalency factor

TEQ - 2,3,7,8-tetrachlorodibenzo-*p*-dioxin equivalents

TR - Tittabawassee River

TRV - toxicity reference value

UCL - upper 95% confidence level

USEPA - U.S. Environmental Protection Agency

WEFH - Wildlife Exposure Factors Handbook

WHO - World Health Organization

Introduction

Soils and sediments of the Tittabawassee and Saginaw river floodplains downstream of Midland, Michigan, USA are contaminated with polychlorinated dibenzofurans (PCDFs) and polychlorinated dibenzo-*p*-dioxins (PCDDs) (Hilscherova *et al.* 2003). Concentrations of PCDDs and PCDFs in sediments and soils collected from the Tittabawassee River floodplain ranged from 1.0×10^{2} to 5.4×10^{4} ng/kg dry weight (dw) while mean PCDD/DF concentrations in upstream reference areas (RAs) were 10- to 20-fold less (Hilscherova *et al.* 2003). The spatial distribution and congener profile of the contaminants suggest the sources of PCDD/DFs to the Tittabawassee River floodplain were byproducts of historical production of industrial organic chemicals as well as on-site storage, treatment and disposal during the early- to mid-1900s prior to modern regulation and waste management practices (Amendola and Barna 1986). A primary level ecological risk assessment (ERA) based on limited biological data noted the potential for adverse impacts on resident wildlife (Galbraith 2003). In the study described herein, the American robin (*Turdus migratorius*; AR) was studied as a terrestrial based receptor species with a direct relationship to floodplain soils in a site-specific, multi-year, multiple lines of evidence approach to further refine measures of exposure. Finally, direct measures of reproductive performance were measured to test the hypothesis that the potential for effects could be predicted based on predicted exposures and estimates of toxicity reference values (TRVs) developed for other species or under laboratory conditions.

The site-specific hydrology of the Tittabawassee River, the unique nature of the graphite carbon source for PCDD/DF congeners (ATS 2009), the lipophilic properties and slow rate of degradation rates of dioxin-like compounds when buried and out of direct sunlight (Mandal 2005) have resulted in a unique mixture of contaminants dominated by PCDF downstream of Midland, Michigan some 100 years after they were released. The Tittabawassee River system receives drainage inputs from approximately 5,426 km^2 of land surface, composed primarily of woodlands, agricultural lands, and urban areas. River depth and width vary greatly with seasonal episodic rain events with lesser, consistent variation resulting from upstream hydroelectricity generation, daily. Sediments are mobilized and deposited in the floodplain as a result of extreme flood events and ice sheet bank scouring associated with the spring thaw. The Tittabawassee River flows southeast into the Saginaw River, which in turn flows northeast to the Saginaw Bay of Lake Huron. The Saginaw River downstream of the Tittabawassee River is wider with a lower flow rate. The Saginaw River is confined by engineered banks that support shipping lanes within and onshore urban development. As a result, the Saginaw River is less susceptible to deposition dynamics within the floodplain and as such, surface sediment PCDD/DF concentrations of the Saginaw and Tittabawassee rivers were similar, whereas floodplain surface soil concentrations of the Tittabawassee River were greater than those of the Saginaw River (Kannan *et al.* 2008).

Selection of representative ecological receptor species is a critical component of risk assessment. Guidance from the U.S. Environmental Protection Agency (USEPA) suggests, in order to apply comparisons across regions, selecting species based upon geographic distribution, intensity and duration of exposure, appropriateness as a surrogate species, sensitivity to some of the primary contaminants of concern (COCs) across sites, ecological function, and relative ease of conducting studies with that organism as well as other criteria (USEPA 1994). The species selected should ideally provide an accurate indication of the magnitude and extent of contamination. As such, a variety of appropriate receptor species were selected to represent the variable nature of contamination about the Tittabawassee and Saginaw river floodplains (Zwiernik *et al.* 2008; Seston *et al.* 2009; Coefield *et al.* 2010; Fredricks *et al.* 2010). For exposure and effects assessments of terrestrial food-web based passerines researchers have utilized a variety of species (Ankley *et al.* 1993; Bishop *et al.* 1995; Custer *et al.* 2005; Arenal *et al.* 2004). In this study, the AR was selected as an appropriate receptor species based on its direct relationship to soil and its exceptional study suitability (Henning *et al.* 2003; Bennett *et al.* 2007).

The AR is the largest, most abundant and most widespread North American thrush. It is easily recognizable with its very audible and unique song and defensive vocalizations. The AR constructs an open cup nest from grass, soil and earthworm castings to begin the breeding season (Sallabanks and James 1999), typically near short grass habitats, at heights manageable for observation by researchers. As such, the presence of the AR is relatively easy to predict, affording researchers an on-site species presence and often sufficient nest density to quantify exposure and assess population condition. Further, the AR has a limited home range during the breeding season (Knupp *et al.* 1977) and has a diet rich with terrestrial plants and invertebrates including earthworms (Howell 1942; Wheelwright 1986), which ensures concentrations of residues of interest will be indicative of local exposure from soils.

A multiple lines of evidence approach was employed to evaluate contaminant exposure and the associated potential for adverse effects. The approach minimizes uncertainties associated with uncontrollable variables associated with single field-based measurement endpoints (Fairbrother 2003). The lines of evidence included here include site-specific assessments of American robin exposure to PCDD/DFs were conducted for both predicted dietary exposure and measured concentrations in tissues of American robins. These exposures were compared to selected toxicity reference values (TRVs) to estimate the risk of adverse effects present to American robin along the TR. This was done in conjunction with site-specific individual and population health measures.

Materials and Methods

Site description

This study was conducted on the Tittabawassee, Chippewa, Pine and Saginaw rivers in and near Midland, Michigan, USA (Figure 1). Nests were located and all samples and reproductive data were collected from within the 100-year floodplain of the individual rivers. Two reference areas (RAs) were located upstream of the suspected sources of PCDD/DFs (Hilscherova *et al.* 2003) on the Tittabawassee River (R-1) and Chippewa and Pine (R-2) rivers (Figure 1). Study areas (SAs) downstream of the apparent sources of PCDD/DFs include approximately 72 km of free flowing river from the upstream boundary, defined as the low-head dam within the city limits of Midland, Michigan, through the confluence of the Tittabawassee and Saginaw rivers to where the Saginaw River enters Saginaw Bay in Lake Huron. The SAs along the Tittabawassee River downstream of Midland included four sites (T-3 to T-6) approximately equidistant, and three sites (S-7 to S-9) located at the initiation, median, and terminus of the Saginaw River. The seven SAs (T-3 to S-9) were selected from the Tittabawassee and Saginaw

rivers, respectively, based on the necessity to discern spatial trends, accessibility privileges, and maximal receptor exposure potential based on floodplain width and measured soil and sediment concentrations (Hilscherova *et al.* 2003). Reference areas and SAs included intermittent agricultural, forested and short grass habitat areas and spanned contiguous foraging areas of between one and three km of river. Only sediments and aquatic food web item collection took place at S-8, with the exception of a limited number of dietary item samples, and as such will not be relevant to this study.

Nest monitoring

Nests were monitored in order to obtain eggs and nestlings for measurement of concentrations of PCDD/DF as well as to collect information of reproductive performance. Nest searching took place throughout the breeding seasons from 2005-2008 and involved investigating suitable nest locations and defensive behavior of adult AR. Robins construct an open cup nest from grass, soil and earthworm castings (Sallabanks and James 1999). Nests are constructed by females at the beginning and during the breeding season, typically on supporting branches of various tree and shrub species, including, but not limited to, box elder (*Acer negundo*), silver maple (*Acer saccharinum*), white pine (*Pinus strobes*), red pine (*Pinus resinosa*), and autumn olive (*Elaeagnus umbellate*), as well as atop wild grape vines (*Vitis sylvestris*) and man-made structures, such as corner posts of pavilions and supporting beams beneath bridges. Nests located during this study were constructed at heights ranging from less than one meter (m) to greater than 17 m, but typically were located at heights observable from the ground with a bicycle mirror attached to a 1.5-3.0 m telescoping pole. For nests located at heights greater than the reach of the telescoping pole, either a 1.8 m step ladder, a 4.7-9.0 m extension ladder or tree climbing gear, including a saddle harness, cable harnesses and tree climbing spikes, was utilized for access.

Nests were visited every third day following nest location (Martin and Guepel 1993) to monitor egg laying, incubation, hatching, fledging, predation and any other event that may have affected nest outcome. The number of successful nests was calculated by summing the number of nests that fledged at least one juvenile. Mayfield nest success index was calculated based upon the duration of observations and daily predation and survival rates (Mayfield 1975). Addled eggs were collected opportunistically while a single viable egg was randomly collected from some clutches, until a sample size of 6 was obtained from each study area, for use in residue quantification. Hatching success was calculated in two ways for nests uninterrupted by nest failure. First, the total number of nestlings following hatch completion was divided by the total number of eggs present prior to hatch initiation. This approach ignored the fertility and hatchability of any egg collected and was referred to as the range-low hatching success. The second approach, range-high hatching success, was adjusted for any viable egg collected and assumed that any such egg would have hatched. Together, these two variables define the range of hatching success, as the range-low hatching success alone may bias hatching success too low or vice versa for the range-high hatching success alone (Henning *et al.* 2003). A maximum of one nestling per nesting attempt was also randomly collected at about twelve days of age, until a sample size of 6 was obtained for each study area, for use in residue quantification. Fledging success was calculated in a similar manner for successful nests, or nests that fledged at least one nestling. The range-low fledging success is equal to the total number of juveniles fledged divided by the number of nestlings present following hatch completion while the range-high fledging success was adjusted for any nestling collected and assumed that any such nestling would have fledged. Productivity, defined as the number of juveniles fledged following the nestling period divided by the number of eggs present prior to hatching, was calculated in a similar manner as hatching and fledging success and was presented to reflect a range, range-low productivity and range-high productivity, for nests observed during the egg-laying or incubation period through the nestling period. Adjusting reproductive endpoints was a necessary compromise of experimental design to obtain the most accurate, nest-specific estimates of concentrations of PCDD/DFs. Clutch size was monitored; however, adjustment for collected eggs was unnecessary. In order to avoid affecting nest outcome, adult AR were collected from known nesting areas, following the breeding season, but prior to migration. Nestlings and adults were monitored for gross external morphological abnormalities during routine handling.

Food web sampling

Collection of AR food items, including invertebrates, plant matter and soil, occurred at nine preselected biological sampling areas (BSAs), seven were located within the SAs and two were located in the RAs. Each BSA included one 30 m × 30 m grid, proximal to the river bank. Site-specific sampling of food items took place at RAs, R-1and R-2, and SAs, T-4 and T-6 in 2003. These, as well as T-3 to T-6, were sampled in 2004 and Saginaw River SAs, S-7 and S-9 were added in 2006. Sampling events occurred in mid-May, June and September to assess potential temporal variation in dietary contaminant exposure.

Composite plant samples were collected by hand during each sampling from a 1 m × 1 m plot randomly selected from within each BSA. Chemically cleaned scissors were used to sever the plants just above the root crown. Plants were separated by species so sample size was based on the diversity of the plant community of the BSA. Once plant material was removed soil was excavated by hand-digging with a chemically cleaned shovel to a depth of 15 cm from which a composite soil and Oligochaeta (earthworm) sample were collected. Forceps were employed to collect surface and subsurface-dwelling terrestrial invertebrates prior to and during excavation of the 1 m × 1 m plot as well as from pitfall traps utilized for small mammal collection of food web items of other receptors (Zwiernik *et al.* 2008). Finally, aerial and plant perching invertebrates were collected from the entire 30 m × 30 m BSA grid utilizing sweep and/or aerial invertebrate nets, as well as incidentally during the collection of aquatic emergent insects attracted to a mercury halide lamp, white sheet, Insect Vac Collection Chambers and Insect Vacs (Bioquip Products, Rancho Dominguez, CA). All collected food items were transferred to a labeled, chemically cleaned glass jar (I-Chem brand, Rockwood, TN). A minimum sample mass of 5 g was collected for each sample type in order to satisfy detection limit standards for residue analysis. Samples were stored on wet ice while in the field. Oligochaeta composite samples from each sampling event were split into two samples with half being depurated of gut content for 24 h. Oligochaeta were rinsed with distilled water prior to residue analysis. All other terrestrial invertebrates were categorized to taxonomic order for each life stage collected during each sampling period per site. Finally, samples were transferred to a -20°C freezer prior to homogenization and extraction.

Chemical analyses

Concentrations of the seventeen 2,3,7,8-substituted PCDD/DF congeners were quantified in all samples while concentrations of polychlorinated biphenyls (PCBs) and dichloro-diphenyl-trichloroethane (DDT) and related metabolites (DDXs) were measured in a subset of eggs and nestlings. Congeners were quantified in accordance with USEPA Method 8290/1668A with minor modifications (USEPA 1998). Collected eggs were opened around the girth with a chemically cleaned scalpel blade and assessed for stage of development and the presence of any abnormalities. Contents were then lyophilized and stored in clean jars until analysis (I-CHEM brand, Rockwood, TN). Concentrations of PCDD/DF in eggs were reported on a fresh mass basis to account for any desiccation during incubation and storage. Adjusted fresh mass was calculated based on egg volume (Hoyt 1979). The mass of egg contents was determined by subtracting the eggshell mass at the time of processing from adjusted fresh mass. Nestling and adult whole body samples were homogenized following removal of beaks, stomach contents, feathers and legs below the tibiotarsus. Nestling and adult whole body homogenates, egg contents and dietary items were homogenized with anhydrous sodium sulfate, spiked with known amounts of ^{13}C-labeled analytes as internal standards to calculate extraction efficiency and Soxhlet extracted in hexane: dichloromethane (1: 1) for 18 hours. The extract was solvent exchanged to hexane and concentrated to 10 mL. Ten percent of each extract was allocated to lipid content quantification. Extracts were then purified via concentrated sulfuric acid treatment prior to passage through silica gel and sulfuric acid silica gel columns and eluted with hexane. Additional column chromatography via elution through acidic alumina produced two fractions for each extract. The first fraction contained the majority of the PCB congeners and pesticide compounds while the second fraction contained PCDD and PCDF congeners. The first fraction from the silica gel columns, eluted with solvents, was combined with the first fraction of the acidic alumina columns and was retained for possible co-contaminant analyses. The second fraction was then passed through a carbon column packed with 1 g of activated carbon-impregnated silica gel. The second fraction of the silica gel column, eluted with toluene, contained the 2,3,7,8-substituted PCDD/DFs and dioxin-like (DL) PCBs.

Individual congeners and compounds were identified and quantified by use of high-resolution gas chromatography/high-resolution mass spectroscopy (HRGC/HRMS) via a Hewlett-Packard 6890 GC (Agilent Technologies, Wilmington, DE) connected to a MicroMass® high resolution mass spectrometer (Waters Corporation, Milford, MA). PCDF and PCDD congeners were separated on a DB-5 capillary column (Agilent Technologies, Wilmington, DE) coated at 0.25 μm (60 m x 0.25 mm i.d.). The mass spectrometer was operated at an EI energy of 60 eV and an ion current of 600 μA. Congeners were identified and quantified by use of single ion monitoring (SIM) at the two most intensive ions of the molecular ion cluster. Concentrations of 2,3,7,8-tetrachlorodibenzofuran (TCDF) were confirmed by using a DB-225 (60 m x 0.25 mm i.d., 0.25 μm film thickness) column (Agilent Technologies, Wilmington, DE). Chemical analyses included pertinent quality assurance practices, including matrix spikes, blanks, and duplicates.

Concentrations of PCDD/DF were expressed as 2,3,7,8-tetrachlorodibenzo-*p*-

dioxin (2,3,7,8-TCDD) equivalents (TEQ). Concentration of TEQ were calculated as the sum of the products of the concentration of each congener multiplied by it's appropriate toxic 2,3,7,8- tetrachlorodibenzo-*p*-dioxin equivalency factor (TEF) as specified by the World Health Organization (WHO) (van den Berg *et al.* 1998) and concentrations expressed as ng $TEQ_{WHO\text{-}Avian}$/ kg on a wet weight basis.

Calculation of average daily potential dose

The potential average daily dose (ADD_{pot}) expressed as ng $TEQ_{WHO\text{-}Avian}$/kg body weight/day, was calculated utilizing the wildlife dose equations for dietary exposures equation 4-8 of the U.S. Environmental Protection Agency (USEPA) Wildlife Exposure Factors Handbook (WEFH) (USEPA 1993). Food intake rate was calculated utilizing USEPA WEFH equation 3-4 with a body mass of 77 g. This approach assumed that all foraging was done within the study area. A literature-derived dietary composition (Howell 1942; Wheelwright 1986) was included: 25% Coleoptera (beetles), 25% Lepidoptera (mostly moths), 18% Oligochaeta, 7% plant and 25% miscellaneous Arthropoda including Orthoptera (mostly grasshoppers), Hemiptera (largely shield bugs or stink bugs), Homoptera (particularly leafhoppers) and Arachnida (spiders). Site-specific (R-1 and R-2; T-3 to T-6; S-7 and S-9) concentrations of $TEQ_{WHO\text{-}Avian}$ were calculated. For PCDD and PCDF, invertebrates have greater concentrations than do plants, thus, the selected literature-derived dietary composition reflects a breeding season dietary composition to calculate dietary exposure because a greater proportion of invertebrates are consumed relative to plants at this time. The strategy applied assured a daily dietary dose that was on the greater end of the exposure distribution that will result in an effects assessment that is protective of the population.

Toxicity reference values

Potential for adverse effects was evaluated by comparing the concentrations of $TEQ_{WHO-Avian}$ in the diet or eggs to available toxicity reference values. Toxicity reference values are quantitative measures of toxicity used to estimate risk utilizing the hazard quotient (HQ) method where the estimate of exposure is compared to a threshold concentration for effect. Toxicity reference values represent concentrations in eggs or the diet less than or at which adverse effects would be expected to occur. Several factors were considered during selection of TRVs, including appropriateness of receptor species, chemical compound, presence of a dose-response relationship, and quantification of ecologically-relevant endpoints associated with sensitive life-stages. In an effort to minimize additional uncertainties associated with the relationship between $TEQ_{WHO-Avian}$ values derived from PCB-based or PCDD/DF-based exposures (Custer *et al.* 2005), consideration was only given to values derived from PCDD/DF-based exposures. Literature-based no observed adverse effect concentrations (NOAECs) and lowest observed adverse effect concentrations (LOAECs) were used in the determination of HQs and subsequent assessment of potential risk. In the present study, TRVs based on concentrations in the diet or in eggs were used to evaluate the potential adverse effects of site-specific contamination.

No laboratory-based dietary dosing studies of the effects of PCDD/DF exist for AR and are limited for Passeriformes in general. Therefore, a dosing study of adult hen ring-necked pheasants (*Phasianus colchicus*) utilizing intraperitoneal (IP) injections of

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TCDD for a 10 wk exposure period was selected for the dietary exposure-based TRV for this study (Nosek *et al.* 1992). While exposing hen pheasants to TCDD via IP injections versus true dietary exposure may be considered grounds for uncertainty, dosing exposure via injection should produce more direct and greater exposures than that of gastrointestinal transfer resulting in any bias producing a lesser TRV or more conservative effects assessment. Another source of uncertainty stems from the species selection of this dosing study as ring-necked pheasant and American robins are not members of the same taxonomic order. Galliformes species are traditionally considered to exhibit greater sensitivity to dioxin-like compound exposures than passerine species (Brunström and Reutergardh 1986; Brunström 1988; Powell *et al.* 1997a). However, recent results suggest that specific differences in the ligand binding domain (LBD) of the aryl hydrocarbon receptor (AhR) of birds are predictive differences in sensitivity to dioxin-like compounds among species of birds (Karchner *et al.* 2006; Head *et al.* 2008). Ring-necked pheasants and AR have the same amino acid sequence in the LBD of the AhR and thus have similar sensitivities to the effects of AhR-active compounds such as PCDD and PCDF (SW Kennedy *personal communication*).

