SI for Moore et al. 2014 Reviews of Environmental Contamination and Toxicology 231

SI Appendix 1. Focal bird species used in the risk assessment for chlorpyrifos

Abert's towhee (*Pipilo aberti*) is a non-migratory species found in the southwestern United States below 1300 m elevation (Phillips et al. 1964). Birds average 47.1 (males) to 44.8 (females) g in body mass (Dunning 1984) and feed on insects and seeds from the ground (Rosenberg et al. 1991).

American crow (*Corvus brachyrhynchos*) can be found throughout North America and consists of both resident and migratory individuals (Black 1941). Crows range in mass from 316 to 575 g (Johnston 1961) and they are omnivorous and opportunistic ground feeders (Verbeek and Caffrey 2002).

American robin (*Turdus migratorius*) breeds throughout most of North America and winters in the southernmost parts of Canada, the United States, and Central America (Godfrey 1986). Adults average 77 g in mass (Sallabanks and James 1999). The diet of the American robin comprises mainly insects and fruit, with insects, particularly earthworms, being important in the spring and summer (Sallabanks and James 2002; Wheelwright 1986).

Blue grosbeak (*Passerina caerulea*) can be found in North America as far north as South Dakota and as far south as Panama (American Ornithologists' Union 1998). The mean mass of blue grosbeaks is 28 g (Dunning 1993) and they mainly forage on insects (Bent 1968, Martin et al. 1961).

Common pheasant (*Phasianus colchicus*) is primarily found on agricultural lands in southern Canada and in the mid- to northern United States (American Ornithologists' Union 1998). It is primarily a sedentary species, but will migrate in search of food (Olsen 1977). Males weigh 900 to 3000 g, and females weigh 500 to 1000 g (Long 1981, Ridgway and Friedmann 1946). The breeding season diet of the common pheasant includes agricultural grains and other vegetation, insects, and seeds (Stromberg 1979).

Dickcissel (*Spiza americana*) breeds in central North America from North Dakota to Texas (American Ornithologists' Union 1998) and winters in central Venezuela (Basili and Temple 1999). Dickcissels forage primarily on ground-dwelling arthropods and seeds (Gross 1921; Temple 2002).

Horned lark (*Eremophilia alpestris*) breeds throughout most of the US, Canada and Mexico, and winters in the US and Mexico (Godfrey 1986; Howell and Webb 1995). The diet of the horned lark is comprised almost entirely of seeds in the winter months, but also includes ground-dwelling insects in the spring, summer and fall (Rotenberry 1980).

Indigo bunting (*Passerina cyanea*) is a long-distance migrant, primarily breeding in the eastern US and southeastern Canada (American Ornithologists' Union 1998) and wintering in Mexico, Central America, and the Caribbean (Howell and Webb 1995). The diet of the indigo bunting includes seeds, berries, and insects gleaned from foliage (Barrows 1912; Butler 1897; Forbes 1883; McAtee 1926; Taber and Johston 1968).

Killdeer (*Charadrius vociferous*) breeds in southern Canada, the US and northern Mexico, and winters in Central America, the Caribbean, Mexico, and the southern and coastal areas of the US (Gauvreau and Alvo 1996; Godfrey 1986; Howell and Webb 1995; Raffaele et al. 1998). The diet is almost entirely arthropods with a small portion of seeds (McAtee and Beal 1924; Wetmore 1916).

Mourning dove (*Zenaida macroura*) can be found throughout southern Canada, the US, central Mexico, Central America, and the Caribbean (Aldrich 1993; Howell and Webb 1995; Otis et al. 2008; Ridgely and Gwynne 1989). The mourning dove is only a partial migrant, and migratory and resident populations co-exist (Chambers et al. 1962). The diet of the mourning dove is entirely comprised of seeds (Lewis 1993; Mirarchi 1993).

Northern bobwhite (*Colinus virginianus*) is typically sedentary and non-migratory, and can be found in the eastern US, southern Ontario, eastern Mexico, and parts of the northern Caribbean (Cadman et al. 1987; Howell and Webb 1995; Raffaele et al. 1998). Adult northern bobwhites weigh 140 to 170 g (Johnsgard 1988) and primarily consume insects and seeds (Brennan and Hurst 1995).

Red-winged blackbird (*Agelaius phoeniceus*) is a partial migrant (Dolbeer 1982) and can be found throughout most of North America (Howell and Webb 1995; Monroe 1968). The red-winged blackbird consumes seeds and insects (Bird and Smith 1964; McNicol et al. 1982).