Dietary-based TRVs were determined by converting the weekly exposure at which adverse effects on fertility and hatching success were determined (1000 ng TCDD/kg/wk) to a LOAEC for daily exposure of 140 ng TCDD/kg/d. The dosing regime was based on orders of magnitude differences and adverse effects were not present at the next lesser dose, 14 ng TCDD/kg/d, which was determined to be the NOAEC for dietary exposure (Table 1). One uncertainty in applying dietary TRVs is that correction by relative potencies among congeners by applying $TEFs_{WHO\text{-}Avian}$ does not correct for differences in rates of assimilation or biotransformation and clearance that would affect the internal dose resulting from a dietary dose. For these reasons, the authors consider measurements of $TEQ_{WHO\text{-}Avian}$ in eggs to be a more accurate estimate of exposure.

The egg tissue-based TRV selected for comparison to concentrations of $TEQ_{WHO\text{-}Avian}$ in AR eggs is based on an egg-injection study that involved dosing eastern bluebird (*Sialia sialis*) eggs with 2,3,7,8-TCDD (Thiel *et al.* 1988). Field collected eastern bluebird eggs were injected with concentrations of 2,3,7,8-TCDD in 10-fold increments ranging from 1 to 100,000 ng/kg wet weight prior to replacement to their original clutches and subsequently incubated by unexposed adults (Table 1). Hatching success was significantly adversely affected at doses greater than 10,000 ng/kg wet weight (LOAEC), while endpoints associated with eggs exposed to less than 1,000 ng/kg wet weight (NOAEC) were not significantly different than those of vehicle-injected controls. Additionally, the key measurement endpoint of the study was hatching success, an ecologically relevant endpoint, for which a dose-response relationship was observed. The minimal taxonomic distance between the two species further strengthened the applicability of the bluebird egg TRV to the eggs of the AR. Closely related species are expected to exhibit similar sensitivity to dioxin-like compounds (Allard *et* al. 2010) and both bluebirds and AR are of the family Turdidae. Not unexpectedly, both have the same genetic code in the area of the genome that appears to dictate species sensitivity to dioxin-like compounds further confirming their direct comparability (SW Kennedy *personal communication*).

Several studies in which eggs were injected with 2,3,7,8-TCDD, were also considered for the AR egg TRV, including ring-necked pheasant (Nosek 1993) and double-crested cormorant (*Phalacrocorax auritus*) (Powell *et al.* 1998; Powell *et al.* 1997b). However, based on the criteria we adopted for selection of a TRV, including species relatedness, ecologically relevant endpoints, a clear dose-response relationship, valid control groups and power to discern effects, none were as robust as the study of the eastern bluebird.

Assessment of hazard and risk

Overall, the potential hazard of PCDD/DF to AR was assessed utilizing a multiple lines of evidence approach incorporating both dietary- and egg-based exposure estimates as well as quantification of site-specific productivity endpoints (Fairbrother 2003). Potential effects of dietary- and egg-based exposures were assessed by calculating hazard quotients. Concentrations of $TEQs_{WHO\text{-}Avian}$ (ng/kg wet weight) in eggs and estimates of dietary exposure ADD_{pot}; expressed as ng $TEQs_{WHO\text{-}Avian}$/kg/d, were divided by TRVs based on either concentrations in eggs or diet and based on either the NOAEC or LOAEC, respectively. Hazard quotients were determined based on the upper 95% confidence level (UCL) for arithmetic means of concentrations in eggs at individual study locations and based on 95^{th} and 50^{th} centile dietary exposures. Arithmetic means were presented rather than geometric means as arithmetic means were greater and provided a more conservative basis from which inferences could be drawn. Incorporation of both dietary- and tissue-based assessment endpoints has been shown to reduce uncertainty in risk assessments of persistent organic pollutants (POPs) (Leonards et al. 2008).

In addition to the point estimates of hazard, semi-probabilistic estimates of risk were determined b y comparing the probability distributions of expected cumulative percent frequencies of exposure based on concentrations of $TEQs_{WHO\text{-}Avian}$ in eggs of AR and ADD_{pot} based on $TEQ_{WHO\text{-}Avian}$ to selected TRVs. Predicted probabilistic distributions were generated utilizing a Monte Carlo approach in SAS® software (Release 9.1; SAS Institute Inc., Cary, NC, USA) for the egg-based risk assessment and a re-sampling approach in R software (Version 2.9.2, R Foundation for Statistical Computing, Vienna, Austria) for the dietary-based risk assessment.

Statistical analyses

Total concentrations of the 17 individual 2,3,7,8-substituted PCDD/DF congeners (∑PCDD/DF) are reported as the sum of all congeners expressed as ng/kg wet weight. To be conservative, for individual congeners for which concentrations were less than the limit of quantification (LOQ) a proxy value of half the LOQ was assigned. Total concentrations of twelve non- and mono-*ortho*-substituted PCB congeners are reported as the sum of these congeners (ΣDL-PCBs) for a subset of egg samples that were screened for co-contaminants. Additionally, dichloro-diphenyl-trichloroethane (2',4' and 4',4' isomers) and dichloro-diphenyl-dichloroethylene (4',4') are reported as the sum of the *o,p* and *p,p* isomers (DDXs) for the same subset of samples as for PCBs.

Statistical analyses were performed using SAS® software (Release 9.1; SAS Institute Inc., Cary, NC, USA) and R software (Version 2.9.2, R Foundation for Statistical Computing, Vienna, Austria). The experimental unit for measurements associated with eggs, nestlings and productivity was the nest, since individual measurements within a clutch cannot be considered independent (Hurlbert 1984).

Similarly nest productivity measurements were reported on a per nest basis, thus making each nesting attempt a separate experimental unit (Pinkowski 1979). Adults were considered individual experimental units unassociated with nests. Prior to the use of non-parametric statistical procedures with PROC NPAR1WAY, normality was evaluated using the Shapiro-Wilks test. To assess the influence of the random effect of year, PROC GLIMMIX was then used for effect level comparisons following non-parametric Kruskal-Wallis test comparisons. Least squares means tests were used to identify significant differences among locations. Differences were considered to be statistically significant at $p < 0.05$.

In order to avoid bias resulting from skewed data, a re-sampling approach with R software (Version 2.9.2, R Foundation for Statistical Computing, Vienna, Austria) was used to estimate 50th centile, 95th centile and maximum ADD_{pot}. The dietary concentrations component of USEPA WEFH equation 4-8 was repeatedly calculated, each time using a randomly sampled dietary item concentration from the data set for each dietary item category. This resulted in a distribution of 10,000 dietary concentrations of which the median of the distribution represented the central tendency of ADD_{pot}. The re-sampling was performed on real measured data to estimate ADD_{pot} rather than on a continuous distribution inferred from the measured data or a range of data in order to avoid assumptions about the distribution of the data. This method is similar to assessments of American mink and great horned owl exposure to PCDD/DFs in the Tittabawassee River floodplain (Zwiernik 2008; Coefield 2010).

Results

Site-specific endpoints

Among all study sites, 240 AR nests were initiated and monitored during the four breeding seasons from 2005 through 2008. Measurement endpoints associated with tissue concentrations of ΣPCDD/DF were quantified in 84 eggs and 53 nestlings collected from individual nesting attempts. Twelve adults were collected for quantification of concentrations of ΣPCDD/DF following the breeding season and 158 composite samples of individual dietary items were collected from the identified BSAs throughout the nesting seasons from 2003-2006 and used to calculate dietary exposure to PCDD/DFs.

Tissue residues

Concentrations of PCDD/DFs and $TEQ_{WHO\text{-}Avian}$ were quantified in AR eggs, nestlings and adults collected at each site. Mean concentrations of $TEQ_{WHO\text{-}Avian}$ in eggs from the Tittabawassee River SAs were 8- to 71-fold greater than those from RAs (Figure 2), while concentrations in eggs collected from the Saginaw River SAs were 2- to 24-fold greater than those of eggs collected from RAs. Profiles of relative concentrations of PCDD/DF comprising $TEQ_{WHO\text{-}Avian}$ in eggs were primarily PCDD congeners at RAs, while downstream SAs were dominated by PCDF congeners, particularly 2,3,4,7,8-pentachlorodibenzofuran (2,3,4,7,8-PeCDF), which accounted for approximately 35% of all congeners in eggs at T-3 to T-6 and 25% at S-7 and S-9 (Figure 3). The maximum egg concentration of ΣPCDD/DF $TEQs_{WHO\text{-}Avian}$ was 1662 ng/kg from T-6. Co-contaminants in eggs were not significantly different between RAs and SAs for ΣDL-PCBs concentrations, DL-PCB TEQs, or DDXs. However, mean DL-PCB TEQ concentrations were 8- and 3-fold greater at Saginaw River SA than RAs and Tittabawassee River SAs, respectively. Mean ΣDL-PCB concentrations were 7- and 2-fold greater at Saginaw River SA than RAs and Tittabawassee River SAs, respectively. Mean ΣDDX concentrations were 2-fold greater at Tittabawassee River SAs than RAs and Saginaw River SAs ($p = 0.0345$). The greatest ΣDL-PCB TEQ concentration was from an egg collected from S-9 (11 ng/kg wet weight). The PCB congener PCB 118 contributed approximately 58% to the total ΣDL-PCB concentration of that egg.

Concentrations of PCDD/DFs and $TEQ_{WHO-Avian}$ in nestlings were greater at SAs than at reference areas. The mean concentrations of $TEQ_{WHO-Avian}$ in nestlings were 4- to 116-fold greater in Tittabawassee River SAs than RAs, while mean concentrations of $TEQ_{WHO-Avian}$ in nestlings from the Saginaw River SA were 2- to 36-fold greater than nestlings collected from RAs (Figure 4). The maximum concentration of $TEQs_{WHO-Avian}$ was 709 ng/kg in nestlings from T-5.

Profiles of relative concentrations of congeners in nestlings resembled those in eggs. Profiles in nestlings from RA were primarily comprised of PCDD while profiles in nestlings from SA were dominated by PCDF, particularly 2,3,4,7,8-PeCDF, which accounted for approximately 31% and 27% in T-3 to T-6 and S-7 and S-9, respectively (Figure 5).

Concentrations of the other residues, monitored in this study, were not significantly different between RAs and SAs. Mean DL-PCB TEQ concentrations were 15- and 5-fold greater at Saginaw River SA than RAs and Tittabawassee River SAs, respectively. Mean ΣDL-PCB concentrations were 22- and 6-fold greater at Saginaw River SA than RAs and Tittabawassee River SAs , respectively. Mean ΣDDX concentrations were 9- to 4-fold greater at Tittabawassee River SAs than RAs and Saginaw River SAs), respectively.

The mean concentrations of $TEQ_{WHO\text{-}Avian}$ in AR adults from the Tittabawassee River SAs were 48-fold greater than those from RAs (Figure 6). The relative contribution of the 17 individual congeners to the sum total for whole body adults was consistent on a spatial basis with those of both eggs and nestlings. Congeners of PCDD were prevalent in adult AR from RA while PCDF congeners were prevalent in adult AR from SAs, particularly 2,3,4,7,8-pentachlorodibenzofuran (2,3,4,7,8-PeCDF), which accounted for approximately 42% of all congeners (Figure 7). The maximum concentration of $TEQs_{WHO\text{-}Avian}$ in adult AR was 268 ng/kg from T-6.

There were no observations of morphological deformities in the observed and/or collected nestlings and adults.

Dietary exposure

Concentrations of ΣPCDD/DFs and $TEQ_{WHO\text{-}Avian}$ were quantified on a temporal and spatial basis for co-located soils, terrestrial plants and a number of invertebrate orders. In general, the mean concentrations of ∑PCDD/DFs and $TEQs_{WHO\text{-}Avian}$ were significantly greater in SA dietary items than in RAs. Arithmetic mean $TEQ_{WHO\text{-}Avian}$ concentrations in dietary items were 11- to 177-fold greater in Tittabawassee River SAs than in RAs in terrestrial plants and Oligochaeta, respectively, while Saginaw River SA mean concentrations of $TEQs_{WHO\text{-}Avian}$ in dietary items were as great as 144-fold greater than that of RAs in Oligochaeta, while terrestrial plants were similar between areas

(Figure 8). The maximum concentration of $TEQs_{WHO\text{-}Avian}$ was 1900 ng/kg wet weight and occurred in Coleoptera collected from T-4.

Profiles of relative concentrations of congeners in dietary items varied in proportion of PCDD and PCDF (Figures 9, 10, 11 and 12). RA dietary items were dominated by PCDD, particularly octachlorodibenzofuran (OCDD), which accounted for approximately 57% to 73% of all congeners in RA dietary items. Plants of Tittabawassee River SAs were dominated by PCDD, with OCDD contributing approximately 53% to the congener composition while Saginaw River SA congeners were similar in the percentage of dioxin and furan congener contribution. At S-7 and S-9 the congener pattern in terrestrial plants was dominated by OCDD, which contributed approximately 25%, but also was comprised of approximately 17% 2,3,7,8-tetrachlorodibenzofuran (2,3,7,8-TCDF). Congener profiles of Coleoptera, Lepidoptera and Oligochaeta collected from Tittabawassee River SAs were characterized by slightly greater percentages of PCDF than PCDD and were dominated by OCDD, which contributed 40% to Coleoptera, 35% to Lepidoptera and 41% to Oligochaeta congener profiles. 2,3,7,8-TCDF contributed 27%, 27% and 17% to Tittabawassee River SA Coleoptera, Lepidoptera and Oligochaeta, respectively, while octachlorodibenzofuran (OCDF) also contributed approximately 13% to the congener profile of Tittabawassee River SA Oligochaeta. Congener profiles of dietary invertebrates from the Saginaw River SA varied in congener contribution, but were largely dominated by OCDD which contributed 48%, 50% and 39% to the relative congener contributions of Coleoptera, Lepidoptera and Oligochaeta, respectively.

Potential average daily dose

Potential average $TEQ_{WHO\text{-}Avian}$ daily doses (ADD_{pot}) expressed as ng/kg body weight (bw)/d) for adult AR were greater at SAs relative to RAs. The 50^{th} centile ADD_{pot} were 142- and 46-fold greater at Tittabawassee and Saginaw river SAs, respectively, while 95^{th} centile ADD_{pot} were 116- to 39-fold greater at Tittabawassee and Saginaw river SAs, respectively. The maximum ADD_{pot} of 880 ng/kg bw/d was observed at Tittabawassee River SAs (Table 2).

Reproductive success

Sixty-eight nests were identified in RAs, while 133 nests were located in Tittabawassee River SAs and 39 in Saginaw River SAs. Nest location varied per site with as few as 15 nests located at S-9 and as many as 64 nests located at T-6. Of the 215 nests for which the outcome was known, 46% fledged at least one nestling. Of the nests of known outcome at least one nestling was fledged at 42%, 50% and 37% of nests in RAs, Tittabawassee River SAs and Saginaw River SAs, respectively (Table 3). The Mayfield daily mortality rate for all nest observations with known outcomes for RAs for 743.5 nest days with 36 nest losses was 0.048 per nest day. Mayfield daily mortality rates were 0.044 per nest day (1284 nest days and 57 nest losses) and 0.053 per nest day (359 nest days and 19 nest losses) in Tittabawassee River and Saginaw River SAs, respectively.

Nests that were preyed upon comprised the majority of nests that were not successful. Criteria for depredation included the loss of all eggs or nestlings prior to a date at which nestlings would have been old enough to fledge, the presence of damaged eggs, such as that of an avian predator puncturing the shell, or evidence of preyed upon nestlings or adults, such as lacerations on the carcass of deceased birds or piles of feathers below the nest.

Mayfield daily mortality rates were significantly different among RAs (743.5 exposure days), Tittabawassee River SAs (1284 exposure days) and Saginaw River SAs (359 exposure days) based on a chi-square test ($p < 0.0001$). Daily mortality rates were 0.048 nest losses/exposure day in RAs, 0.044 nest losses/exposure day in Tittabawassee River SAs and 0.053 nest losses/exposure day in Saginaw River SAs. Daily mortality rates were significantly different between RAs and Tittabawassee River SAs ($p < 0.001$), between RAs and Saginaw River SAs ($p = 0.0008$) and between Tittabawassee River SAs and Saginaw River SAs ($p < 0.001$).

In general, most reproductive endpoints were not significantly different between RAs and SAs with the exception of hatch success (Table 4). Mean clutch size was 3.2, 3.2 and 3.5 for RAs, Tittabawassee River SAs and Saginaw River SAs, respectively. Range-low hatch success was 87% in RAs, 74% for T-3 to T-6 and 65% in S-7 and S-9, while range-high hatch success was 96%, 82% and 75% in RAs, Tittabawassee River SAs and Saginaw River SAs, respectively. Range-low fledging success was 74%, 76% and 80%, while range-high fledging success was 93%, 98% and 100% for R-1 and R-2, T-3 to T-6 and S-7 to S-9, respectively. Range-low productivity was 72%, 59% and 49% for RAs, Tittabawassee River SAs and Saginaw River SAs, respectively. Range-high productivity was 84% in R-1 and R-2, 72% in T-3 to T-6 and 62% in S-7 and S-9.

Effects assessment

The 50^{th} centile, 95^{th} centile and maximum ADD_{pot} for Tittabawassee River SAs exceeded both the dietary-based LOAEC and NOAEC. The 50^{th} centile ADD_{pot} exceeded only the NOAEC, while the 95^{th} centile and maximum ADD_{pot} exceeded both the LOAEC and NOAEC for Saginaw River SAs. 95^{th} centile HQs at Tittabawassee River SAs were greater than 40 based on the NOAEC and greater than 4 based on the LOAEC, while 95^{th} centile HQs at Saginaw River SAs were greater than 10 based on the NOAEC and greater than 1 based on the LOAEC. RA ADD_{pot} did not exceed either dietary-based TRV (Figure 13).

The predicted probabilistic distributions of expected cumulative percent frequencies based on concentrations of potential average ADD_{pot} calculated from site-specific food web-based dietary exposure for adult ARs were compared to selected TRVs. The probability of the ADD_{pot} exceeding the NOAEC (14 ng/kg/d wet weight; (Nosek *et al.* 1992)) at Tittabawassee and Saginaw River SAs, was approximately 99% and approximately 92%, respectively, while that of the ADD_{pot} for the RA was < 1% (Figure 14). The probability of the ADD_{pot} exceeding the LOAEC (140 ng/kg/d wet weight; (Nosek *et al.* 1992)) at Tittabawassee and Saginaw River SAs, was approximately 99% and 20%, respectively, while that of the ADD_{pot} for the RA was < 1%.

The hazard quotients generated from $TEQs_{WHO\text{-}Avian}$ concentrations in eggs compared to relevant TRVs were not indicative of hazard to American robins. The upper

95% confidence level (UCL: arithmetic mean) of $TEQs_{WHO\text{-}Avian}$ concentrations in eggs were not greater than the TRVs based on either the LOAEC or NOAEC. Egg HQs based on both LOAECS and NOAECS were less than 1 among all sites (Figure 15).

The predicted probabilistic distributions of expected cumulative percent frequencies based on concentrations of ΣPCDD/DF $TEQs_{WHO\text{-}Avian}$ in eggs of ARs were compared to selected TRVs. Predicted distributions of ΣPCDD/DF $TEQs_{WHO\text{-}Avian}$ in eggs exceeded the NOAEC (1,000 ng/kg wet weight; (Thiel *et al.* 1988)) at Tittabawassee and Saginaw River SAs, while that of the RAs did not (Figure 16). Approximately 4% of the Tittabawassee River SA predicted distribution exceeded the NOAEC, while < 1% of the predicted distribution of the Saginaw River SAs exceeded the NOAEC. The Tittabawassee River SA predicted distribution exceeded the LOAEC (10,000 ng/kg wet weight; Thiel *et al.* 1988) by < 1%.

Discussion

Species selection

American robins were a useful receptor species. The AR allowed evaluation of accumulation of PCDD/DF from soil, plants and invertebrates by a species that was probably maximally exposed. Widespread distribution and sufficient breeding and foraging habitat on site also allowed for assessment of reproductive output of the population. Both eggs and nestlings were of sufficient mass to meet analytical detection limits and not as limited as other terrestrial passerine species, such as the house wren. The size of the AR population was sufficient relative to other terrestrial passerine species, such as the eastern bluebird, which were more limited in suitable habitat availability for this study. The major limiting factor for gathering data for this AR study was person hours available for locating active nests. Unlike the aforementioned cavity nesting terrestrial species, the AR will not occupy a nest box of known location predetermined by the researchers. Therefore, many hours of observation are necessary to search for nests. Furthermore, mark and recapture data are more readily obtainable from species that utilize nest boxes, whereas trapping species that utilize open cup nests presents additional challenges to researchers. Trapping of adult ARs is difficult and very time consuming with a greater potential to injure adults than for the cavity nesting birds that can easily be trapped in the box.

Multiple lines of evidence

American robins residing within the Tittabawassee River floodplain were exposed to elevated concentrations of dioxin-like compounds, however the comprehensive site-specific data set described within, when employed in a multiple-line-of evidence approach, was unable to identify with any certainty either the potential for, or site-measured contaminant related individual- or population-level adverse effects. Establishing whether or not a site-relevant contaminant exposure has the potential to adversely impact individuals is a key component in ascertaining causation when differences in individual or population health are noted in field-measured parameters. Two different methods of exposure and effects assessments indicated contrasting potential for hazard to ARs in the SA.

Dietary-based exposure and assessment

A hazard assessment based on estimated $ADDs_{pot}$ and applicable TRVs indicated there was potential for adverse effects for ARs in Tittabawassee River SAs and most likely for ARs in Saginaw River SAs while no potential for adverse effects was indicated in RAs. The expected threshold for effects should be observed at concentrations between the LOAEC and NOAEC. Therefore, based on this line of evidence, there is some ambiguity about the Saginaw River SA hazard assessment due to the 50^{th} centile being < 1.0, however, adverse affects seem likely as the LOAEC-based HQ for the 95^{th} centile and both the 50^{th} and 95^{th} centile NOAEC-based HQs were > 1.0 for dietary items in Saginaw River SAs (Figure 13).

In comparison, concentrations in pooled dietary samples from tree swallow nestlings exposed to dioxin-like compounds ranged from 72 to 230 ng TEQ/kg from the Woonasquatucket River in Rhode Island, USA (Custer *et al.* 2005). This corresponded to reduced hatching success for exposed tree swallow populations. While this approach suggests exposure for Woonasquatucket River study area tree swallows was 6 to 18 times greater than concentrations that are considered safe, the dietary samples were pooled and subsequently not directly comparable to the estimated ADD_{pot} of the present study. Also, the congener profiles in dietary item samples were dissimilar between the studies as Woonasquatucket River study area dietary items were dominated by 2,3,7,8-TCDD, 1,2,3,4,6,7,8-HpCDD and OCDD while the SAs of the present study were dominated by 2,3,7,8-TCDF, OCDD and to a lesser extent OCDF, further making the studies less comparable as the toxicokinetics may vary between congeners.

American robin $ADDs_{pot}$ were equal to or less than those of house wrens of a parallel assessment in the same SAs where no adverse effects were observed in house wrens (Fredricks *et al.* 2010b). The 50th centile AR $ADDs_{pot}$ were within the 95% confidence interval estimated $ADDs_{pot}$ of house wrens, however, no adverse effects were indicated in individual and population condition measurements for house wrens. More weight may be afforded to the house wren study relative to the Woonasquatucket River tree swallow study for comparison purposes as the relative contributions of congeners to the mixture of dioxin-like compounds should be more similar between parallel studies.

Assessing the exposure by use of the ADD_{pot} approach is less certain than measuring concentrations in adults, nestlings or eggs. Application of the ADD_{pot} is useful if it is not possible to make measurements of concentrations in eggs or nestlings and information is available for the potential dietary items or these concentrations can be predicted from measurements in soils. In applying the ADD_{pot} approach it is assumed that literature-based dietary composition is appropriate. Also, it might be more conservative as the proportion of earthworms is greater than that suggested by the literature from which the dietary composition was derived. It was felt that earthworms were understated in those studies (Howell 1942; Wheelwright 1986) as the frequencies were based on stomach content analysis which may misrepresent Oligocheata as they are soft-bodied and more readily digestible relative to more chitinous invertebrates. The ADD_{pot} approach also assumes the normalized ingestion rate is appropriate and that the ARs limit their foraging to the floodplain. Further, the estimated potential average daily dose is what is potentially available, not necessarily what is bioavailable for uptake.

Another uncertainty in applying dietary TRVs is that correction by relative potencies among congeners by applying $TEFs_{WHO}$ does not correct for differences in rates of assimilation or biotransformation and clearance that would affect the internal dose resulting from a dietary dose. For these reasons, the authors consider measurements of $TEQ_{WHO\text{-}Avian}$ in eggs to be a more accurate estimate of exposure.

Tissue-based exposure and assessment

PCDD/DFs in AR egg, nestlings and adults were greater in SA tissues than in the RA AR tissues, as was the case in downstream dietary items. The generally dominant furan congener, however, differed between dietary item and receptor tissue congener contributions. Dietary item congener profiles were dominated by 2,3,7,8-TCDF while robin tissue profiles were dominated by 2,3,7,8-PeCDF. This may be the result of TCDF metabolism as avian (Elliott *et al.* 1996; Kubota *et al.* 2005) and mammalian research suggests the rate of metabolism of 2,3,7,8-TCDF with increased concentrations of dioxin-like compounds and induction of cytochrome P450 while 2,3,4,7,8-PeCDF is sequestered in the liver (van den Berg *et al.* 1994; Zwiernik *et al.* 2008). This is a potential result of the differing number of carbon hydrogen bonds, however, caution must be observed when extrapolating this to avian species as laboratory toxicokinetics studies of dioxin-like compounds are limited for birds.

In contrast to the dietary-based hazard assessment, a hazard assessment based on measured egg $TEQs_{WHO\text{-}Avian}$ concentrations indicated there was minimal potential for adverse effects for ARs upstream and downstream of Midland as LOAEC- and NOAEC-based HQs were < 1 (Figure 15). The predicted frequency distributions of concentrations of $TEQ_{WHO\text{-}Avian}$ in eggs suggest 4% of the eggs in Tittabawassee River SAs exceed the NOAEC, while less than 1% of Saginaw River SAs exceed the same threshold value (Figure 16). The same distributions indicate that less than 1% of Tittabawassee River SA eggs exceed the LOAEC, while Saginaw River SA eggs do not exceed the LOAEC. Assuming the actual threshold for effects occurs between the NOAEC and the LOAEC, based on relevant egg-based TRVs and 95% UCL exposures in eggs, adverse effects are not expected for ARs.

The aforementioned Woonasquatucket River tree swallow study indicated that an estimated lethal concentration for 50% (LCE50) of the tree swallow eggs exposed to dioxin-like compounds was 1,700 ng/kg TEQs, which corresponded to reduced hatch success (Custer 2005). This LCE50 value is greater than 6-fold the mean TEQ concentrations of AR eggs in the most exposed study areas of the Tittabawassee River floodplain. As such, we expect that being 6-fold lesser than the LCE50 suggests little to no potential for adverse effects. However, this does not suggest TEQ concentrations similar to those in eggs of the Tittabawassee River would not occur at an ecologically relevant point on the lethal concentration estimate curve below the 50% effective dose for the Woonasquatucket River study. Also, mean study area TEQ concentrations in AR eggs were less than those in study area house wren eggs in a parallel study (Fredricks *et al.* 2010) where house wren individual and population condition adverse effects were not indicated, which further enforces the expectation for a lack of potential for adverse effects to ARs downstream of Midland.

Measures of individual and population condition

Of the individual and population health parameters quantified for the field measure of effects, hatching success was deemed to be the most sensitive and robust. Other ecologically relevant endpoints were measured, such as fledging success, nest success and productivity to understand the overall population health, however, there are uncertainties associated with these endpoints as populations experiencing reduced hatching success could experience compensatory mechanisms in post hatch survival due to less within nest competition for resources. Additionally, the TRVs selected are based on hatching success, thus allowing for a direct comparison of the same measurement endpoint between the field and controlled laboratory studies. While each quantified endpoint is relevant to the overall individual and population condition assessment, hatching success should be considered of significant importance due to the aforementioned criteria.

There were significant differences about range-low hatch success and range-high hatch success, however, these differences did not appear to be related to PCDD/DF exposure, but rather as a random effect of year. Kruskal-Wallis comparisons indicated significant differences between areas for range-low hatch success ($p = 0.0297$) and range-high hatch success ($p = 0.0145$). Comparisons utilizing generalized linear mixed models in PROC GLIMMIX suggest the random effect of year accounts for some or all of the variability as the differences of range-low hatch success ($p = 0.0838$) are no longer significant while the significance of the differences among range-high hatch success is reduced ($p = 0.0570$). This suggests the random effect of year on the data may contribute to the significant differences rather than site-specific exposure. Additionally, a key factor for establishing causation is the presence of a dose-response effect. For this study the range-low and range-high hatch success for the Tittabawassee River SAs were intermediate while the AR tissue ΣPCDD/DF $TEQ_{WHO-Avian}$ concentrations were greatest. Conversely the range-low success and range-high hatch success were least in Saginaw River SAs where ΣPCDD/DF $TEQ_{WHO-Avian}$ concentrations were intermediate. This suggests these significant differences in hatch success are not dose-dependent relative to PCDD/DF exposure.

Mayfield daily mortality rates were significantly different between RAs and SAs. The difference among daily mortality rates was also not dose-dependent as the greatest daily mortality rate was observed where PCDD/DF concentrations in tissues were intermediate and least where concentrations in tissues were greatest. Interestingly, where daily mortality rate was greatest (Saginaw River SAs), no nests were abandoned. Depredation accounted for the loss of each failed nest. While depredation accounted for the majority of nest failure in RAs and Tittabawassee River SAs, each area experienced nest failure due to abandonment (two nests per area).

Rates of hatching success observed for American robins nestling within the Tittabawassee River floodplain were comparable to values reported as species norms. Range-high hatch success and range-low hatch success were greater than or similar to that of ARs from a DDE study in which hatching success (60-69%) was unaffected by contaminant burden (Elliott *et al.* 1994). Range-high hatch success and range-low hatch success were also within the range of measured hatching success (45-100%) of 99 avian species from a genetic similarity and hatching success study (Spottiswoode and Møller

2004). Further, range-high hatch success and range-low hatch success of the present study were all greater than the hatching success reported by Young (1955) in the reference areas of a breeding behavior and nesting study. The proportions of successful nests of RAs and all SAs in this study were also greater than those (25 and 21-24%) of RAs of other studies of AR (Henning *et al.* 2003; Ortega *et al.* 1997).

Uncertainty assessment

The greatest uncertainty regarding the present study, like many other hazard assessments, was rooted about the selection of TRVs, as the chosen TRVs may have a significant influence on the subsequent assessment of risk. Applicable TRVs should reflect endpoints relevant to survival or fitness and limit extrapolations across species and taxonomic class while considering the context of variability in chemical-specific toxicological data set and species-specific response. Recent research (Allard *et al.* 2010) suggests methods for deriving TRVs through the compilation of data from multiple studies for a single species, or multiple species where applicable, in order to generate dose-response curves in order to isolate appropriate effective doses (EDs) to use as TRVs rather than the more conventional NOAEC and LOAEC approach of HQ quantification. While we recognize the validity of the ED approach, sufficient data were not available to generate EDs for this study.

The greatest proportion of research investigating the effects dioxin-like compounds on avian species has been conducted on the white domestic chicken (*Gallus domesticus*) and has overwhelmingly acknowledged the chicken as the most sensitive species to these POPs (Brunström and Reutergardh 1986; Brunström 1988; Powell *et al.*

1996; Henshel *et al.* 1997; Brunström and Halldin 1998; Blankenship *et al.* 2003). While this research has revealed reliable ED data relative to applicable endpoints, there is now a strong enough data set to conclude that the selection of chicken derived EDs as TRVs will most likely result in overly conservative hazard assessments. Moreover, recent research further supports this conclusion, suggesting there is a molecular basis for variation in avian species-specific sensitivities to dioxin-like compounds and that the chicken is unique (Karchner *et al.* 2006; Head *et al.* 2008). As such, TRVs were selected from studies based on species relatedness, including genetic congruence of the ligand binding domain of the aryl hydrocarbon receptor (AhR) construct to that of the AR. The egg tissue-based exposure TRVs selected, while displaying limitations inherent in field studies, was based on a study of the eastern bluebird which like the AR is a member of the family Turdidae (Thiel *et al.* 1988). The dietary-based exposure TRVs selected were derived from intraperitoneal injections of TCDD in hen ring-necked pheasants (Nosek *et al.* 1992a). The major limitation of this study stems from the differences in absorption, distribution, metabolism and excretion from intraperitoneal injections rather than a true dietary dosing study.

Additional confidence in the appropriate selection TRVs is granted from recent research investigating the differences between species-specific sensitivities to dioxin-like compounds which suggest sensitivities are potentially tied to amino acid substitution differences in the AhR LBD between species (Kennedy *in preparation*). Based on these AhR LBD results, the AR was classified as a species with moderate sensitivity to dioxin-like compounds. The eastern bluebird has an AhR LBD that is identical to the AR while the ring-necked pheasant is only one substitution different but responds similarly to exposure to dioxin-like compounds. Thus, based on numerous criteria we concluded that the most scientifically defensible TRVs for this AR hazard assessment were the individual studies selected.

Conclusion

Hazard assessments of dietary-based exposures of AR populations downstream of Midland predicted there was potential for adverse effects; however, tissue-based exposures based on PCDD/DFs residue concentrations in eggs were not indicative of the potential for adverse effects. Subsequent assessment of reproductive endpoints revealed significant differences between reference and study areas hatching success in AR populations of the floodplains near Midland. Interestingly, the significant differences between reference areas and study areas were least where exposure was greatest and greatest where exposure was intermediate, and the effect did not appear to be dose-related. Moreover, all measures of individual and population health for ARs exposed to dioxin-like compounds in this study were similar to or greater than those reported in the literature for un-exposed AR population. Further, a parallel study of house wrens with similarly greater exposure to PCDD/DFs in SAs revealed no observable effects. Possible explanations for the disagreement between the tissue- and dietary-based exposure assessments included the possibility that the tissue-based TRVs were too liberal as the doses utilized, which established the NOAEC and LOAEC, may not have characterized well the true threshold values for potential effects or the dietary-based TRVs may have been overly conservative based on intraperitoneal injections in the ring-necked pheasant instead of true dietary adsorption. Uncertainties about the estimate of ADD_{pot} values including dietary composition and time spent on-site may also explain this disparity.

Based on the weight-of-evidence we were not able to conclude that ARs foraging and breeding within the Tittabawassee River floodplain are at risk to experience adverse population-level effects as a result of their exposure to PCDD/DFs. While the dietary-based hazard assessment as well as noted differences in hatching success suggested both the potential for and presence of adverse effects, the remaining lines of evidence either conflicted or weakened this interpretation. The more directly measured tissue based exposure assessment did not identify the potential for adverse effects. Furthermore, individual and population health measures including clutch size, fledging success and productivity were not different between exposed and reference areas and similar to hatching success, were not different than values reported as normal in the literature. Mayfield survival estimates noted that reproductive survival rates were greatest in the TR SAs, which consistently had the greatest exposure. Moreover, hatching success, which was generally lesser in the exposed areas could not be directly linked to contaminant exposure as a key criteria for establishing stressor causation is the identification of a dose response. When measured egg contaminant burdens were compared to hatching success by the eight individual study sites the response did not appear to be dose related.

Animal Use

All aspects of the study that involved the use of animals were conducted in the most humane way possible. To achieve that objective, all aspects of the study design were performed following standard operating procedures (Protocol for Monitoring and

Collection of Box-Nesting Passerine Birds 03/04-045-00; Field studies in support of Tittabawassee River Ecological Risk Assessment 03/04-042-00) approved by Michigan State University's Institutional Animal Care and Use Committee (IACUC). All of the necessary state and federal approvals and permits (Michigan Department of Natural Resources Scientific Collection Permit SC1252, US Fish and Wildlife Migratory Bird Scientific Collection Permit MB102552-1, and sub-permitted under US Department of the Interior Federal Banding Permit 22926) are on file at MSU-WTL.

Table 1. Toxicity reference values (TRVs) for total $TEQs_{WHO\text{-}Avian}$ concentrations selected for comparison to American robins exposed to PCDD/DFs in the river systems downstream of Midland, Michigan, USA during 2005–2008.

Exposure type	NOAEC	LOAEC	Reference
Dietary exposure-based[a]	14	140	Nosek et al. 1992
Egg exposure-based[b]	1,000	10,000	Thiel et al. 1998

[a] ng/kg/d wet weight
[b] ng/kg wet weight

Table 2. Potential average $TEQ_{WHO-Avian}$[a] daily dose (ADD_{pot}; ng/kg body weight/d) calculated from site-specific food web-based dietary[b] exposure for adult American robins breeding during 2003-2006 within the river floodplains near Midland, Michigan, USA.

	R-1 and R-2[c]	T-3 to T-6	S-7 and S-9
50th Centile	1.9[d,e]	270	89
95th Centile	5.1	590	200
Maximum	6.3	880	290

[a] $TEQ_{WHO-Avian}$ were calculated based on the 1998 avian WHO TEF values

[b] Literature based dietary composition (Howell 1942; Wheelwright 1986)

[c] R-1 to R-2 = Tittabawassee and Chippewa rivers reference area; T-3 to T-6 = Tittabawassee River study area; S-7 to S-9 = Saginaw River study area

[d] Values were rounded and represent only two significant figures

[e] Food ingestion rate was calculated from equations in The Wildlife Exposure Factors Handbook (US EPA 1993)

Table 3. Nest outcomes for American robins breeding in the floodplains near Midland, MI during 2005-2008.