Vesper sparrow (*Pooecetes gramineus*) breeds from sea level to 3000 m elevation (Ligon 1961), and from the mid-latitudes of the US north to the mid-latitudes of Canada (Campbell et al. 2001; Cannings et al. 1987; Gilligan et al. 1994; Godfrey 1986; Peck and James 1987; Semenchuk 1992; Smith 1996). The wintering range of the vesper sparrow spans the southern US and Mexico (Howell and Webb 1995; Root 1988). Males and females average 23 to 24 g (Jones and Cornely 2002). The vesper sparrow eats grasses, seeds and foliage-dwelling insects (Best 1972, Feist 1968).

Western meadowlark (*Sturnella neglecta*) consists of both migratory and non-migratory populations, and is primarily confined to central and western North America (Davis and Lanyon 2008; Owens and Myres 1973; Rotenberry and Wiens 1980). The diet of the western meadowlark is mainly comprised of insects, with a small proportion of seeds and grains (Bryant 1914; Maher 1974; Orians 1985).

SI Appendix 2. Description of the TIM model

TIM v1 was the model used by EPA (USEPA 2005) to estimate the risks of flowable carbofuran to avian species that forage in treated fields. The basic structure of the model is summarized here.

TIM v1 has two 12-hr time steps per day. For each time step, a binomial probability function is used to determine if an individual bird uses the treated field as a source of food and water. If a bird is determined to be in the treated area during a particular time step, the general model used to calculate pesticide exposure is (Equation SI 1):

$$NIR_{total}(t) = \frac{CI_{total}(t)}{BW} \qquad \text{(SI 1)}$$

where,

$NIR_{total}(t)$ is the body mass-normalized pesticide burden at time step t after application (mg active ingredient [ai] kg^{-1} body weight [bw] over the time step);

$CI_{total}(t)$ is the total body burden of pesticide at time step t after application (mg ai); and

BW is the individual bird body weight (kg).

The total pesticide body burden for an individual bird at a specific time step is calculated (Equation SI 2) as:

$$CI_{total}(t) = CI_{food}(t) + CI_{water}(t) + CI_{total}(t-1) x\, f_{retained} \qquad \text{(SI 2)}$$

where,

$CI_{food}(t)$ is the total intake of pesticide in food at time t after application (mg pesticide over the time step);

$CI_{water}(t)$ is the intake of pesticide in drinking water at time t after application (mg pesticide over the time step);

$CI_{total}(t\text{-}1)$ is the total intake of pesticide one time step before the current time step (mg pesticide over the time step); and

$f_{retained}$ is the fraction of pesticide intake retained in the bird at the end of a time step (unitless).

Pesticide intake from food, $CI_{food}(t)$, is calculated (Equation SI 3):

$$CI_{food}(t) = \sum_k C_k(f) x\, TDIR\ x\ 0.5\ x\ DF_k\ x\ FC_k \qquad \text{(SI 3)}$$

where,

$C_k(t)$ is the concentration of pesticide in the k^{th} food item at time t after application (mg pesticide kg^{-1} wet mass [ww]);

$TDIR$ is the total daily intake in diet of a bird (kg ww $bird^{-1}$);

DF_k is the fraction of the diet attributed to the k^{th} food source (unitless);

0.5 is the fraction of the $TDIR$ consumed in each of the two time steps modeled for each day (unitless); and

FC_k is the fraction of the k^{th} food source containing the pesticide (unitless).

Pesticide intake from water, $CI_{water}(t)$, is calculated (Equation SI 4):

$$CI_{water} = C_w \ x \ DWIR \ x \ 0.5 \qquad \text{(SI 4)}$$

where,

C_w is the concentration of pesticide in drinking water sources (mg L^{-1});

$DWIR$ is the daily drinking water intake rate (L kg^{-1} bw) of the bird; and

0.5 is the fraction of the $DWIR$ consumed in each of the two time steps modeled for each day (unitless).

TIM v1 includes seven species of bird for corn (i.e., eastern and western meadowlark, horned lark, vesper sparrow, red-winged blackbird, mourning dove, and killdeer) and six species for alfalfa (i.e., dickcissel, western meadowlark, grasshopper sparrow, mourning dove, vesper sparrows, and mallard).

Following review by the SAP in 2001 (SAP 2001), TIM v1 was modified and a new version created, TIM v2 (USEPA 2008). The major changes in TIMV v2 were:

- Replacement of actual focal species with hypothetical generic bird species that are meant to represent species occurring in and around agro-environments.
- Incorporation of a 1-hour time step to facilitate inclusion of a bimodal feeding pattern.
- Incorporation of an algorithm (Markov Chain) that simulates temporal correlation between sequential foraging events.
- Development of a new model for estimating pesticide residues in on-field drinking water sources (puddles).

In addition to the modifications suggested by the SAP in 2001, inhalation and dermal exposure models were added to TIM.