	All nesting attempts					
	R-1 and R-2		T-3 to T-6		S-7 and S-9[a]	
	n	Total (%)[b]	*n*	Total (%)	*n*	Total (%)
2005						
Hatched[c]	8	5 (63%)	12	9 (75%)	-	-
Fledged[d]	9	5 (56%)	12	7 (58%)	-	-
Predated	9	4 (44%)	12	3 (25%)	-	-
Abandoned	9	0 (0%)	12	1 (8%)	-	-
Other	9	0 (0%)	12	1 (8%)[f]	-	-
Unknown	9	0 (0%)	12	0 (0%)	-	-
Failed[e]	9	0 (0%)	12	0 (0%)	-	-
2006						
Hatched	2	2 (100%)	12	7 (58%)	10	8 (80%)
Fledged	1	0 (0%)	17	5 (29%)	10	4 (40%)
Predated	1	1 (100%)	16	10 (59%)	10	6 (60%)
Abandoned	1	0 (0%)	16	1 (6%)	10	0 (0%)
Other	1	0 (0%)	16	0 (0%)	10	0 (0%)
Unknown	1	0 (0%)	16	0 (0%)	10	0 (0%)
Failed	1	0 (0%)	16	0 (0%)	10	0 (0%)
2007						
Hatched	32	14 (44%)	43	27 (63%)	9	4 (44%)
Fledged	31	11 (35%)	43	19 (44%)	9	3 (33%)
Predated	31	18 (58%)	43	24 (56%)	9	6 (66%)
Abandoned	31	2 (6%)	43	0 (0%)	9	0 (0%)
Other	31	0 (0%)	43	0 (0%)	9	0 (0%)
Unknown	31	0 (0%)	43	0 (0%)	9	0 (0%)
Failed	31	0 (0%)	43	0 (0%)	9	0 (0%)

Table 3. con't

2008						
Hatched	22	14 (64%)	51	34 (67%)	11	7 (64%)
Fledged	22	10 (45%)	50	30 (60%)	11	4 (36%)
Predated	22	11 (50%)	50	19 (38%)	11	7 (64%)
Abandoned	22	0 (0%)	50	0 (0%)	11	0 (0%)
Other	22	1 (5%) [g]	50	1 (2%) [f]	11	0 (0%)
Unknown	22	0 (0%)	50	0 (0%)	11	0 (0%)
Failed	22	0 (0%)	50	0 (0%)	11	0 (0%)
Overall						
Hatched	64	35 (54%)	118	77 (65%)	30	19 (62%)
Fledged	63	26 (42%)	122	61 (50%)	30	11 (37%)
Predated	63	34 (53%)	121	56 (46%)	30	19 (63%)
Abandoned	64	2 (3%)	121	2 (2%)	30	0 (0%)
Other	64	1 (2%) [g]	121	2 (3%) [f]	30	0 (0%)
Unknown	64	0 (0%)	121	0 (0%)	30	0 (0%)
Failed	64	0 (0%)	121	0 (0%)	30	0 (0%)

[a] S-7 and S-9 were monitored 2006-2008

[b] Percent of *n*

[c] At least one egg in clutch hatched

[d] At least one nestling from brood fledged

[e] Each egg failed to hatch

[f] Weather related failure

[g] Human disturbance related failure

Table 4. Productivity measurements for American robins breeding in the floodplains near Midland, MI during 2005-2008.

	All nesting attempts					
	R-1 and R-2		T-3 to T-6		S-7 and S-9[a]	
	n	Mean (SE)[b]	*n*	Mean (SE)	*n*	Mean (SE)
Clutch Size	30	3.2 (0.3)	42	3.2 (0.3)	12	3.5 (0.5)
Range-low Hatching Success	24	87%^{A} (5.9%)	42	74%^{AB} (4.5%)	10	65%^{B} (8.1%)
Range-high Hatching Success[c]	24	96%^{A} (5.2%)	42	82%^{B} (3.9%)	10	75%^{B} (7.5%)
Range-low Fledging Success	24	74% (7.8%)	59	76% (5.3%)	10	80% (9.6%)
Range-high Fledging Success[d]	24	93% (2.8%)	59	98% (1.8%)	10	100% (4.0%)
Range-low Productivity[e]	18	72% (9.8%)	33	59% (7.2%)	6	49% (13%)
Range-high Productivity[f]	18	84% (5.4%)	33	72% (4.0%)	6	62% (9.3%)

[a] S-7 and S-9 were monitored during 2006-2008

[b] Means with different uppercase letters were significantly different ($P<0.05$)

[c] Range-high hatching success includes any eggs removed for contaminant analyses as successfully hatched eggs

[d] Range-high fledging success includes nestlings collected for contaminant analyses if remainder of clutch was successful

[e] Productivity is defined as the number of nestlings fledged per eggs laid

[f] Range-high productivity considers eggs removed for contaminant analyses as fledglings

Table 5. Concentrations of seventeen 2,3,7,8-substituted furan and dioxin congeners in eggs of American robins collected during 2005-2008 within the Chippewa, Tittabawassee and Saginaw river floodplains, Midland, MI, USA. Values[a] (ng/kg wet weight) are given as the arithmetic mean[b] ± 1 SD over the range.

Contaminant[c]	R-1 and R-2 *n*=21	T-3 to T-6 *n*=49	S-7 and S-9 *n*=14
2378-TCDF	0.27±0.13 0.11-0.53 ND=18	11±15 0.27-72 ND=3	2±1.4 0.3-4.4 ND=1
23478-PeCDF	1.5±0.56 0.4-2.6	240±280 16-1600	87±70 2.7-190
12378-PeCDF	0.21±0.073 0.085-0.36 ND=16	7.6±9.9 0.12-50 ND=4	1.3±1 0.2-3.2 ND=4
234678-HxCDF	0.53±0.3 0.18-1.4 ND=4	7.4±7.1 0.66-37 ND=2	3±2.1 0.65-6.1 ND=0
123789-HxCDF	0.36±0.11 0.14-0.59	1.2±1 0.21-7.4	0.84±0.35 0.4-1.6
123678-HxCDF	0.92±0.51 0.31-2.2	31±32 1.1-160	12±9.4 1.2-26
123478-HxCDF	1.2±0.58 0.36-2.5	97±0.99 4.4-490	47±38 1.5-100
1234789-HpCDF	0.58±0.30 0.14-1.5 ND=19	2.5±1.5 0.52-6.6 ND=9	1.2±0.69 0.36-2.6 ND=6
1234678-HpCDF	2.7±2.1 0.6-8.1	50±34 3.7-130	38±27 4.3-78

Table 5. con't

12346789-OCDF	1.3±1.2 0.26-4.4 ND=7	21±23 1.2-130 ND=4	11±10 1.3-31 ND=0
2378-TCDD	2.8±1.5 0.73-6	3.9±1.9 1.1-8.5	2.4±1 0.91-4.3
12378-PeCDD	2.6±1.3 0.97-6.4	3.3±1.8 0.96-11	3.3±2 1.2-8.6
123789-HxCDD	0.74±0.36 0.31-1.8 ND=5	1.1±0.48 0.4-2.5 ND=12	0.81±0.24 0.27-1.2 ND=3
123678-HxCDD	5.1±3.9 1.7-20	13±7.7 3.8-32	12±5.4 3.4-21
123478-HxCDD	1.7±0.86 0.62-4.1	2.1±0.93 0.57-5.8 ND=2	2.6±1.4 0.65-6.1
1234678-HpCDD	8.5±11 1.8-52	28±21 5.7-130	18±8.3 4.8-35
12346789-OCDD	13±13 2.6-66	81±74 11-400	41±25 9-91

[a] Values have been rounded and represent only two significant figures

[b] Concentrations below limit of detection assigned a concentration of 1/2 the detection limit in the calculation of arithmetic means; total number below detection limit indicated below range

[c] TCDF = tetrachlorodibenzofuran; PeCDF = pentachlorodibenzofuran; HxCDF= hexachlorodibenzofuran; HpCDF = heptachlorodibenzofuran; OCDF = octachlorodibenzofuran; TCDD = tetrachlorodibenzo-*p*-dioxin; PeCDD = pentachlorodibenzo-*p*-dioxin; HxCDD = hexachlorodibenzo-*p*-dioxin; HpCDD = heptachlorodibenzo-*p*-dioxin; OCDD = octachlorodibenzo-*p*-dioxin

Table 6. Concentrations of selected co-contaminants in eggs of American robins collected during 2005-2008 within the Chippewa, Tittabawassee and Saginaw river floodplains, Midland, MI, USA. Values[a] (ng/kg wet weight) are given as the arithmetic mean[b] ± 1 SD over the range.

Contaminant	R-1 and R-2 *n*=5	T-3 to T-6 *n*=28	S-7 and S-9 *n*=12
PCB 77	1.9±1 0.75-3.2 ND=4	4.8±6.1 1.1-33 ND=26	16±25 1.7-88 ND=9
PCB 81	2±1.1 0.81-3.5 ND=4	4.9±6.7 1.2-37 ND=27	12±14 1.9-40 ND=11
PCB 126	2.8±1.6 0.82-4.8 ND=5	5.3±4.4 1-24 ND=26	11±10 2.1-38 ND=8
PCB 169	4.5±2.2 1.1-6.8 ND=4	10±8.6 3.5-43 ND=13	11±5.1 4.6-23 ND=7
PCB 105	67±42 14-120	140±220 16-850	650±1300 35-4400
PCB 114	13±8.2 4.5-26	61±53 5.7-260 ND=1	110±140 14-400
PCB 118	410±240 160-760	1200±1800 110-8500	3500±5300 270-18000
PCB 123	7.4±5.3 3.3-17 ND=1	10±13 1.1-51 ND=17	74±150 2.3-500 ND=8

Table 6. con't

PCB 156	170±64 84-260	520±1100 99-5900	760±640 130-2000
PCB 157	54±21 26-83	140±270 30-1500	250±260 32-890
PCB 167	51±22 32-87	91±130 13-640 ND=2	210±270 23-940
PCB 189	30±16 13-54	110±83 35-400	260±240 49-920
2,4'-DDT [c]	0.11±0.085 0.029-0.24 ND=1	0.096±0.098 0.02-0.54 ND=13	0.027±0.01 0.012-0.048 ND=11
2',4'-DDE [d]	78±61 37-180	160±110 25-550	61±49 20-190
4,4'-DDT	12±22 0.47-52	12±12 0.034-43 ND=1	2.1±2.4 0.029-6.1 ND=1

[a] Values have been rounded and represent only two significant figures

[b] Concentrations below limit of detection assigned a concentration of 1/2 the detection limit in the calculation of arithmetic means; total number below detection limit indicated below range

[c] DDT = dichloro-diphenyl-trichloroethane

[d] DDE = dichloro-diphenyl-dichloroethylene

Table 7. Concentrations of seventeen 2,3,7,8-substituted furan and dioxin congeners in nestlings of American robins collected during 2005-2008 within the Chippewa, Tittabawassee and Saginaw river floodplains, Midland, MI, USA. Values[a] (ng/kg wet weight) are given as the arithmetic mean[b] ± 1 SD over the range.

Contaminant[c]	R-1 and R-2 *n*=12	T-3 to T-6 *n*=25	S-7 and S-9 *n*=8
2378-TCDF	1.5±4.8 0.046-17 ND=8	15±25 0.3-120	4.1±5.8 0.47-18
23478-PeCDF	0.87±0.47 0.27-1.8	160±150 4.1-630	54±53 3.8-140
12378-PeCDF	0.16±0.14 0.041-0.55 ND=10	11±18 0.089-94 ND=3	3±4 0.12-12
234678-HxCDF	0.35±0.23 0.1-0.75 ND=4	5.6±4.9 0.28-20	2.1±1.7 0.97-5.6
123789-HxCDF	0.25±0.20 0.054-0.57 ND=11	0.52±0.54 0.16-2.4 ND=20	0.29±0.18 0.13-0.6 ND=7
123678-HxCDF	0.43±0.25 0.13-0.83	16±14 0.54-51	6.1±6.2 1.3-19
123478-HxCDF	0.71±0.44 0.18-1.6	76±65 1.3-250	28±31 2.3-90
1234789-HpCDF	0.32±0.19 0.11-0.64 ND=10	2.8±2.1 0.19-8.6 ND=4	1.1±1.4 0.31-3.8 ND=2

Table 7. con't

1234678-HpCDF	1.5±0.98 0.4-3.7	41±31 1.6-110	22±24 7.5-78
12346789-OCDF	1±0.67 0.24-2.1	24±20 0.6-79	11±15 2.6-45
2378-TCDD	1.5±1 0.27-3.6	2.7±1.4 0.82-6.3	1.2±0.66 0.56-2.4
12378-PeCDD	1.2±0.77 0.37-3.1	2.6±1.2 0.83-6	2.2±2.5 0.79-8.2
123789-HxCDD	0.39±0.21 0.13-0.81 ND=4	0.86±0.47 0.22-1.9 ND=2	0.59±0.32 0.25-1.2 ND=2
123678-HxCDD	1.9±1.6 0.5-6	6.9±4.2 1.5-19	6.4±7.4 1.5-20
123478-HxCDD	0.72±0.49 0.24-1.9 ND=1	1.7±0.84 0.58-4.1	1.6±2.1 0.45-6.7
1234678-HpCDD	4.5±3.8 1.1-12	25±18 3.5-69	15±15 3.5-41
12346789-OCDD	9.8±7.0 3-23	76±58 7.4-210	36±35 8.1-100

[a] Values have been rounded and represent only two significant figures
[b] Concentrations below limit of detection assigned a concentration of 1/2 the detection limit in the calculation of arithmetic means; total number below detection limit indicated below range
[c] TCDF = tetrachlorodibenzofuran; PeCDF = pentachlorodibenzofuran; HxCDF= hexachlorodibenzofuran; HpCDF = heptachlorodibenzofuran; OCDF = octachlorodibenzofuran; TCDD = tetrachlorodibenzo-*p*-dioxin; PeCDD = pentachlorodibenzo-*p*-dioxin; HxCDD = hexachlorodibenzo-*p*-dioxin; HpCDD = heptachlorodibenzo-*p*-dioxin; OCDD = octachlorodibenzo-*p*-dioxin

Table 8. Concentrations of selected co-contaminants in American robin nestlings collected during 2005-2008 within the Chippewa, Tittabawassee and Saginaw river floodplains, Midland, MI, USA. Values[a] (ng/kg wet weight) are given as the arithmetic mean[b] ± 1 SD over the range.

Contaminant	R-1 and R-2 *n*=1	T-3 to T-6 *n*=5	S-7 and S-9 *n*=5
PCB 77	0.46	1.7±1.4	5.1±5.9
	-	0.8-4.2	0.56-12
PCB 81	0.35	2.5±2.5	7.2±9.8
	-	0.48-6.5	0.61-23
PCB 126	0.59	1.5±0.58	4.5±4.7
	-	0.8-2.4	0.82-11
		ND=1	ND=1
PCB 169	1.1	3.8±1.9	3.9±3.2
	-	1.8-6.3	1-9.2
PCB 105	17	51±19	470±660
	-	20-66	15-1500
PCB 114	4.2	86±110	91±140
	-	15-280	12-340
PCB 118	126	660±680	2800±4200
	-	124-1850	117-9800
PCB 123	3.7	17±11	90±110
	-	5.2-32	5.6-220
PCB 156	50	270±330	530±700
	-	41-850	60-1700
PCB 157	13	55±54	150±190
	-	11-150	15-400
PCB 167	16	36±35	150±190
	-	6-97	9-430

Table 8. con't

PCB 189	10	69±55	130±150
	-	18-140	16-380
2,4'-DDT [c]	0.008	0.021±0.015	0.012±0.0013
	-	0.0095-0.047	0.011-0.014
2',4'-DDE [d]	9.2	90±50	20±16
	-	36-170	7.3-48
4,4'-DDT	0.37	4.7±2.1	0.5±0.48
	-	1.2-6.9	0.19-1.3

[a] Values have been rounded and represent only two significant figures

[b] Concentrations below limit of detection assigned a concentration of 1/2 the detection limit in the calculation of arithmetic means; total number below detection limit indicated below range

[c] DDT = dichloro-diphenyl-trichloroethane

[d] DDE = dichloro-diphenyl-dichloroethylene

Table 9. Concentrations of seventeen 2,3,7,8-substituted furan and dioxin congeners in American robin adults collected during 2005-2008 within the Chippewa, Tittabawassee and Saginaw river floodplains, Midland, MI, USA. Values[a] (ng/kg wet weight) are given as the arithmetic mean[b] ± 1 SD over the range.

Contaminant[c]	R-1 and R-2 *n*=6	T-3 to T-6 *n*=6
2378-TCDF	0.069±0.034 0.034-0.13 ND=2	8.8±6.6 1.6-19
23478-PeCDF	0.72±0.21 0.43-0.93	140±85 22-240
12378-PeCDF	0.11±0.065 0.025-0.2 ND=6	5.7±3.8 1.4-10
234678-HxCDF	0.18±0.088 0.099-0.32 ND=3	2.5±1.2 0.67-4
123789-HxCDF	0.22±0.14 0.1-0.49 ND=6	0.37±0.18 0.19-0.61 ND=6
123678-HxCDF	0.25±0.11 0.16-0.45 ND=1	9±4.5 1.9-14
123478-HxCDF	0.36±0.2 0.17-0.74 ND=1	55±31 8.1-81
1234789-HpCDF	0.32±0.16 0.14-0.54 ND=6	1.2±0.65 0.26-1.8

Table 9. con't

1234678-HpCDF	0.47±0.29 0.29-0.18 ND=2	18±12 3.8-35
12346789-OCDF	0.27±0.15 0.081-0.46 ND=5	12±16 0.86-44
2378-TCDD	1±0.72 0.35-2	1.3±0.52 0.64-1.8
12378-PeCDD	1.1±1 0.56-3.2	1.5±0.73 0.55-2.5
123789-HxCDD	0.41±0.38 0.11-1.1 ND=3	0.42±0.18 0.21-0.65 ND=2
123678-HxCDD	1.9±2 0.75-5.9	3.5±2.5 1.3-8.2
123478-HxCDD	0.87±0.95 0.28-2.8 ND=1	0.94±0.76 0.23-2.4
1234678-HpCDD	1.9±1.9 0.49-5.8	9.9±7.1 1.7-21
12346789-OCDD	3.7±2.8 1-7.8	53±71 4.6-190

[a] Values have been rounded and represent only two significant figures
[b] Concentrations below limit of detection assigned a concentration of 1/2 the detection limit in the calculation of arithmetic means; total number below detection limit indicated below range

Table 9. con't

[c] TCDF = tetrachlorodibenzofuran; PeCDF = pentachlorodibenzofuran; HxCDF= hexachlorodibenzofuran; HpCDF = heptachlorodibenzofuran; OCDF = octachlorodibenzofuran; TCDD = tetrachlorodibenzo-*p*-dioxin; PeCDD = pentachlorodibenzo-*p*-dioxin; HxCDD = hexachlorodibenzo-*p*-dioxin; HpCDD = heptachlorodibenzo-*p*-dioxin; OCDD = octachlorodibenzo-*p*-dioxin

Table 10. Concentrations of seventeen 2,3,7,8-substituted furan and dioxin congeners in Oligochaeta collected during 2005-2008 within the Chippewa, Tittabawassee and Saginaw river floodplains, Midland, MI, USA. Values[a] (ng/kg wet weight) are given as the arithmetic mean[b] ± 1 SD over the range.

Contaminant[c]	R-1 and R-2 *n*=6	T-3 to T-6 *n*=12	S-7 and S-9 *n*=4
2378-TCDF	0.39±0.41 0.078-1.1 ND=3	170±94 53-390	130±160 6.7-360
23478-PeCDF	0.23±0.19 0.037-0.54 ND=2	42±27 12-100	40±48 2.5-110
12378-PeCDF	0.096±0.066 0.034-0.18 ND=5	60±39 16-150	49±59 2.9-130
234678-HxCDF	0.12±0.068 0.041-0.22 ND=4	3±1.9 0.9-7.8 ND=1	1.5±1.7 0.22-4 ND=2
123789-HxCDF	0.091±0.05 0.05-0.16 ND=6	0.75±0.55 0.19-2 ND=5	0.82±0.64 0.27-1.5 ND=4
123678-HxCDF	0.19±0.13 0.039-0.39 ND=2	9.7±7 2.9-28	5.3±5 1-12
123478-HxCDF	0.31±0.18 0.096-0.53 ND=1	42±32 13-120	31±31 4.5-72
1234789-HpCDF	0.19±0.12 0.08-0.41 ND=5	3.5±2.8 1-11 ND=1	2.1±1.1 1.2-3.5

Table 10. con't

1234678-HpCDF	1.7±1.2 0.46-3.6	76±60 21-200	76±26 41-100
12346789-OCDF	2.5±1.6 0.41-4.5	140±110 34-380	82±36 42-110
2378-TCDD	0.32±0.41 0.021-1.1 ND=2	6.9±18 0.34-63	1.2±1.5 0.2-3.5
12378-PeCDD	0.21±0.17 0.039-0.51 ND=2	1.2±1.1 0.25-4 ND=1	1.4±1.3 0.79-8.2
123789-HxCDD	0.22±0.14 0.073-0.46 ND=2	1±0.74 0.29-2.7 ND=4	0.58±0.42 0.2-1.2 ND=3
123678-HxCDD	0.3±0.23 0.075-0.72 ND=2	3.6±3 0.7-9.8 ND=1	2.9±2.2 0.78-5.6
123478-HxCDD	0.11±0.067 0.041-0.21 ND=5	0.72±0.72 0.16-2.8 ND=8	0.51±0.43 0.21-1.1 ND=4
1234678-HpCDD	3.6±2.4 1.1-7.5	43±26 10-96	24±16 11-45
12346789-OCDD	30±19 8.5-59	430±290 110-1100	250±160 111-420

[a] Values have been rounded and represent only two significant figures

[b] Concentrations below limit of detection assigned a concentration of 1/2 the detection limit in the calculation of arithmetic means; total number below detection limit indicated below range

Table 10. con't

[c] TCDF = tetrachlorodibenzofuran; PeCDF = pentachlorodibenzofuran; HxCDF= hexachlorodibenzofuran; HpCDF = heptachlorodibenzofuran; OCDF = octachlorodibenzofuran; TCDD = tetrachlorodibenzo-*p*-dioxin; PeCDD = pentachlorodibenzo-*p*-dioxin; HxCDD = hexachlorodibenzo-*p*-dioxin; HpCDD = heptachlorodibenzo-*p*-dioxin; OCDD = octachlorodibenzo-*p*-dioxin

Table 11. Concentrations of seventeen 2,3,7,8-substituted furan and dioxin congeners in Coleoptera collected during 2005-2008 within the Chippewa, Tittabawassee and Saginaw river floodplains, Midland, MI, USA. Values[a] (ng/kg wet weight) are given as the arithmetic mean[b] ± 1 SD over the range.