SI Appendix 3. Description of LiquidPARAM and GranPARAM

1 Detailed description of the structure of LiquidPARAM

The following sections describe the structure of LiquidPARAM in detail.

1.1 Processes Modeled in LiquidPARAM

The first step in the model is to define the pesticide use scenario (i.e., crop, number of applications, application times, methods and rates, and drinking water scenario). This information is used to estimate the initial (t_0) concentrations of CPY in food items of birds (i.e., seeds, fruits, grass, broadleaf forage, foliage-dwelling invertebrates, soil surface invertebrates, below ground invertebrates, flying invertebrates) and in on-field drinking water sources (i.e., dew and puddles) for each of the 1000 fields included in the model. Degradation rates are then entered to determine the concentrations of CPY on food items and in water at each of the time steps following initial application. If there is more than one pesticide application, the model estimates concentrations for each application on the application dates specified by the user. For second and third applications, residue concentrations existing prior to application are added to the residue concentrations estimated for the new application.

The biological portion of LiquidPARAM requires the selection of: 1) a focal species, 2) bird sex, 3) the temporal foraging pattern to be modeled, and 4) rate of metabolism. Each focal species has a distribution for mean proportion of time that a bird population forages in treated fields (PT). For each field, a value is selected from this distribution and combined with input values of zero and one to create a field-specific distribution. A PT is then randomly chosen from this distribution for each of the 20 individuals in the field. Food and drinking water intake rates are also a function of the focal species chosen. Intake rates are based on allometric relationships (Nagy et al. 1999; USEPA 1993). Each individual body mass used as an input to the allometric relationships is taken from distributions specific to males, females, or combined sexes (i.e., assuming 1:1 ratios of males to females). The temporal foraging pattern selected by the user (i.e., equal feeding throughout daylight hours, gorge-feeding in the morning and evening, or peak feedings in morning and evening with a midday lull) determines what proportion of the daily food and water intake rates occur in any given hourly time step. Thus, the hourly dose for an individual bird for a given time step is calculated (Equation SI 5):

$$HD = PT\ x\ PDI\ x\ [(C_w\ x\ DWIR) +\ (FIR\ x\ \sum_{i=1}^{n} C_i\ x\ P_i)] \qquad \text{(SI 5)}$$

where,

HD is hourly dose (mg ai kg^{-1} bw hr^{-1});

PT is proportion of time step spent foraging in treated fields;

PDI is proportion of the total daily food and water intake occurring in that time step;

C_w is concentration in water (mg ai L^{-1});

$DWIR$ is drinking water intake rate (L kg^{-1} bw d^{-1});

FIR is food intake rate (kg ww kg^{-1} bw d^{-1});

C_i is concentration in the i^{th} food item (mg ai kg^{-1} bw); and

P_i is proportion of the i^{th} food item in the diet.

The amount of CPY retained by a bird from one time step to the next is governed by the rate of metabolism (Equation SI 6):

$$HRD = HD_t + HRD_{t-1} \, x \, f_{retained} \qquad \text{(SI 6)}$$

where,

HRD is hourly retained dose (mg ai kg^{-1} bw);

t is the current time step;

$t-1$ is the previous time step; and

$f_{retained}$ is the fraction of CPY retained in the bird after accounting for metabolism of the compound.

Once HRD has been calculated for each of the time steps in LiquidPARAM (60 d x 24 hr d^{-1} = 2040 hourly time steps), the model searches for the maximum hourly retained dose (acute exposure) or rolling-average TDI (total daily intake for chronic exposure) that occurred during the 60-d period following initial exposure. It is these values that are compared to the acute and chronic effects metrics to determine if the bird is adversely affected (Fig. SI 1A).

The approach used in LiquidPARAM to determine the fate of an individual bird for an acute exposure is the same as that used by EPA (USEPA 2005). The first step is to estimate the Z score of the maximum hourly retained dose. The Z score is calculated (Equation SI 7):

$$Z = (\log HRD_{max} - \log LD50) \, x \, Slope \qquad \text{(SI 7)}$$

where,

HRD_{max} is the maximum hourly retained dose (mg ai kg^{-1} bw);

$LD50$ is the dose estimated to cause 50% mortality; and

$Slope$ is the probit slope of the dose-response curve.