Contaminant[c]	R-1 and R-2 *n*=9	T-3 to T-6 *n*=12	S-7 and S-9 *n*=9
2378-TCDF	2.2±2.8 0.35-8.8 ND=2	470±410 100-1600	68±66 18-210
23478-PeCDF	0.9±0.97 0.23-3.1 ND=1	120±100 11-350	15±14 3.5-45
12378-PeCDF	0.59±0.81 0.079-2.6 ND=4	120±91 9.8-370	18±19 2.2-62
234678-HxCDF	0.5±0.4 0.19-1.3 ND=3	6.3±4.4 0.88-16	1.5±1.2 0.55-4.2 ND=1
123789-HxCDF	0.22±0.09 0.11-0.39 ND=9	0.91±0.97 0.14-4.1 ND=10	0.44±0.29 0.083-0.98 ND=9
123678-HxCDF	0.66±0.64 0.21-2 ND=3	14±11 2.6-41	2.9±2.3 0.61-7.1 ND=1
123478-HxCDF	1.2±1.6 0.21-4.9 ND=6	58±45 7.6-160	10±8.2 2.1-27
1234789-HpCDF	0.38±0.27 0.15-0.91 ND=8	3.3±2.5 0.89-11 ND=2	1.5±3.2 0.11-10 ND=7

Table 11. con't

1234678-HpCDF	6.4±8 0.41-25	79±48 14-160	56±110 6.2-340
12346789-OCDF	6.2±11 0.39-36	69±72 12-320	47±89 2-260
2378-TCDD	1.1±0.7 0.23-2.1	3.5±1.6 1.4-6.4	1.1±0.55 0.33-2.1
12378-PeCDD	0.9±0.51 0.22-1.7 ND=2	2.9±1.3 1.2-6.4	1.2±0.57 0.33-2.1
123789-HxCDD	1±0.7 0.23-2.2 ND=2	3.9±3.9 0.92-17	1.5±1.7 0.23-5.8 ND=1
123678-HxCDD	2.3±1.8 0.29-5.9 ND=1	9±6.3 2.1-29	12±26 0.98-82
123478-HxCDD	0.69±0.36 0.24-1.1 ND=2	2.2±1.2 0.89-4.9	0.69±0.38 0.24-1.3 ND=4
1234678-HpCDD	21±24 1.4-83	93±61 21-230	120±270 12-830
12346789-OCDD	130±170 5.5-560	710±520 86-2000	360±560 69-1800

[a] Values have been rounded and represent only two significant figures

[b] Concentrations below limit of detection assigned a concentration of 1/2 the detection limit in the calculation of arithmetic means; total number below detection limit indicated below range

Table11. con't

[c] TCDF = tetrachlorodibenzofuran; PeCDF = pentachlorodibenzofuran; HxCDF= hexachlorodibenzofuran; HpCDF = heptachlorodibenzofuran; OCDF = octachlorodibenzofuran; TCDD = tetrachlorodibenzo-*p*-dioxin; PeCDD = pentachlorodibenzo-*p*-dioxin; HxCDD = hexachlorodibenzo-*p*-dioxin; HpCDD = heptachlorodibenzo-*p*-dioxin; OCDD = octachlorodibenzo-*p*-dioxin

Table 12. Concentrations of seventeen 2,3,7,8-substituted furan and dioxin congeners in Lepidoptera collected during 2005-2008 within the Chippewa, Tittabawassee and Saginaw river floodplains, Midland, MI, USA. Values[a] (ng/kg wet weight) are given as the arithmetic mean[b] ± 1 SD over the range.

Contaminant[c]	R-1 and R-2 *n*=7	T-3 to T-6 *n*=6	S-7 and S-9 *n*=8
2378-TCDF	0.37±0.25 0.1-0.7 ND=4	42±30 6.7-73	9.7±8.5 2-27
23478-PeCDF	0.18±0.081 0.057-0.29 ND=3	11±8.5 1.4-21	2.6±2.4 0.53-7.1
12378-PeCDF	0.14±0.066 0.059-0.24 ND=3	13±9.3 2.1-23	3±2.7 0.63-7
234678-HxCDF	0.097±0.049 0.063-0.17 ND=6	0.85±0.69 0.1-2 ND=2	0.93±1.7 0.079-5.1 ND=3
123789-HxCDF	0.1±0.033 0.077-0.17 ND=7	0.21±0.078 0.11-0.31 ND=6	0.27±0.12 0.01-0.45 ND=8
123678-HxCDF	0.11±0.057 0.061-0.21 ND=5	1.7±1.2 0.24-2.9 ND=1	1.4±2.4 0.21-7.2 ND=2
123478-HxCDF	0.23±0.13 0.067-0.4 ND=3	7.5±5.1 0.91-14	2.6±2.2 0.41-6.1
1234789-HpCDF	0.19±0.057 0.11-0.27 ND=7	0.41±0.22 0.2-0.73 ND=4	0.34±0.2 0.092-0.66 ND+6

Table 12. con't

1234678-HpCDF	0.7±0.3 0.37-1.3	5.8±4.3 1.4-11	4.5±3.3 0.89-10.5
12346789-OCDF	0.48±0.25 0.19-93 ND=4	4.8±5.9 1.1-16	4±4.8 0.17-15 ND=3
2378-TCDD	0.15±0.056 0.067-0.2 ND=4	0.41±0.14 0.25-0.62	0.26±0.16 0.075-0.45 ND=3
12378-PeCDD	0.19±0.057 0.1-0.26 ND=4	0.4±0.085 0.27-0.52 ND=1	0.6±0.88 0.14-2.8 ND=4
123789-HxCDD	0.24±0.096 0.14-0.37 ND=3	0.5±0.21 0.17-0.74 ND=1	1.8±4.3 0.11-12 ND=5
123678-HxCDD	0.28±0.12 0.16-0.44 ND=3	0.68±0.34 0.25-1.2 ND=1	2.4±5.2 0.25-15 ND=1
123478-HxCDD	0.17±0.044 0.099-0.22 ND=4	0.26±0.13 0.16-0.5 ND=4	0.72±1.4 0.12-4.3 ND=6
1234678-HpCDD	2.5±0.81 1.2-3.4	7.3±4 3.3-14	38±90 2.6-260
12346789-OCDD	11±4.9 5-17	44±28 19-86	160±370 8.2-1100

[a] Values have been rounded and represent only two significant figures

[b] Concentrations below limit of detection assigned a concentration of 1/2 the detection limit in the calculation of arithmetic means; total number below detection limit indicated below range

Table12. con't

[c] TCDF = tetrachlorodibenzofuran; PeCDF = pentachlorodibenzofuran; HxCDF= hexachlorodibenzofuran; HpCDF = heptachlorodibenzofuran; OCDF = octachlorodibenzofuran; TCDD = tetrachlorodibenzo-*p*-dioxin; PeCDD = pentachlorodibenzo-*p*-dioxin; HxCDD = hexachlorodibenzo-*p*-dioxin; HpCDD = heptachlorodibenzo-*p*-dioxin; OCDD = octachlorodibenzo-*p*-dioxin

Table 13. Concentrations of seventeen 2,3,7,8-substituted furan and dioxin congeners in terrestrial plants collected during 2005-2008 within the Chippewa, Tittabawassee and Saginaw river floodplains, Midland, MI, USA. Values[a] (ng/kg wet weight) are given as the arithmetic mean[b] ± 1 SD over the range.

Contaminant[c]	R-1 and R-2 *n*=9	T-3 to T-6 *n*=18	S-7 and S-9 *n*=12
2378-TCDF	1.1±0.98 0.44-2.8 ND=6	35±30 1.5-91 ND=1	3±2.4 0.86-9.3
23478-PeCDF	0.84±0.6 0.31-2.2 ND=6	9.9±8.3 0.64-25 ND=2	0.9±0.9 0.15-2.9 ND=5
12378-PeCDF	0.82±0.85 0.27-2.9 ND=7	12±10 0.63-27 ND=2	0.93±1 0.14-3.5 ND=5
234678-HxCDF	0.74±0.51 0.3-1.9 ND=9	1.4±0.9 0.3-4 ND=9	0.3±0.18 0.11-0.66 ND=12
123789-HxCDF	1±0.64 0.35-2.5 ND=8	1±0.65 0.41-3.3 ND=18	0.41±0.24 0.15-0.9 ND=12
123678-HxCDF	0.86±0.54 0.28-1.9 ND=7	2.5±2.1 0.27-7.2 ND=7	0.36±0.2 0.11-0.72 ND=10
123478-HxCDF	0.95±0.66 0.31-2.2 ND=7	10±8.6 0.81-27 ND=1	0.61±0.55 0.11-1.9 ND=7

Table 13. con't

1234789-HpCDF	0.9±0.34 0.49-1.5 ND=9	2±1.2 0.46-5.3 ND=11	0.67±0.5 0.091-1.5 ND=12
1234678-HpCDF	1.6±1.1 0.46-4 ND=4	24±23 1.8-85 ND=1	1±1.1 0.072-3.4 ND=9
12346789-OCDF	3.7±3.1 0.65-10 ND=4	45±47 2.3-190 ND=1	1.3±1.1 0.15-3.3 ND=10
2378-TCDD	0.98±0.73 0.35-2.6 ND=8	0.94±0.53 0.26-2.2 ND=14	0.27±0.16 0.093-0.57 ND=12
12378-PeCDD	0.88±0.34 0.49-1.4 ND=6	0.97±0.41 0.38-1.8 ND=15	0.39±0.26 0.14-1.1 ND=11
123789-HxCDD	0.9±0.42 0.32-1.5 ND=6	1.3±0.76 0.31-3.4 ND=14	0.42±0.19 0.17-0.69 ND=12
123678-HxCDD	0.75±0.43 0.3-1.7 ND=9	1.8±1.2 0.35-5 ND=12	0.48±0.22 0.19-0.81 ND=12
123478-HxCDD	0.74±0.41 0.37-1.6 ND=9	1.1±0.68 0.33-3.1 ND=18	0.42±0.19 0.17-0.7 ND=12
1234678-HpCDD	4.6±1.7 1.9-7	22±18 2.1-71	1.1±0.67 0.3-2.4 ND=5
12346789-OCDD	33±26 12-92	190±150 18-600	5±4.6 0.75-13 ND=4

Table 13. con't

[a] Values have been rounded and represent only two significant figures

[b] Concentrations below limit of detection assigned a concentration of 1/2 the detection limit in the calculation of arithmetic means; total number below detection limit indicated below range

[c] TCDF = tetrachlorodibenzofuran; PeCDF = pentachlorodibenzofuran; HxCDF= hexachlorodibenzofuran; HpCDF = heptachlorodibenzofuran; OCDF = octachlorodibenzofuran; TCDD = tetrachlorodibenzo-*p*-dioxin; PeCDD = pentachlorodibenzo-*p*-dioxin; HxCDD = hexachlorodibenzo-*p*-dioxin; HpCDD = heptachlorodibenzo-*p*-dioxin; OCDD = octachlorodibenzo-*p*-dioxin

Table 14. Concentrations of seventeen 2,3,7,8-substituted furan and dioxin congeners in other dietary components collected during 2005-2008 within the Chippewa, Tittabawassee and Saginaw river floodplains, Midland, MI, USA. Values[a] (ng/kg wet weight) are given as the arithmetic mean[b] ± 1 SD over the range.

Contaminant[c]	R-1 and R-2 *n*=13	T-3 to T-6 *n*=15	S-7 and S-9 *n*=8
2378-TCDF	0.5±0.27 0.054-0.46 ND=2	50±79 3.5-290	7.7±11 0.043-0.63
23478-PeCDF	0.22±0.12 0.054-0.46 ND=1	13±20 1-75	1.9±2.4 0.16-6.8
12378-PeCDF	0.13±0.066 0.048-0.26 ND=4	14±22 1.2-79 ND=1	2.1±2.9 0.16-8.1
234678-HxCDF	0.16±0.12 0.062-0.42 ND=8	1.3±1.5 0.21-5.4 ND=2	0.24±0.22 0.063-0.67 ND=6
123789-HxCDF	0.12±0.036 0.058-0.2 ND=13	0.25±0.14 0.046-0.54 ND=13	0.18±0.11 0.082-0.42 ND=8
123678-HxCDF	0.18±0.15 0.06-0.55 ND=7	2.2±2.8 0.31-10 ND=1	0.43±0.47 0.065-1.1 ND=5
123478-HxCDF	0.28±0.34 0.063-1.3 ND=5	8.8±10 0.76-35	1.3±1.5 0.062-3.6 ND=1
1234789-HpCDF	0.19±0.12 0.069-0.5 ND=13	0.71±0.76 0.14-3 ND=8	0.3±0.3 0.088-0.94 ND=7

Table 14. con't

1234678-HpCDF	1.2±2 0.1-7.5 ND=3	15±18 2.1-59	6.1±11 0.26-33
12346789-OCDF	0.73±0.98 0.14-3.8 ND=4	15±13 2.5-45	130±320 1.4-930 ND=1
2378-TCDD	0.29±0.37 0.048-1.4 ND=7	0.63±0.75 0.086-2.4 ND=5	0.19±0.19 0.043-0.63 ND=5
12378-PeCDD	0.34±0.32 0.092-1.3 ND=5	0.63±0.63 0.1-1.9 ND=6	0.37±0.38 0.11-1.2 ND=6
123789-HxCDD	0.37±0.46 0.077-1.4 ND=7	0.78±0.77 0.11-2.8 ND=4	0.38±0.55 0.061-1.7 ND=7
123678-HxCDD	0.67±0.99 0.08-3.7 ND=5	1.6±1.7 0.29-4.9 ND=2	1±2.1 0.071-6.1 ND=6
123478-HxCDD	0.36±0.51 0.079-1.9 ND=7	0.54±0.46 0.049-1.5 ND=7	0.3±0.34 0.062-1 ND=7
1234678-HpCDD	7.6±14 0.97-52	19±19 2.8-58	13±32 0.21-93
12346789-OCDD	48±78 3.8-280	160±160 17-550	8.9±19 0.12-56

[a] Values have been rounded and represent only two significant figures

[b] Concentrations below limit of detection assigned a concentration of 1/2 the detection limit in the calculation of arithmetic means; total number below detection limit indicated below range

Table 14. con't

[c] TCDF = tetrachlorodibenzofuran; PeCDF = pentachlorodibenzofuran; HxCDF= hexachlorodibenzofuran; HpCDF = heptachlorodibenzofuran; OCDF = octachlorodibenzofuran; TCDD = tetrachlorodibenzo-*p*-dioxin; PeCDD = pentachlorodibenzo-*p*-dioxin; HxCDD = hexachlorodibenzo-*p*-dioxin; HpCDD = heptachlorodibenzo-*p*-dioxin; OCDD = octachlorodibenzo-*p*-dioxin

Table 15. Concentrations of seventeen 2,3,7,8-substituted furan and dioxin congeners in soils collected during 2003-2006 within the Chippewa, Tittabawassee and Saginaw river floodplains, Midland, MI, USA. Values[a] (ng/kg wet weight) are given as the arithmetic mean[b] ± 1 SD over the range.

Contaminant[c]	R-1 and R-2 *n*=11	T-3 to T-6 *n*=23	S-7 and S-9 *n*=8
2378-TCDF	3.7±2.8 1.1-9	3800±3100 260-13000	1900±2300 3.6-6700
23478-PeCDF	1.8±1.6 0.57-5.5	1500±1200 110-4600	600±620 0.98-1900
12378-PeCDF	1.4±1.1 0.4-3.6 ND=4	2000±1600 130-6000	750±760 1-2300
234678-HxCDF	1.1±0.71 0.47-2.1 ND=2	140±98 13-360	63±38 0.31-130
123789-HxCDF	0.28±0.28 0.081-1 ND=11	27±21 1.6-72 ND=10	13±9.4 0.19-31 ND=1
123678-HxCDF	1.4±1 0.53-3.3 ND=2	320±230 30-840	160±110 0.38-350
123478-HxCDF	3.8±3 1.4-9.7	1600±1100 130-4200	710±500 1.3-1700
1234789-HpCDF	1.1±0.74 0.19-2.2 ND=3	210±130 29-560	120±61 0.27-210

Table 15. con't

1234678-HpCDF	14±11 4.5-35	3200±2200 450-8400	2800±1800 5.8-5500
12346789-OCDF	22±15 7.2-48	5100±3500 1200-13000	3500±1800 8.5-5900
2378-TCDD	2.4±3.3 0.13-9.1 ND=1	41±46 7.7-180	14±8.4 0.1-28 ND=1
12378-PeCDD	1.7±1.7 0.37-5.2	36±26 6.2-110	19±9 0.22-31
123789-HxCDD	2.2±1.7 0.75-6.2	53±40 13-200	28±12 0.79-40
123678-HxCDD	2.7±2.1 0.98-7.4	110±70 29-310	66±30 0.62-100
123478-HxCDD	0.93±0.73 0.19-2.2 ND=2	22±16 4.9-83	11±6 0.22-21 ND=1
1234678-HpCDD	35±23 13-77	2000±1100 700-4400	900±410 7.9-1400
12346789-OCDD	300±190 108-590	20000±12000 6000-47000	9600±4400 58-14000

[a] Values have been rounded and represent only two significant figures

[b] Concentrations below limit of detection assigned a concentration of 1/2 the detection limit in the calculation of arithmetic means; total number below detection limit indicated below range

Table 15. con't

[c] TCDF = tetrachlorodibenzofuran; PeCDF = pentachlorodibenzofuran; HxCDF= hexachlorodibenzofuran; HpCDF = heptachlorodibenzofuran; OCDF = octachlorodibenzofuran; TCDD = tetrachlorodibenzo-*p*-dioxin; PeCDD = pentachlorodibenzo-*p*-dioxin; HxCDD = hexachlorodibenzo-*p*-dioxin; HpCDD = heptachlorodibenzo-*p*-dioxin; OCDD = octachlorodibenzo-*p*-dioxin

Table 16. Raw productivity measurements for all nesting attempts for American robins in the river floodplains near Midland, Michigan during 2005.

ID	Clutch Date[a]	BSA	Period	Eggs	Eggs Sampled	Nestlings	Nestlings Sampled	Fledglings	Nest Fate[e]
1	May 24	R-1	2	2	1	1[b]	1	0	Succ
2	May 23	R-1	2	4	1	3[b]	1	2	Succ
3	May 26	R-1	2	3	1	2[b]	1	1	Succ
4	June 2	R-1	2	4	1	0	0	0	Dep
5	June 4	R-1	2	4	1	-	-	-	-
6	June 10	R-1	2	4	1	3[b]	1	2	Succ
7	May 18	R-2	2	-	1	2	1	1	Succ
8	June 9	R-2	2	3	1	-	-	0	Dep
9	-	R-2	2	3	1	0	0	0	Dep
10	-	R-2	2	2[c]	1	0	0	0	Dep
11	-	R-2	2	3	1	-	-	-	-
12	May 9	T-3	2	4	1	2[b]	1	1	Succ
13	May 21	T-3	2	4[c]	1	3[b]	1	2	Succ
14	May 23	T-3	2	3	1	2[b]	0	0	Dep
15	June 2	T-4	2	-	-	3	1	2	Succ
16[d]	-	T-4	2	0	0	0	0	0	Abnd
17	-	T-4	2	2	1	-	-	-	-

Table 16. con't

18	May 6	T-5	2	4	1	3[b]	1	2	Succ
19	May 11	T-5	2	3	1	2[b]	1	1	Succ
20	May 12	T-5	2	4	1	3[b]	0	0	Wthr
21	-	T-5	2	1	1	0	0	0	Dep
22	-	T-5	2	4	1	-	-	-	-
23	May 9	T-6	2	-	1	2	1	1	Succ
24	May 11	T-6	1	3	0	0	0	0	Dep
25	May 11	T-6	2	1	1	-	-	-	-
26	May 16	T-6	2	-	1	3	1	2	Succ
27	-	T-6	2	5	1	-	-	-	-
28	-	T-6	2	3	1	-	-	-	-

[a] Clutch initiation date estimated from available data where incubation and nestling periods approximately 13 days in duration each

[b] Uninterrupted hatch period confirmed

[c] Uninterrupted incubation period confirmed

[d] No eggs laid

[e] Succ = successful, Dep = depredated, Abnd = abandoned and Wthr= weather-related failure

Table 17. Raw productivity measurements for all nesting attempts for American robins in the river floodplains near Midland, Michigan during 2006.

ID	Clutch Date[a]	BSA	Period	Eggs	Eggs Sampled	Nestlings	Nestlings Sampled	Fledglings	Nest Fate[d]
29	May 17	R-1	2	-	-	4	0	0	Dep
30	May 18	R-2	2	4	1	3[b]	1	-	-
31	April 22	T-3	2	-	-	3	0	-	Succ
32	-	T-3	2	5	1	-	-	-	-
33	-	T-3	2	3	1	-	0	0	Dep
34	-	T-3	2	4	1	-	-	-	-
35	-	T-3	2	4	0	-	-	-	-
36	May 18	T-4	2	4	1	2	-	-	-
37	-	T-4	2	4	1	0	0	0	Dep
38	-	T-4	2	1	1	0	0	0	Abnd
39	-	T-4	2	3	1	0	0	0	Dep
40	June 2	T-5	2	-	-	4	1	3	Succ
41	-	T-5	2	3	1	0	0	0	Dep
42	-	T-5	2	2	0	-	-	-	-
43	May 17	T-6	2	4	1	3[b]	1	2	Succ
44	May 17	T-6	2	3[c]	0	1[b]	0	0	Dep
45	May 17	T-6	2	4[c]	0	1[b]	1	0	Succ
46	May 22	T-6	2	4[c]	0	0	0	0	Dep
47	June 3	T-6	2	-	-	4	1	3	Succ

Table 17. con't

48	-	T-6	2	-	0	-	0	0	Dep
49	-	T-6	2	4	0	-	-	0	Dep
50	-	T-6	2	3	0	-	-	0	Dep
51	-	T-6	2	-	0	-	-	0	Dep
52	May 7	S-7	2	4	1	3[b]	1	2	Succ
53	June 8	S-7	2	4	1	-	1	-	Succ
54	July 2	S-7	2	-	-	-	1	-	-
55	-	S-7	2	-	1	0	0	0	Dep
56	-	S-7	2	3	1	-	-	0	Dep
57	-	S-7	2	3	1	-	-	-	-
58	-	S-7	2	4	1	-	-	-	-
59	-	S-7	2	3	1	-	-	-	-
60	-	S-7	2	-	-	2	0	-	-
61	-	S-7	2	4	1	-	-	-	-
62	April 23	S-9	2	-	-	2	1	1	Succ
63	May 3	S-9	2	-	-	3	1	2	Succ
64	May 15	S-9	2	4	1	1	0	-	-
65	May 17	S-9	2	3	1	2[b]	0	0	Dep
66	May 27	S-9	2	-	-	3	0	0	Dep
67	-	S-9	2	3	1	-	-	-	-
68	-	S-9	2	1	0	0	0	0	Dep
69	-	S-9	2	2	1	-	-	-	Dep

[a] Clutch initiation date estimated from available data where incubation and nestling periods approximately 13 days in duration each

Table 17. con't

[b] Uninterrupted hatch period confirmed

[c] Uninterrupted incubation period confirmed

[d] Succ = successful, Dep = depredated and Abnd = abandoned

Table 18. Raw productivity measurements for all nesting attempts for American robins in the river floodplains near Midland, Michigan during 2007.

ID	Clutch Date[a]	BSA	Period	Eggs	Eggs Sampled	Nestlings	Nestlings Sampled	Fledglings	Nest Fate[d]
70	April 27	R-1	2	2[b]	0	0	0	0	Abnd
71	April 27	R-1	2	4[b]	0	4[c]	0	4	Succ
72	April 29	R-1	2	2[b]	0	2[c]	0	2	Succ
73	May 2	R-1	2	4[b]	0	4[c]	0	0	Dep
74	May 3	R-1	2	4[b]	0	4[c]	0	0	Dep
75	May 6	R-1	2	4[b]	0	4[c]	0	4	Succ
76	May 12	R-1	2	2[b]	0	2[c]	0	2	Succ
77	May 16	R-1	2	3[b]	0	0	0	0	Dep
78	May 29	R-1	2	-	0	3	0	3	Succ
79	May 29	R-1	2	-	-	2	0	2	Succ
80	June 19	R-1	2	4[b]	0	0	0	0	Dep
81	-	R-1	2	3	0	0	0	0	Dep
82	-	R-1	2	1	0	0	0	0	Dep
83	-	R-1	2	1	0	0	0	0	Dep
84	-	R-1	2	3[b]	0	0	0	0	Dep
85	-	R-1	2	2	0	0	0	0	Dep
86	-	R-1	2	2	0	0	0	0	Dep

Table 18. con't

87	-	R-1	2	3	0	0	0	0	Abnd
88	-	R-1	2	3	0	0	0	0	Dep
89	-	R-1	2	4 [b]	0	0	0	0	Dep
90	May 2	R-2	2	-	-	-	0	4	Succ
91	May 23	R-2	2	-	-	-	0	4	Succ
92	May 18	R-2	2	4 [b]	0	4 [c]	0	-	Succ
93	May 30	R-2	2	3 [b]	0	3 [c]	0	3	Succ
94	June 12	R-2	2	3 [b]	0	0	0	0	Dep
95	June 13	R-2	2	-	0	2	-	-	-
96	June 16	R-2	2	-	0	4	0	3	Succ
97	July 15	R-2	1	2 [b]	0	0	0	0	Dep
98	-	R-2	1	4 [b]	0	0	0	0	Dep
99	-	R-2	2	2	0	0	0	0	Dep
100	-	R-2	2	4 [b]	0	0	0	0	Dep
101	-	R-2	2	1	0	0	0	0	Dep
102	May 1	T-3	2	3	0	3 [c]	0	0	Dep
103	May 6	T-3	2	4 [b]	0	4 [c]	0	4	Succ
104	June 1	T-3	2	-	-	4	0	4	Succ
105	June 20	T-3	2	-	0	1	0	1	Succ
106	June 26	T-3	2	-	-	3	0	0	Dep
107	-	T-3	2	1	0	0	0	0	Dep
108	-	T-3	2	3 [b]	0	0	0	0	Dep

Table 18. con't

109	-	T-3	2	1 [b]	0	0	0	0	Dep
110	-	T-3	1	3	0	0	0	0	Dep
111	April 20	T-5	2	4 [b]	0	3 [c]	0	3	Succ
112	May 3	T-5	2	-	-	2	0	2	Succ
113	May 8	T-5	2	-	-	2	0	2	Succ
114	May 9	T-5	2	-	-	3	0	3	Succ
115	June 4	T-5	2	4	0	4 [c]	0	3	Succ
116	June 7	T-5	2	-	-	3	0	3	Succ
117	-	T-5	2	-	0	-	0	0	Dep
118	April 20	T-6	2	-	0	4	0	4	Succ
119	April 23	T-6	2	4 [b]	0	0	0	0	Dep
120	April 23	T-6	2	4 [b]	0	0	0	0	Dep
121	April 27	T-6	2	3 [b]	0	3 [c]	0	0	Dep
122	May 19	T-6	2	4	0	3 [c]	0	0	Dep
123	May 19	T-6	2	4 [b]	0	4 [c]	0	4	Succ
124	May 22	T-6	2	3 [b]	0	1	0	0	Dep
125	May 25	T-6	2	4	0	3 [c]	0	0	Dep
126	June 7	T-6	2	-	-	3	0	3	Succ
127	June 10	T-6	2	3	0	3 [c]	0	3	Succ
128	June 13	T-6	2	3 [b]	0	3 [c]	0	3	Succ
129	June 14	T-6	2	4 [b]	0	3 [c]	0	2	Succ
130	June 16	T-6	2	2 [b]	0	1 [c]	0	1	Succ

Table 18. con't

131	June 20	T-6	2	3 [b]	0	3 [c]	0	3	Succ
132	June 21	T-6	2	3 [b]	0	3	0	2	Succ
133	July 4	T-6	1	-	-	3	0	3	Succ
134	-	T-6	2	-	0	2	0	0	Dep
135	-	T-6	2	1	0	0	0	0	Dep
136	-	T-6	1	-	-	3	0	-	-
137	-	T-6	2	3 [b]	0	0	0	0	Dep
138	-	T-6	2	3	0	0	0	0	Dep
139	-	T-6	2	4 [b]	0	0	0	0	Dep
140	-	T-6	2	3 [b]	0	0	0	0	Dep
141	-	T-6	2	2 [b]	0	0	0	0	Dep
142	-	T-6	2	2 [b]	0	0	0	0	Dep
143	-	T-6	2	4	0	0	0	0	Dep
144	-	T-6	2	3	0	0	0	0	Dep
145	-	T-6	2	4 [b]	0	0	0	0	Dep
146	May 5	S-7	2	4 [b]	0	1 [c]	0	1	Succ
147	-	S-7	2	1	0	0	0	0	Dep
148	-	S-7	2	1	0	0	0	0	Dep
149	-	S-9	2	3 [b]	0	0	0	0	Dep
150	May 12	S-9	1	4 [b]	0	2 [c]	0	2	Succ
151	May 18	S-9	2	2 [b]	0	1 [c]	0	1	Succ
152	May 22	S-9	2	4	0	2	0	0	Dep

Table 18. con't

153	-	S-9	2	3	0	0	0	0	Dep
154	-	S-9	2	3 [b]	0	0	0	0	Dep

[a] Clutch initiation date estimated from available data where incubation and nestling periods approximately 13 days in duration each

[b] Uninterrupted incubation period confirmed

[c] Uninterrupted hatch period confirmed

[d] Succ = successful, Dep = depredated and Abnd = abandoned

Table 19. Raw productivity measurements for all nesting attempts for American robins in the river floodplains near Midland, Michigan during 2008.

ID	Clutch Date[a]	BSA	Period	Eggs	Eggs Sampled	Nestlings	Nestlings Sampled	Fledglings	Nest Fate[d]
155	April 10	R-1	2	3	0	3[c]	1	2	Succ
156	May 15	R-1	2	-	-	4	0	3	Succ
157	May 18	R-1	1	3	0	3[c]	0	3	Succ
158	May 22	R-1	2	-	0	3	1	0	Succ
159	May 27	R-1	2	4	0	4[c]	0	2	Succ
160	May 30	R-1	2	3[b]	0	2[c]	0	2	Succ
161	July 2	R-1	1	2[b]	0	1[c]	0	1	Succ
162	-	R-1	2	3[b]	0	0	0	0	Dep
163	April 16	R-2	2	2	0	2[c]	0	0	Dep
164	April 22	R-2	2	3[b]	0	3[c]	1	2	Succ
165	May 8	R-2	2	4[b]	0	4[c]	1	3	Succ
166	May 13	R-2	2	4[b]	0	0	0	0	Dep
167	May 26	R-2	2	-	-	3	0	0	Dep
168	June 6	R-2	2	4[b]	0	3[c]	1	2	Succ
169	June 8	R-2	2	4[b]	0	3[c]	0	0	Dep
170	-	R-2	2	4[b]	0	0	0	0	Dep
171	-	R-2	2	2	0	0	0	0	Dep

Table 19. con't

172	-	R-2	2	3	0	0	0	0	Dep
173	-	R-2	2	3 [b]	0	0	0	0	Dep
174	-	R-2	2	-	-	4	0	0	Dep
175	-	R-2	2	4	0	0	0	0	Dep
176	-	R-2	1	3 [b]	0	0	0	0	Hum
177	April 27	T-3	2	3 [b]	0	3 [c]	1	2	Succ
178	June 11	T-3	2	-	0	2	1	1	Succ
179	June 13	T-3	2	-	-	2	1	1	Succ
180	June 13	T-3	2	2 [b]	0	1 [c]	1	0	Succ
181	June 15	T-3	2	-	-	2	0	2	Succ
182	July 9	T-3	1	3 [b]	0	2 [c]	0	2	Succ
183	-	T-3	2	3 [b]	0	2 [c]	0	0	Dep
184	-	T-3	2	2 [b]	0	0	0	0	Dep
185	April 30	T-4	2	-	-	4	1	3	Succ
186	May 9	T-4	2	4	0	4 [c]	0	4	Succ
187	May 15	T-4	2	2 [b]	0	2 [c]	1	1	Succ
188	May 18	T-4	2	4 [b]	0	3 [c]	1	2	Succ
189	May 19	T-4	2	3 [b]	1	1 [c]	1	0	Succ
190	June 4	T-4	2	-	-	4	1	3	Succ
191	June 27	T-4	1	4 [b]	0	1 [c]	0	1	Succ
192	July 8	T-4	1	2 [b]	0	2 [c]	0	-	-
193	-	T-4	2	1	0	0	0	0	Dep

Table 19. con't

194	-	T-4	2	2	0	0	0	0	Dep
195	April 11	T-5	2	-	-	4	1	3	Succ
196	April 12	T-5	2	-	-	4	1	3	Succ
197	April 19	T-5	2	-	-	4	0	4	Succ
198	April 19	T-5	2	-	-	3	1	2	Succ
199	April 26	T-5	2	4	0	3 [c]	0	3	Succ
200	May 2	T-5	2	4 [b]	0	3 [c]	0	3	Succ
201	May 5	T-5	2	3	0	0	0	0	Dep
202	May 22	T-5	2	4 [b]	0	2 [c]	0	2	Succ
203	June 7	T-5	2	4	0	4 [c]	0	4	Succ
204	-	T-5	2	2	0	0	0	0	Dep
205	-	T-5	2	4	0	0	0	0	Dep
206	-	T-5	2	3 [b]	0	0	0	0	Dep
207	April 21	T-6	2	4	0	0	0	0	Dep
208	May 1	T-6	2	4	0	0	0	0	Dep
209	May 7	T-6	2	4	0	4 [c]	0	4	Succ
210	May 8	T-6	2	4 [b]	0	4 [c]	1	3	Succ
211	May 11	T-6	2	-	-	3	0	3	Succ
212	May 18	T-6	2	4 [b]	0	2 [c]	0	2	Succ
213	May 19	T-6	2	-	0	4	0	4	Succ
214	May 28	T-6	2	4 [b]	0	2 [c]	0	2	Succ
215	June 6	T-6	2	-	-	1	0	1	Succ

Table 19. con't

216	June 10	T-6	2	-	-	3	0	1	Succ
217	June 14	T-6	2	4	0	2 [c]	0	2	Succ
218	-	T-6	2	4	0	0	0	0	Dep
219	-	T-6	2	4 [b]	0	0	0	0	Dep
220	-	T-6	2	2	0	0	0	0	Dep
221	-	T-6	2	1	0	0	0	0	Dep
222	-	T-6	2	3	0	0	0	0	Dep
223	-	T-6	2	3 [b]	0	0	0	0	Dep
224	-	T-6	2	1	0	0	0	0	Dep
225	-	T-6	2	2 [b]	0	0	0	0	Wthr
226	-	T-6	2	2	0	1	0	0	Dep
227	-	T-6	2	-	-	4	0	0	Dep
228	April 21	S-7	2	4 [b]	0	4 [c]	1	3	Succ
229	April 23	S-7	2	4 [b]	0	0	0	0	Dep
230	May 1	S-7	2	3 [b]	0	-	0	0	Dep
231	May 7	S-7	2	3 [b]	0	2 [c]	0	-	-
232	May 8	S-7	2	3	0	0	0	0	Dep
233	May 12	S-7	2	4 [b]	0	4 [c]	0	0	Dep
234	May 27	S-7	2	4 [b]	0	3 [c]	0	0	Dep
235	May 31	S-7	2	-	-	3	1	2	Succ
236	June 3	S-7	2	4 [b]	0	3 [c]	1	2	Succ
237	-	S-7	2	3	0	0	0	0	Dep

Table 19. con't

238	-	S-7	2	4	0	0	0	0	Dep
239	June 16	S-9	2	-	-	3	0	3	Succ

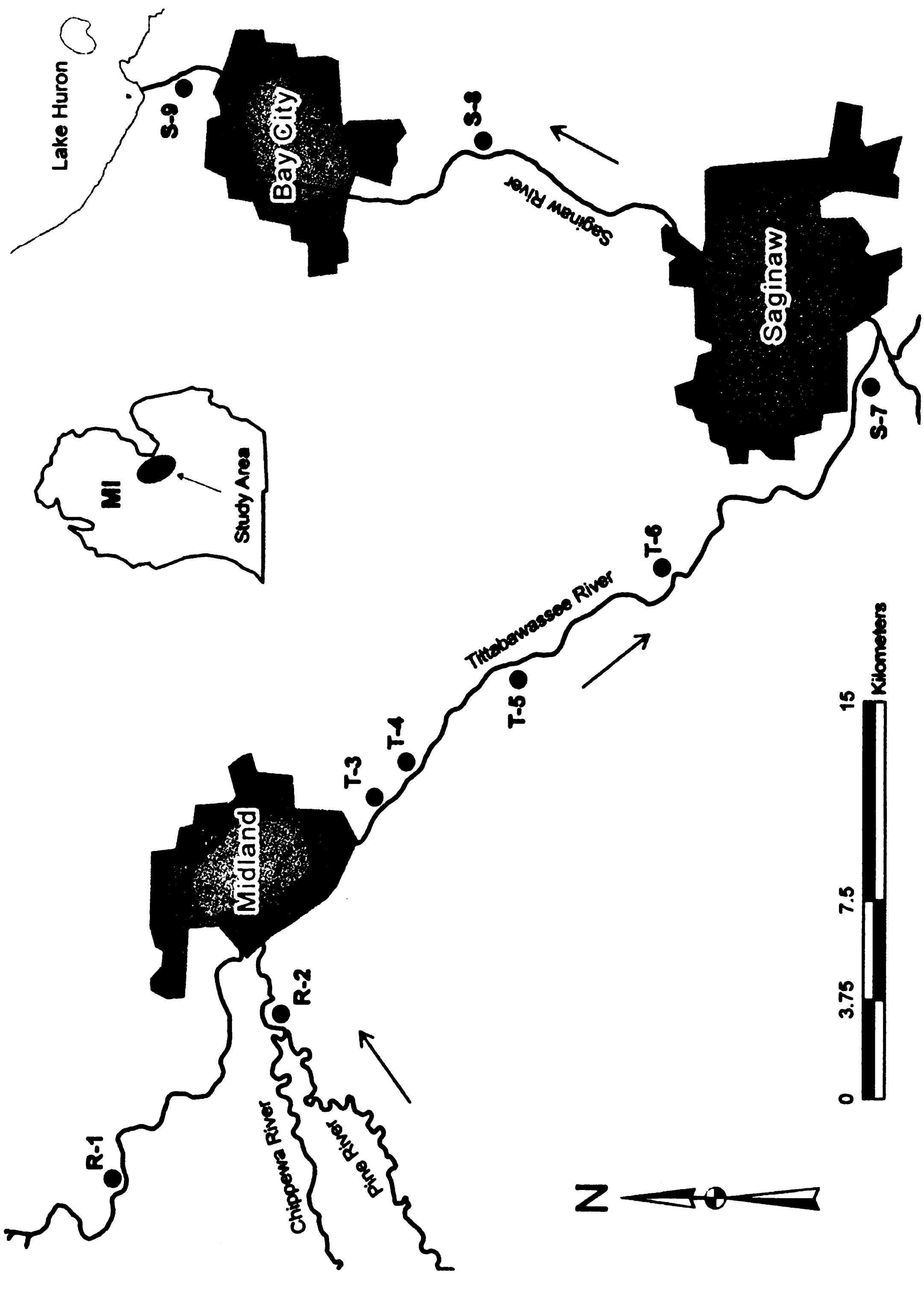
[a] Clutch initiation date estimated from available data where incubation and nestling periods approximately 13 days in duration each

[b] Uninterrupted incubation period confirmed

[c] Uninterrupted hatch period confirmed

[d] Succ = successful, Dep = depredated, Hum = human-related failure and Wthr= weather-related failure

Figure 1. Study site locations within the Chippewa River, Pine River, Tittabawassee River and Saginaw River floodplains, Michigan, USA. Reference Areas (R-1 and R-2), Tittabawassee River Study Areas (T-3 to T-6), and Saginaw River Study Areas (S-7 and S-9) were monitored from 2005–2008. Only sediments and aquatic food web item collection took place at S-8, with the exception of a limited number of dietary item samples. Direction of river flow is indicated with arrows; source of contamination is enclosed in a dotted oval.