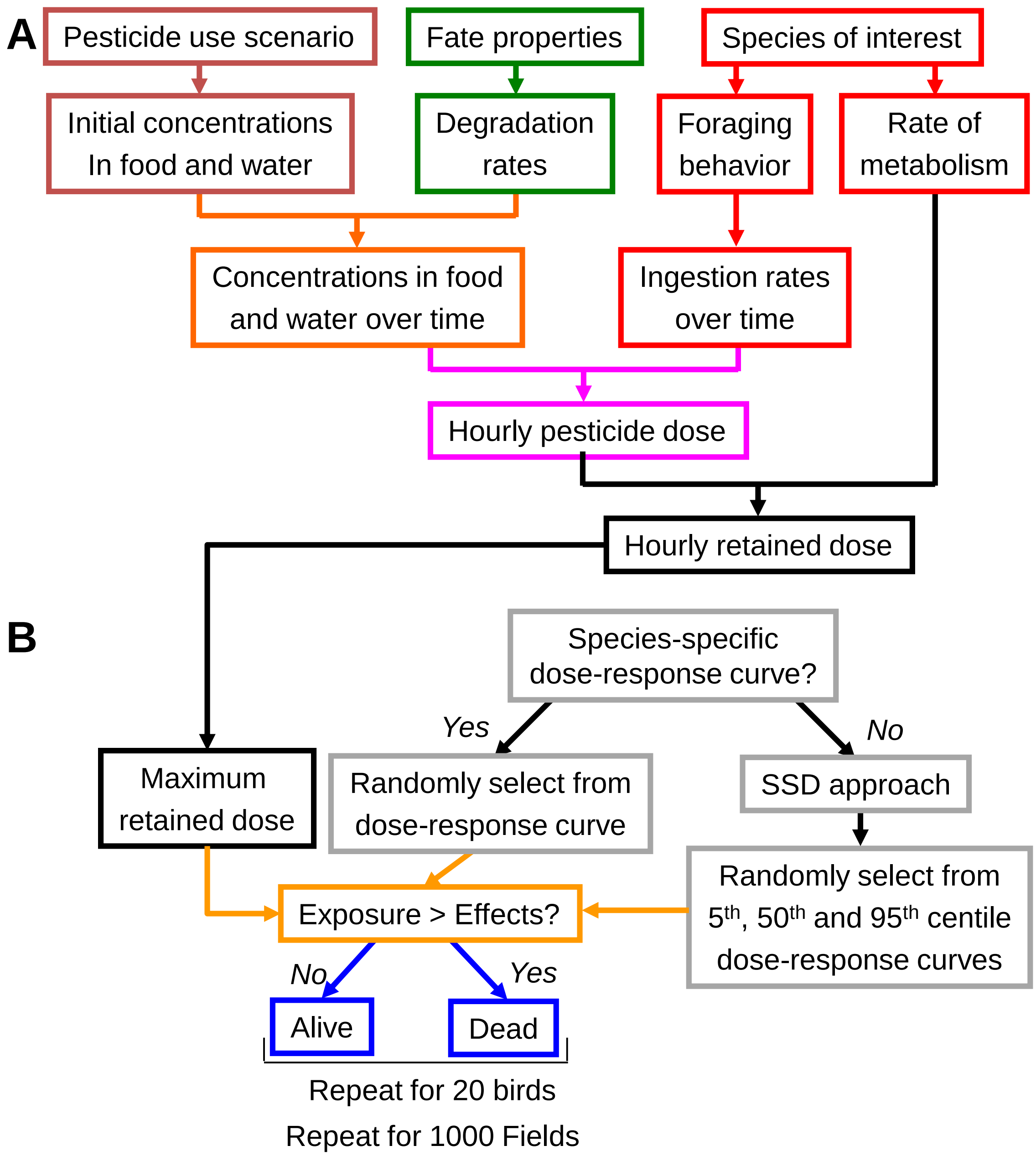

Fig. SI 1 Components of acute portion of LiquidPARAM (Fig. 4 from Moore et al. 2013)

The Z score is an estimate of where the maximum hourly retained dose would occur on the acute dose-response curve derived using a log-probit model. Next, the Z

score is converted to a value with a range from zero to one by entering the *Z* score in the standard normal distribution (mean = 0, standard deviation = 1). The resulting value is the individual risk estimate. The determination of whether a bird survives or dies is made by comparing the individual risk estimate to a randomly selected value from a uniform distribution with a range of zero to one. If the random number is less than the individual risk estimate, the individual is dead. Otherwise, the bird survives. This process is repeated for each of 20 birds on each of 1000 fields, as done by EPA (USEPA 2005).

Ideally, a similar methodology would be used to determine chronic effects with the goal of determining magnitude of effect to each bird rather than the acute binary effect of alive or dead. In the case of CPY, however, no chronic studies were available for birds with a sufficient number of treatments to enable derivation of a dose-response curve (see section 5 in Moore et al. 2013). For this assessment, we estimated the probabilities that the maximum chronic *TDI* exceeded the NOEL and the LOEL for the most sensitive species tested.

Section 1.2 describes the equations and inputs used in the exposure modeling conducted for flowable CPY.

1.2 Input Parameters for Exposure Component of LiquidPARAM

Number of applications and application interval. The model allows use of 1, 2 or 3 pesticide applications. For each pattern of use of CPY, the maximum number of applications and minimum interval between applications permitted on the label of Lorsban® Advanced were used in simulations (Table SI 1). For alfalfa, we assumed that there would be 3 applications, although the label permits up to 4 applications per season. Currently, LiquidPARAM lacks the capability to model 4 applications. This is a limitation of the model. Residue levels of CPY are not expected to accumulate to substantially higher levels with successive applications because of the short half-life of CPY on food items (less than 3 d, see below) and the minimum re-treatment interval of 10 d in alfalfa. Not being able to model the fourth application would be of greater concern for more persistent pesticides.

Application method and fraction of field treated. For each pattern of use, the user must choose from one of three applications methods, i.e., in-furrow, banded, or broadcast. Distance between crop rows and row width are a function of crop type and method of application. In the banded and in-furrow application scenarios, CPY is not spread evenly throughout the field, but is concentrated on the planted rows. These factors were accounted for by considering the width of the application bands and the distance between rows to calculate the fraction of the total field area treated. For broadcast application scenarios (e.g., foliar spray, airblast), CPY is evenly spread over the entire field and, therefore the fraction of total field treated is equal to 1.0. Based on the review of patterns of use of Lorsban® Advanced (Gomez 2009; Solomon et al. 2013), broadcast applications were assumed for all uses except broccoli, field corn and sweet corn. For corn, banded application is generally used for the second post-plant application (Solomon et al. 2013). For broccoli, banded application is generally used for all applications, either at-plant or post-plant. For banded applications in corn, the width of the band was assumed to be 18 cm (7 in) with row spacings of 1.3 m (40 in) for field corn and 0.9 m (30 in) for sweet corn. For broccoli, the band width was assumed to be 20 cm (8 in) with a row spacing of 1.3 m (40 in).

For scenarios with broadcast application, the entire field was assumed to be treated. Therefore, all food items on the field were assumed to have residues of CPY. In-furrow or banded applications are limited to the portion of the treated field constituting furrows or bands. Because some invertebrates are mobile, the model assumes that all invertebrates on the field are contaminated, which is the same conservative assumption made by EPA (USEPA 2005). Concentrations of CPY in invertebrates with banded or in-furrow treatment are not simply the average field application rate times the RUD (residues from a unit dosage, i.e., mg ai kg^{-1} ww lb^{-1} ai A^{-1}). Instead, the concentrations in invertebrates are determined by multiplying the effective application rate in the treated portion of the field times the RUD. The effective application rate is the average application rate multiplied by the inverse of the fraction of field treated. Thus, for banded application in broccoli, where $1/5^{th}$ of the field is treated, concentrations of CPY are 5-fold greater than would be the case if the average field application rate had been used in the calculation. Conversely, seeds, fruits, grass, and broadleaf forage are assumed to occupy fixed positions in the treated field. Therefore, the fraction of these items that are contaminated with CPY is equal to the fraction of field treated. For vegetative food items, the average concentration of CPY across the treated field is unaffected by consideration of fraction of field treated (i.e., greater concentrations in treated areas is offset by lesser portions of field being treated). Because exposure of birds is averaged over space and time, in LiquidPARAM, there is no need to consider fraction of field treated when calculating concentrations of CPY predicted for the plants in the diets of birds. This was also the case in TIM for fruits, grass and broadleaf foliage (USEPA 2005).

Application rate. In LiquidPARAM, application rate is a user-defined parameter for each application. For this assessment, application rates were set to the maximum labeled rates for Lorsban® Advanced (Table SI 1). Thus, the most conservative values were used for application rate.