Lake Huron
S-9
Bay City
S-8
Saginaw River
Saginaw
S-7
MI
Study Area
T-6
Tittabawassee River
T-5
T-4
T-3
Midland
R-2
R-1
Chippewa River
Pine River
N
0
3.75
7.5
15
Kilometers

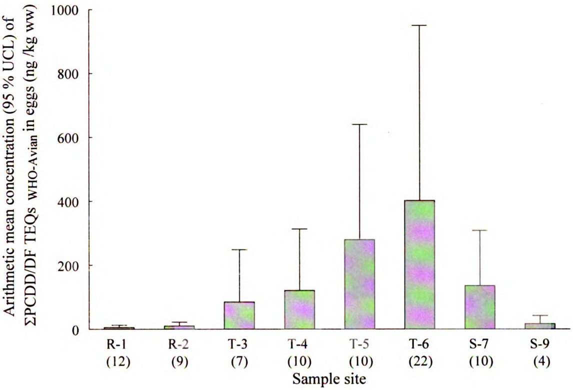


Figure 2. Mean concentrations of ∑PCDD/DF $TEQs_{WHO\text{-}Avian}$ in American robin eggs collected during 2005-2008 from the river floodplains near Midland, Michigan, USA. Error bars indicate the 95% upper confidence level; Reference areas (R-1 and R-2); Tittabawassee River study areas (T-3 to T-6); and Saginaw River study areas (S-7 and S-9). Samples sizes are indicated in parentheses below the sample sites.

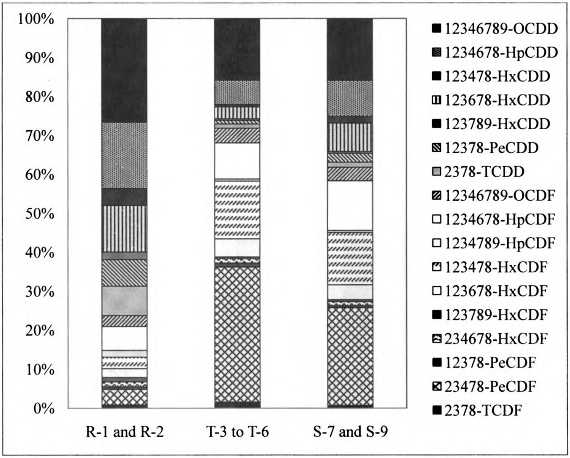


Figure 3. Mean congener percent contributions in American robin eggs collected during 2005-2008 from the Chippewa, Tittabawassee and Saginaw river floodplains, Midland, Michigan, USA. R-1 to R-2 includes reference areas, T-2 to T-6 includes Tittabawassee River study areas and S-7 and S-9 includes Saginaw River study areas. Congeners include octachlorodibenzo-*p*-dioxin (OCDD), heptachlorodibenzo-*p*-dioxin (HpCDD), hexachlorodibenzo-*p*-dioxin (HxCDD), pentachlorodibenzo-*p*-dioxin (PeCDD), tetrachlorodibenzo-*p*-dioxin (TCDD), octachlorodibenzofuran (OCDF), heptachlorodibenzofuran (HpCDF), hexachlorodibenzofuran (HxCDF), pentachlorodibenzofuran (PeCDF) and tetrachlorodibenzofuran (TCDF).

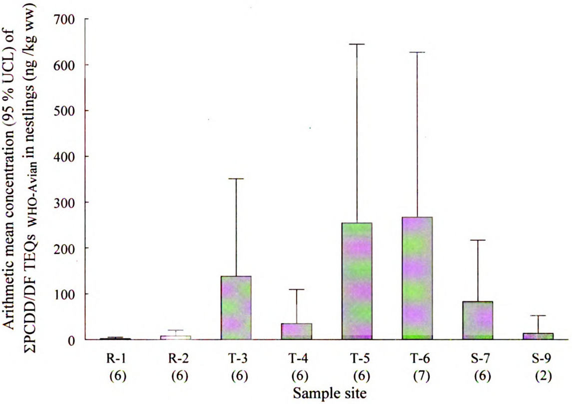


Figure 4. Mean concentrations of ∑PCDD/DF $TEQs_{WHO\text{-}Avian}$ in American robin nestlings collected during 2005-2008 from the river floodplains near Midland, Michigan, USA. Error bars indicate the 95% upper confidence level; Reference areas (R-1 and R-2); Tittabawassee River study areas (T-3 to T-6); and Saginaw River study areas (S-7 and S-9). Samples sizes are indicated in parentheses below the sample sites.

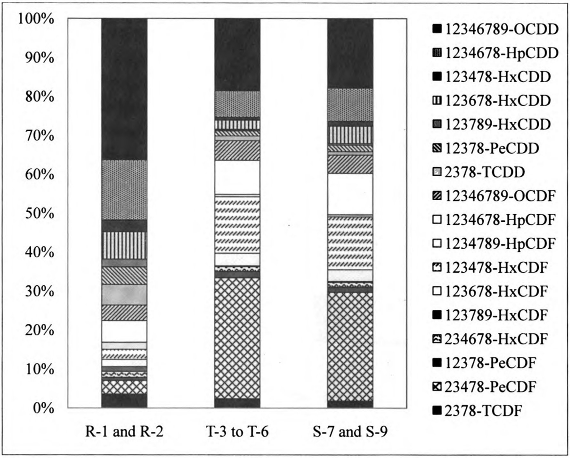


Figure 5. Mean congener percent contributions in nestling American robins collected during 2005-2008 from the Chippewa, Tittabawassee and Saginaw river floodplains, Midland, Michigan, USA. R-1 to R-2 includes reference areas, T-2 to T-6 includes Tittabawassee River study areas and S-7 and S-9 includes Saginaw River study areas. Congeners include octachlorodibenzo-*p*-dioxin (OCDD), heptachlorodibenzo-*p*-dioxin (HpCDD), hexachlorodibenzo-*p*-dioxin (HxCDD), pentachlorodibenzo-*p*-dioxin (PeCDD), tetrachlorodibenzo-*p*-dioxin (TCDD), octachlorodibenzofuran (OCDF), heptachlorodibenzofuran (HpCDF), hexachlorodibenzofuran (HxCDF), pentachlorodibenzofuran (PeCDF) and tetrachlorodibenzofuran (TCDF).

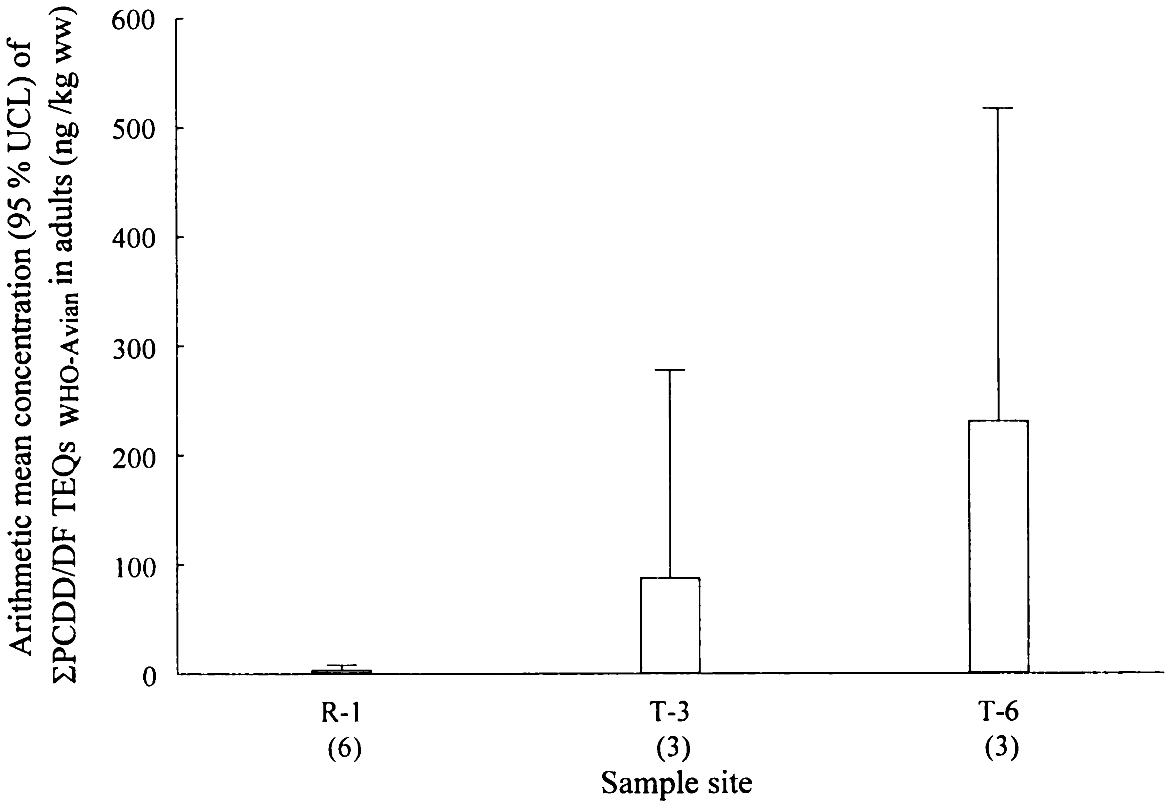


Figure 6. Mean concentrations of ∑PCDD/DF TEQs$_{\text{WHO-Avian}}$ in American robin adults collected during 2005-2008 from the river floodplains near Midland, Michigan, USA. Error bars indicate the 95% upper confidence level; Reference areas (R-1 and R-2); and Tittabawassee River study areas (T-3 to T-6). Samples sizes are indicated in parentheses below the sample sites.

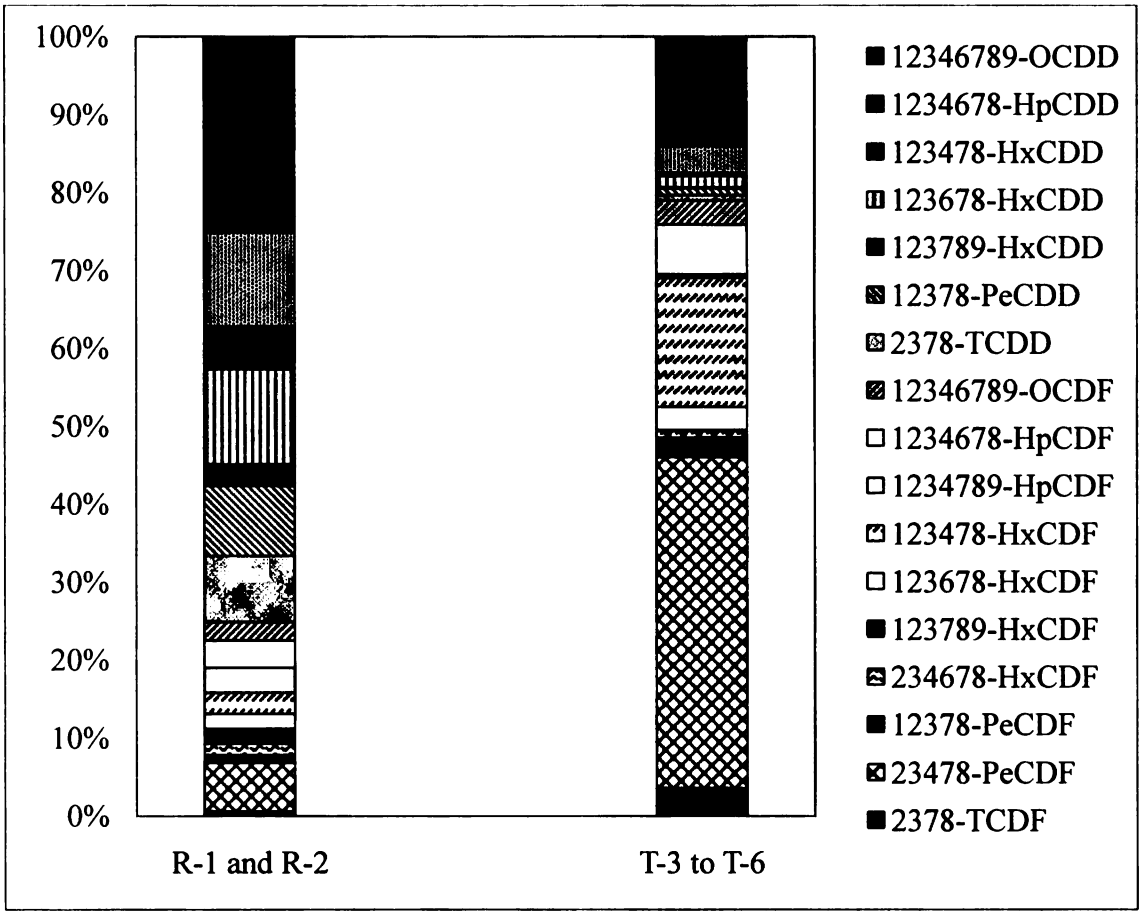


Figure 7. Mean congener percent contributions in adult American robins collected during 2007 from the Chippewa and Tittabawassee river floodplains, Midland, Michigan, USA. R-1 to R-2 includes reference areas and T-3 to T-6 includes Tittabawassee River study areas. Congeners include octachlorodibenzo-*p*-dioxin (OCDD), heptachlorodibenzo-*p*-dioxin (HpCDD), hexachlorodibenzo-*p*-dioxin (HxCDD), pentachlorodibenzo-*p*-dioxin (PeCDD), tetrachlorodibenzo-*p*-dioxin (TCDD), octachlorodibenzofuran (OCDF), heptachlorodibenzofuran (HpCDF), hexachlorodibenzofuran (HxCDF), pentachlorodibenzofuran (PeCDF) and tetrachlorodibenzofuran (TCDF).

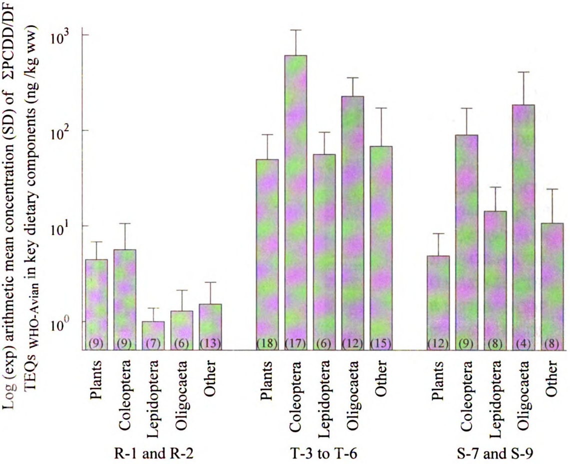


Figure 8. Arithmetic mean concentrations of ∑PCDD/DF TEQs$_{\text{WHO-Avian}}$ in key dietary components collected during 2004-2006 from the river floodplains near Midland, Michigan, USA. Error bars indicate the standard deviation; Reference areas (R-1 and R-2); Tittabawassee River study areas (T-3 to T-6); and Saginaw River study areas (S-7 and S-9). Samples sizes are indicated in parentheses within the bars.

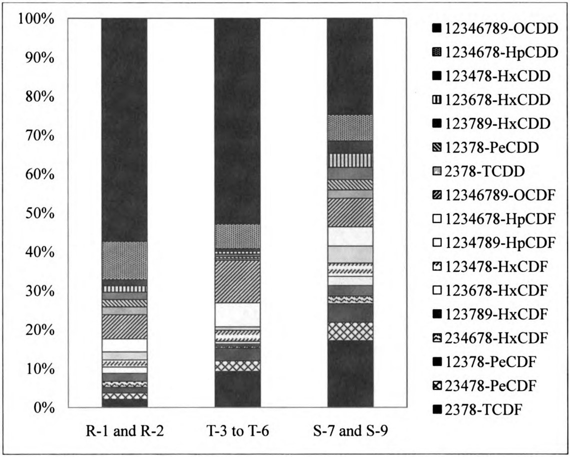


Figure 9. Mean congener percent contributions in terrestrial plants collected during 2003-2006 from the Chippewa, Tittabawassee and Saginaw river floodplains, Midland, Michigan, USA. R-1 to R-2 includes reference areas, T-3 to T-6 includes Tittabawassee River study areas and S-7 and S-9 includes Saginaw River study areas. Congeners include octachlorodibenzo-*p*-dioxin (OCDD), heptachlorodibenzo-*p*-dioxin (HpCDD), hexachlorodibenzo-*p*-dioxin (HxCDD), pentachlorodibenzo-*p*-dioxin (PeCDD), tetrachlorodibenzo-*p*-dioxin (TCDD), octachlorodibenzofuran (OCDF), heptachlorodibenzofuran (HpCDF), hexachlorodibenzofuran (HxCDF), pentachlorodibenzofuran (PeCDF) and tetrachlorodibenzofuran (TCDF).

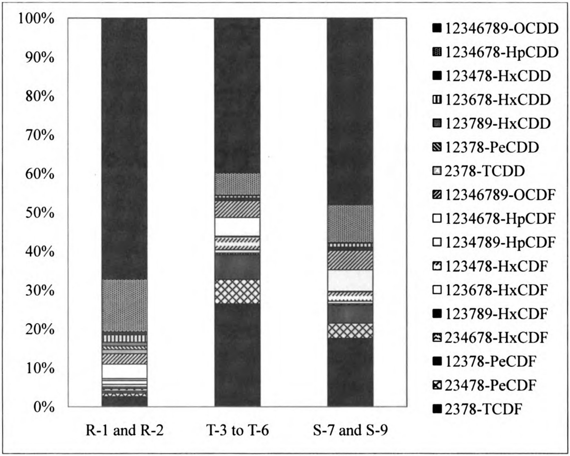


Figure 10. Mean congener percent contributions in terrestrial Coleoptera collected during 2003-2006 from the Chippewa, Tittabawassee and Saginaw river floodplains, Midland, Michigan, USA. R-1 to R-2 includes reference areas, T-3 to T-6 includes Tittabawassee River study areas and S-7 and S-9 includes Saginaw River study areas. Congeners include octachlorodibenzo-*p*-dioxin (OCDD), heptachlorodibenzo-*p*-dioxin (HpCDD), hexachlorodibenzo-*p*-dioxin (HxCDD), pentachlorodibenzo-*p*-dioxin (PeCDD), tetrachlorodibenzo-*p*-dioxin (TCDD), octachlorodibenzofuran (OCDF), heptachlorodibenzofuran (HpCDF), hexachlorodibenzofuran (HxCDF), pentachlorodibenzofuran (PeCDF) and tetrachlorodibenzofuran (TCDF).

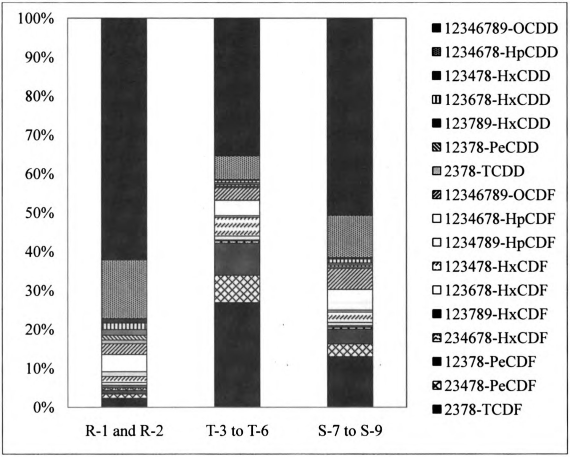


Figure 11. Mean congener percent contributions in terrestrial Lepidoptera collected during 2003-2006 from the Chippewa, Tittabawassee and Saginaw river floodplains, Midland, Michigan, USA. R-1 to R-2 includes reference areas, T-3 to T-6 includes Tittabawassee River study areas and S-7 and S-9 includes Saginaw River study areas. Congeners include octachlorodibenzo-*p*-dioxin (OCDD), heptachlorodibenzo-*p*-dioxin (HpCDD), hexachlorodibenzo-*p*-dioxin (HxCDD), pentachlorodibenzo-*p*-dioxin (PeCDD), tetrachlorodibenzo-*p*-dioxin (TCDD), octachlorodibenzofuran (OCDF), heptachlorodibenzofuran (HpCDF), hexachlorodibenzofuran (HxCDF), pentachlorodibenzofuran (PeCDF) and tetrachlorodibenzofuran (TCDF).

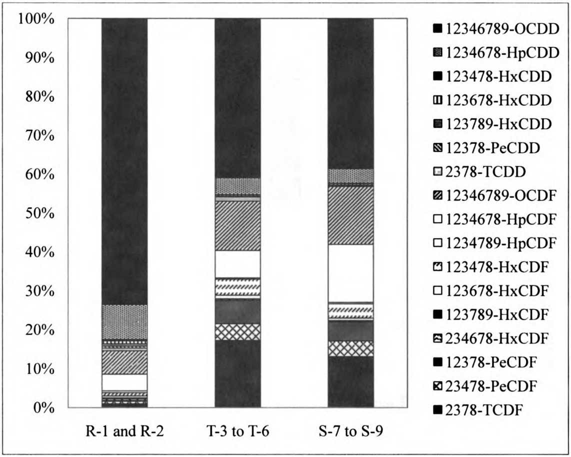


Figure 12. Mean congener percent contributions in depurated terrestrial Oligochaeta collected during 2003-2006 from the Chippewa, Tittabawassee and Saginaw river floodplains, Midland, Michigan, USA. R-1 to R-2 includes reference areas, T-3 to T-6 includes Tittabawassee River study areas and S-7 and S-9 includes Saginaw River study areas. Congeners include octachlorodibenzo-*p*-dioxin (OCDD), heptachlorodibenzo-*p*-dioxin (HpCDD), hexachlorodibenzo-*p*-dioxin (HxCDD), pentachlorodibenzo-*p*-dioxin (PeCDD), tetrachlorodibenzo-*p*-dioxin (TCDD), octachlorodibenzofuran (OCDF), heptachlorodibenzofuran (HpCDF), hexachlorodibenzofuran (HxCDF), pentachlorodibenzofuran (PeCDF) and tetrachlorodibenzofuran (TCDF).

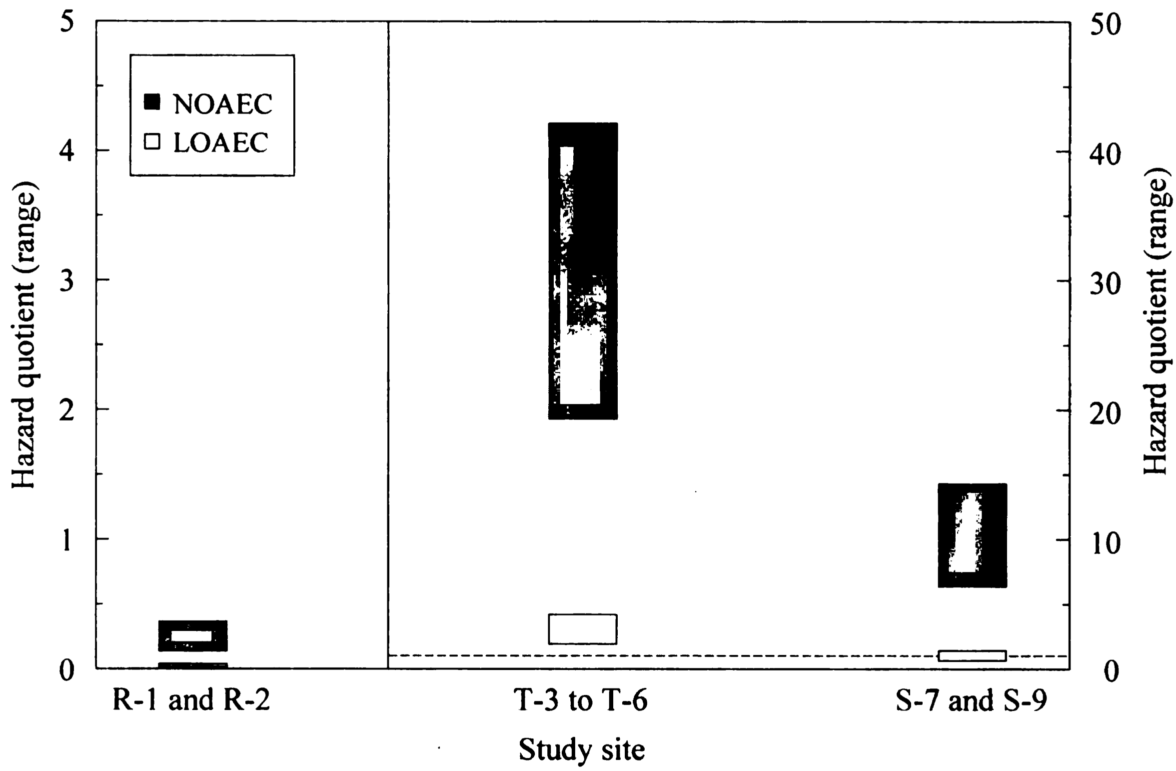


Figure 13. Hazard quotients (HQs) for the effects of potential ∑PCDD/DF $TEQs_{WHO\text{-}Avian}$ daily dietary dose from site-specific food web-based dietary exposure for adult American robins during 2003-2006 from the river floodplains near Midland, Michigan based on the no observable effect concentration (NOAEC) and the lowest observable adverse effect concentration (LOAEC). HQs based on measured concentration ranges are presented; left y-axis for reference areas (R-1 and R-2); right y-axis for Tittabawassee River study areas (T-3 to T-6) and Saginaw River study areas (S-7 and S-9); lower end of bars bound by 50^{th} centile HQ value and upper end bound by 95^{th} centile HQ value; dashed horizontal reference line of right y-axis indicates HQ value of 1.

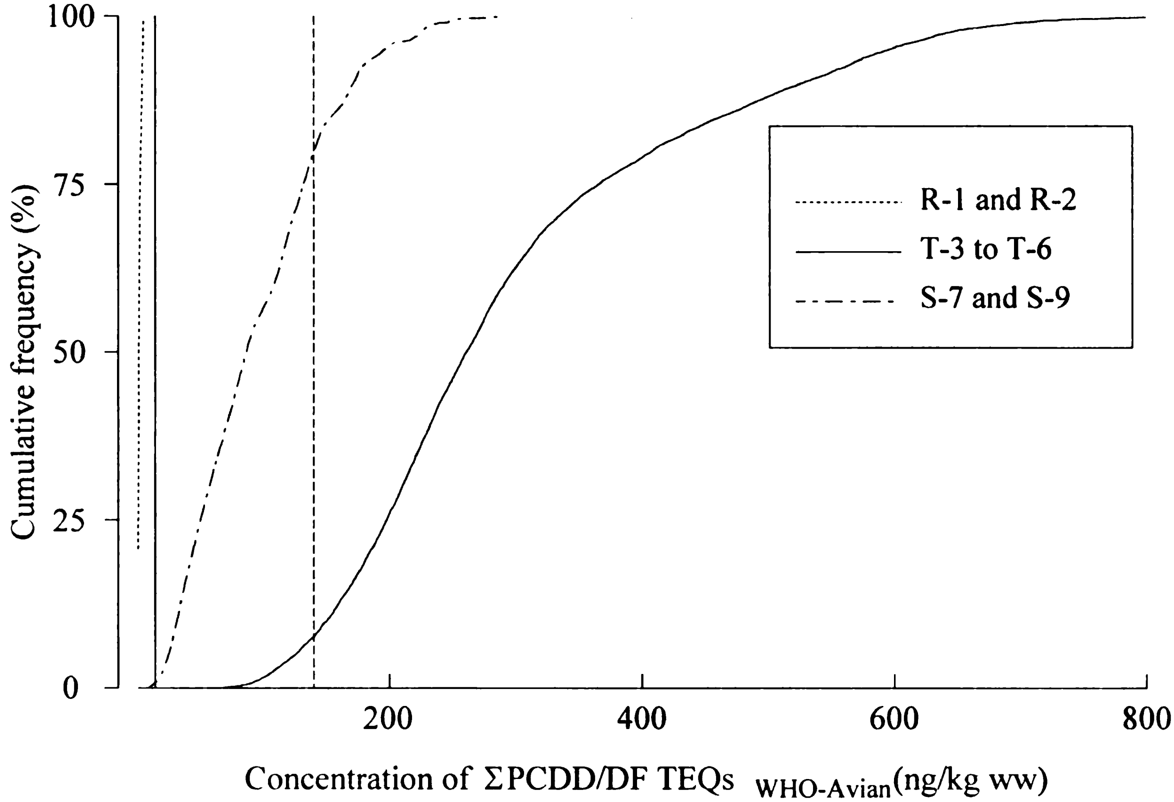


Figure 14. Modeled probabilistic distribution of expected cumulative percent frequencies for potential average $TEQ_{WHO\text{-}Avian}$ daily dose (ADD_{pot}; ng/kg body weight/d) calculated from site-specific food web-based dietary exposure for adult American robins breeding during 2003-2006 within the floodplains near Midland, Michigan, USA. 10,000 replications per site; R-1 and R-2 indicated by a dotted line; T-3 to T-6 indicated by a solid line; S-7 and S-9 indicated by a dotted-dashed line; Y-axis offset to show R-1 and R-2; NOAEC indicated by a vertical solid bar; LOAEC indicated by a vertical dashed bar; TRVs derived from Nosek *et al.* 1992.

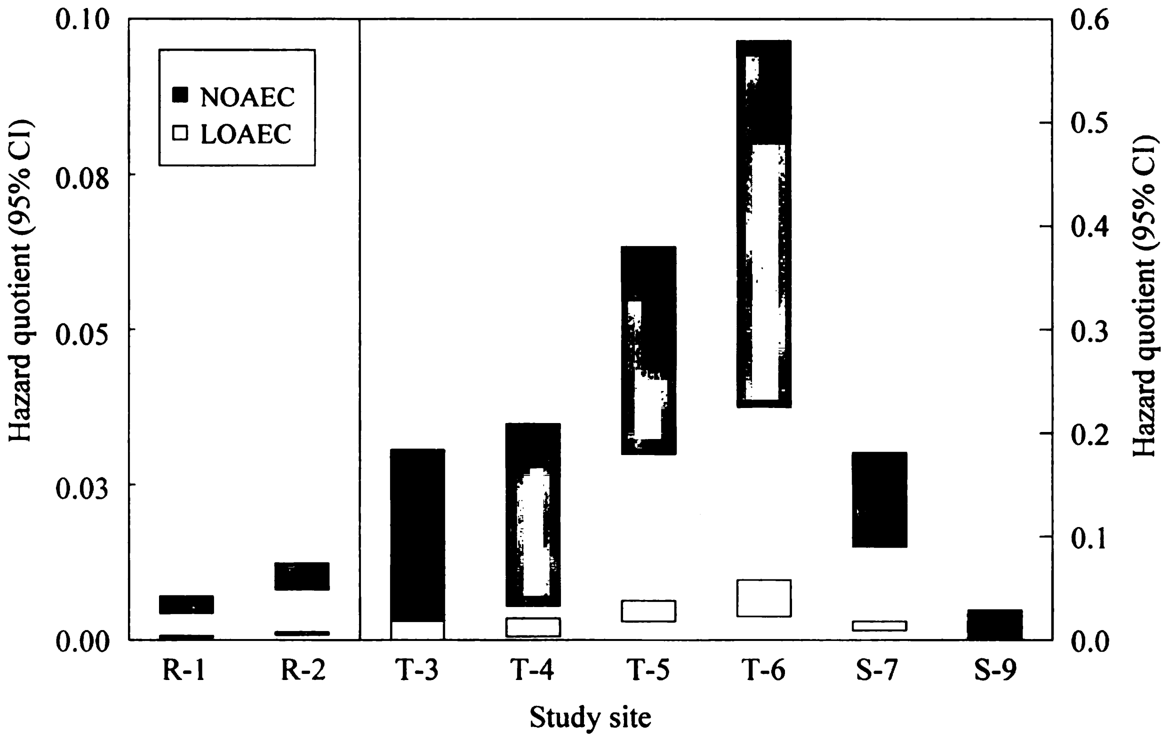


Figure 15. Hazard quotients (HQs) for the effects of ∑PCDD/DF TEQs$_{\text{WHO-Avian}}$ for American robin eggs collected during 2005-2008 from the river floodplains near Midland, Michigan based on the no observable effect concentration (NOAEC) and the lowest observable adverse effect concentration (LOAEC). HQs based on 95% confidence intervals (LCL/UCL) derived from arithmetic mean concentrations are presented; left y-axis for reference areas (R-1 and R-2); right y-axis for Tittabawassee River study areas (T-3 to T-6) and Saginaw River study areas (S-7 and S-9); lower end of bars bound by 95% LCL HQ value and upper end bound by 95% UCL HQ value.

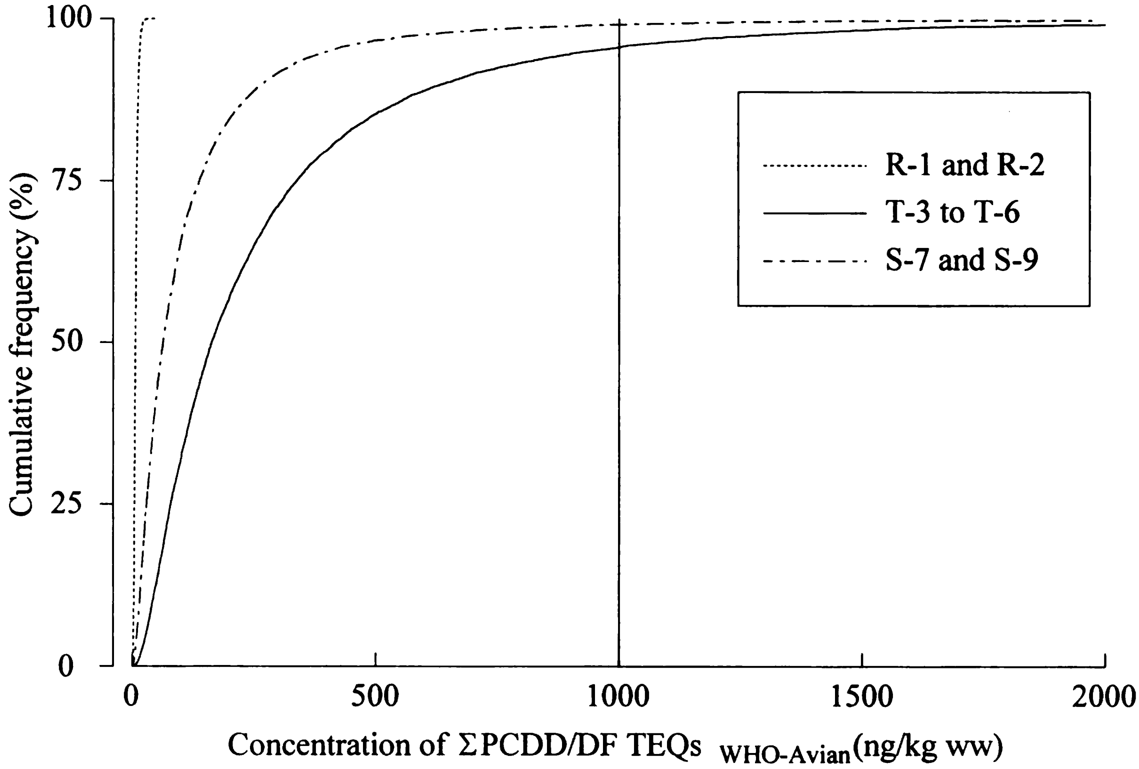


Figure 16. Modeled probabilistic distribution of expected cumulative percent frequencies for American robin egg $TEQ_{WHO\text{-}Avian}$ concentrations ng/kg wet weight in site-specific eggs collected from the river floodplains near Midland, Michigan in 2005-2008. 10,000 replications per site; R-1 and R-2 indicated by a dotted line; T-3 to T-6 indicated by a solid line; S-7 and S-9 indicated by a dotted-dashed line; Y-axis offset to show R-1 and R-2; NOAEC indicated by a vertical solid bar; LOAEC (not indicated) is 10,000 ng TEQs/kg wet weight; TRVs derived from Thiel *et al.* 1988.

Equation 3-4. Derived by Nagy (1987) - Food ingestion (FI) rate from metabolizable energy and free-living metabolic rate:

$$FI(g/day) = 0.398Wt^{0.850}$$

where Wt = average mass of passerine receptor

Equation 4-8. Generic equation for estimating oral doses of contaminants in wildlife:

$$ADD_{pot}\ (ng/kg\ bw/day) = \sum_{k=1}^{m} (C_k \times FR_k \times NIR_k)$$

where ADD_{pot} = potential average daily does (ng/kg-day), C_k = Average contaminant concentration in k^{th} type of food (ng/kg), FR_k = fraction of intake of the k^{th} food type that is contaminated, NIR_k = normalized ingestion rate of k^{th} food type on a wet weight basis (ng/kg-day) and m = number of contaminated food types

Figure 17. US EPA wildlife exposures handbook (USEPA WEH) equations utilized during estimation of potential average daily dose (ADD_{pot}) for American robins of the Chippewa, Tittabawassee and Saginaw river floodplains during 2004=2006.

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