Table SI 1 Exposure scenarios for Lorsban® Advanced

Crop	Use pattern	Application rate		Focal bird species
		kg ha^{-1}	lb A^{-1}	
Alfalfa	Southern Plains – applied broadcast with 10-d interval	1.05 0.53	0.94 & 0.47	Dickcissel, Mourning dove, Red-winged blackbird, Vesper sparrow, Western meadowlark
Almond	California - applied airblast post-plant 2X (May, hull-split) with 10-d interval	2.07	1.88	Abert's towhee, American crow, Blue grosbeak, Mourning dove, Red-winged blackbird
Apple	Northwest - applied airblast delayed dormant to petal fall	2.11	1.88	American crow, Blue grosbeak, Mourning dove, Red-winged blackbird
Broccoli	California - applied band at-plant and post-plant 3X with 10-d interval	2.36	2.11	American crow, Horned lark, Mourning dove, Red-winged blackbird
Cherry	Michigan - applied broadcast post-plant	2.11	1.88	American crow, Blue grosbeak, Mourning dove, Red-winged blackbird
Corn	Midwest - applied broadcast at-plant and band post-plant 3X with 10-d interval	1.12	1	American robin, Horned lark, Killdeer, Mourning dove, Northern bobwhite, Red-winged blackbird, Vesper sparrow
Grape	California - applied airblast prior to bud break	2.11	1.88	American crow, Blue grosbeak, Mourning dove, Northern bobwhite, Red-winged blackbird
Grapefruit	Florida - applied airblast post-plant (Apr-Jun)	2.80	2.5	American crow, Blue grosbeak, Mourning dove, Northern bobwhite, Red-winged blackbird
Orange	California - applied airblast post-plant (May-Aug)	6.28	5.6	Abert's towhee, American crow, Blue grosbeak, Mourning dove, Red-winged blackbird
Pecan	Georgia - applied airblast 3X with 10-d interval	1.05	0.94	American crow, Blue grosbeak, Mourning dove, Northern bobwhite, Red-winged blackbird
Soybean	Louisiana - applied broadcast post-plant 3X with 14-d interval (May-Aug)	1.05	0.94	Blue grosbeak, Dickcissel, Horned lark, Indigo bunting, Mourning dove, Red-winged blackbird
Sweet corn	Florida - applied broadcast at-plant and band post-plant 3X with 10-d interval	1.12	1	American crow, Mourning dove, Northern bobwhite, Red-winged blackbird

Nomograms for vegetation and insects. Concentrations of pesticide on vegetation and insects immediately after application are not available for most uses of pesticides and this is also true for CPY. To address this issue in assessments of pesticides, a nomogram is generally used to estimate predicted concentrations of pesticide residues on food items consumed by wildlife. The Environmental Effects and Fate Division, U.S. Environmental Protection Agency uses nomograms, based on applications to terrestrial crops, to estimate exposure to non-target species (Baehr and Habig 2001). The terrestrial nomograms were described by Hoerger and Kenaga (1972) and Kenaga (1973) and subsequently re-evaluated by Fletcher et al. (1994). The nomograms produced by Fletcher et al. (1994) estimate residues on short grass, long grass, leafy crops and forage, fruits, and seeds. Residues from a unit dosage (RUDs) are calculated by dividing the measured concentrations from a variety of field studies by corresponding application rates. Concentrations of pesticide present on each food item are assumed to be directly proportional to rate of application. This method of normalization also assumes that mode of application is unimportant, and run-off from the plant is insignificant (Baehr and Habig 2001). The day zero values from the Fletcher et al. (1994) nomograms for the vegetation categories are presented in Table SI 2.

Table SI 2 Day 0 residue values (RUDs) on dietary item categories (Fletcher et al. 1994)

Category	N	RUD (mg ai kg^{-1} ww lb^{-1} ai A^{-1})			
		Minimum	Maximum	Mean	Standard deviation
Short range grass	18	15.3	194	84.8	60.3
Long grass	46	0.12	197	36	40.6
Leaves, leafy crops	152	0.23	296	35	45
Forage (legumes)	96	0.05	350	45	56.7
Pods and seeds (legumes)	26	0.05	24.6	4	5.9
Fruit	108	0	40.7	5.4	9.8

Numerous field studies have been conducted to determine concentrations of CPY on dietary items following application. These studies were reviewed with the goal of deriving CPY-specific RUDs for dietary items of birds feeding in orchards and for field and/or row crops. Because different classes of invertebrates had different concentrations, RUDs were derived for each of the following types of invertebrates: soil surface, below ground, foliage-dwelling, and flying. By using data for the day of application for vegetative items and peak values for invertebrates from day of application or the following day, means and standard deviations for each dietary item were calculated.

Because distributions for each RUD were intended to represent among-field variability, only one set of values per field were used in the calculations. Thus, if sample size was one for a field, then the raw data were used in the above calculations. If sample size was greater than one for a field, a mean was calculated for use in calculating among-field means and standard deviations. In cases where data were insufficient (i.e., grass for orchards, fruit for field and row crops), the standard nomograms used by EPA (USEPA 2004) were used. The final RUDs used in the assessment of the flowable formulation of CPY are shown (Table SI 3). In LiquidPARAM, the calculated means and standard deviations from field studies were used to parameterize lognormal distributions. In the modeling runs, random values were drawn from the RUD distributions for each application to each of the 1000 fields in a simulation. The randomly chosen values were then multiplied by the corresponding application rate to estimate starting residue concentrations on each of the avian dietary items.

Table SI 3 Day 0 residue values (RUDs) on dietary item categories for chlorpyrifos risk assessment

Crop type	Dietary item	RUD (mg ai kg^{-1} ww lb^{-1} ai A^{-1})			References
		Mean	Standard deviation	Sample size	
Orchards	Soil surface invertebrates	1.58	0.933	13	Frese et al. 2008, Gallagher et al. 1994, Lawrence 2006, McQuillen et al. 1998b, Wilkens et al. 2008
	Below ground invertebrates	0.14	**0.079**[b]	1	McQuillen et al. 1998b
	Foliage-dwelling invertebrates	14.6	12.8	11	Frese et al. 2008, Lawrence 2006, McQuillen et al. 1998b, Wilkens et al. 2008
	Flying invertebrates	0.145	**0.082**	1	McQuillen et al. 1998b
	Grass	*84.8*[a]	*60.3*	*18*	Fletcher et al. 1994
	Broadleaf forage	30.7	9.1	5	Frese et al. 2008, Gallagher et al. 1994
	Seeds	0.085	**0.048**	1	McQuillen et al. 1998b
	Fruits	0.746	0.250	12	Iwata et al. 1983
Field and Row Crops	Soil surface invertebrates	4.16	6.70	15	Brown et al. 2006, Dawson 1986a,b, Frey et al. 1994, McQuillen et al. 1998a, Schneider and Wilkens 2008
	Below ground invertebrates	1.48	**1.60**	1	McQuillen et al. 1998a
	Foliage-dwelling invertebrates	13.7	6.77	6	Brown et al. 2006, McQuillen et al. 1998a
	Flying invertebrates	0.13	**0.14**	1	McQuillen et al. 1998a
	Grass	148	205	12	Arch 2006, Booth et al. 2005, Brewer 1987, Myers et al. 1976, Racke and Robb 1994, Sears and Chapman 1979
	Broadleaf forage	122	68.8	5	Frey et al. 1994, McCall et al. 1984

Crop type	Dietary item	RUD (mg ai kg^{-1} ww lb^{-1} ai A^{-1})			References
		Mean	Standard deviation	Sample size	
	Seeds	4.55	2.94	4	Booth et al. 2005, McQuillen et al. 1998a
	Fruits	*5.52*	*9.8*	*108*	Fletcher et al. 1994

[a] In absence of chlorpyrifos-specific data, Fletcher et al. nomograms, indicated in italics, were used
[b] When n=1 (indicated in bold), standard deviations were calculated from coefficient of variation for all other dietary items within the crop type

Concentrations in drinking water. In LiquidPARAM, two sources of drinking water are available to birds on treated fields: puddles and dew on food items. Off-site sources of water are assumed to contain no CPY, as assumed in the EPA assessment for carbofuran (USEPA 2005).

Three puddle scenarios are available in LiquidPARAM to represent on-field sources of drinking water. One scenario assumes that puddles are present on the field from a precipitation event prior to or during application of CPY. Puddles are unlikely to be present on the day of application because farmers generally do not apply during or immediately following significant precipitation events. Such applications would lead to substantial losses of pesticide to runoff. In addition, use of heavy farm equipment on saturated fields would be difficult. A second scenario assumes that a rainfall event occurs one day after application. A third scenario assumes that rainfall is insufficient to create puddles on the treated area over the course of the entire exposure period modeled. In this scenario, dew is the only source of drinking water from on-field sources.

In the first two scenarios, puddles are assumed to persist for one day only, as was assumed in the EPA assessment for carbofuran (USEPA 2005). When puddles are not on the field, drinking water is assumed to be from dew present during the first 4 hr of each day, and from off-field sources for subsequent time steps. In this assessment, it was assumed that birds obtained drinking water from dew during the first morning of each application and from off-field sources in the afternoon, from on-field puddles on the day after each application, and then shifted back to dew and off-site sources on subsequent days. Assuming a significant rainfall event after each application on each field in the model is a conservative assumption.

Concentrations of CPY in puddles formed the day after application were assumed to equal concentrations of CPY in runoff water predicted from simulations. The PRZM model was used to estimate a mass of pesticide and a volume of runoff for each day simulated over a 36-year period (for additional details on the PRZM modeling, see Williams et al. 2013). These outputs were used to estimate the field-wide average runoff concentration of CPY for each precipitation event in the PRZM run that resulted in runoff on the day after pesticide application. Means and standard deviations were calculated for each pattern of use and used to parameterize a lognormal distribution of concentration in puddles on the day following application. Results of these simulations are shown in Table SI 4 for each of the patterns of use considered in this assessment (see Table SI 1).

Table SI 4 Day 1 puddle concentrations estimated from PRZM

Use pattern	Concentration (mg ai L^{-1} lb ai A^{-1})	
	Mean	Standard deviation
Alfalfa	0.122	0.0309
Almond	0.0442	0.0324
Apple/Cherry	0.00993	0.0191
Broccoli	0.0808	0.109
Corn	0.0599	0.0645
Grape	0.0247	0.0457
Grapefruit	0.00566	0.0139
Orange	0.0243	0.0170
Pecan	0.0429	0.0576
Soybean	0.025	0.0387
Sweet corn	0.0472	0.0618

Concentration of CPY in dew. The equilibrium partitioning model used in TIM was used to estimate the concentration of CPY in dew on the foliage of treated plants in LiquidPARAM. The equilibrium partitioning model assumes that CPY in a treated plant can associate with water or organic carbon in the foliage. The following equation was used to estimate CPY concentrations in dew (Equation SI 8):

$$C_w(dew) = \frac{C_k}{K_{oc}\ x\ f_{oc}} \qquad \text{(SI 8)}$$

where,

$C_w(dew)$ is the concentration of CPY in dew (mg L^{-1});

C_k is the concentration of CPY in broadleaf forage leaves (mg kg^{-1} ww);

K_{oc} is the organic-carbon partition coefficient for CPY (L kg^{-1}); and

f_{oc} is the fraction of organic carbon in leaves.

A K_{OC} of 8216 L kg^{-1} was used in the equation (Mackay et al. 2013). Using the same data as EPA has used (USEPA 2005), the f_{OC} value of 0.40 derived for alfalfa, clover, bluegrass, corn stalk, and small grain straw was used in LiquidPARAM.

Dissipation rates. Data from field studies of flowable CPY were used to derive the dissipation half-lives for below-ground invertebrates (Frese et al. 2008; Gallagher et al. 1994; Schneider and Wilkens 2008; Wilkens et al. 2008) and foliage-dwelling invertebrates (Brown et al. 2006; Frese et al. 2008; Wilkens et al. 2008). Each of these studies had at least 4 data points collected for free-ranging arthropods over a period of greater than 7 d. Assuming first-order kinetics, DT50s for below-ground invertebrates ranged from 1.82 (Gallagher et al. 1994) to 4.05 d (Wilkens et al. 2008). The corresponding range for foliage-dwelling invertebrates was 0.93 (Brown et al. 2006) to 3.09 d (Frese et al. 2008). Mean DT50s for below-ground invertebrates and foliage-dwelling invertebrates were 3.12 and 2.35 d, respectively. For this assessment, a mean DT50 of 2.86 d was assumed, which is the combined mean determined for below-ground and foliage-dwelling invertebrates.

As with insects, there are a number of field studies meeting the criterion of having at least 4 data points collected for vegetative dietary items over a period of greater than 7 d. The DT50s estimated for grass range from 0.39 to 6.69 d and have a mean of 2.92 d (Dawson 1987; Day 1986, Gale 1997; Portwood and Williams 1995). For broadleaf forage, DT50s range from 1.20 to 4.02 d in a representative leafy crop, i.e., sugar beet tops (Livingstone 2006a,b; Old 2005, 2006) with a mean of 2.09 d. The mean DT50s for grass and broadleaf forage were used in this assessment.

The mean half-life value ($t_{½}$) for each food item was used to calculate a mean dissipation rate (r) with Equation SI 9:

$$r = \frac{\ln(0.5)}{t_{\frac{1}{2}}} \qquad \text{(SI 9)}$$

The dissipation rates for avian food items calculated from the mean half-life values were 0.237, 0.332, and 0.242 d^{-1} for grass, broadleaf forage, and insects, respectively. These values convert to 0.00984, 0.0137 and 0.0101 hr^{-1} for grass, broadleaf forage, and insects, respectively. Because residues in seeds and fruit do not have data from which DT50s can be derived, the dissipation rate for residues on seeds and fruit was assumed to be equivalent to the dissipation rate for residues on grass.

To calculate concentrations in food items of wildlife in time steps following application of CPY, LiquidPARAM dissipates the time zero concentration in each field by use of the following formula (Equation SI 10):

$$C_k(t) = C_k(t_0)e^{-rt} \qquad \text{(SI 10)}$$

where,

$C_k(t)$ is the residue concentration in the k^{th} food item at time step t after treatment (mg kg^{-1});

$C_k(t_0)$ is the randomly selected starting residue concentration at time zero in the field of interest;

r is the dissipation rate constant for CPY in the k^{th} food item; and *t* is the time in one hr increments after CPY application.

Concentrations of CPY in water also decline over time. In TIM v1, it was not necessary to incorporate rate of dissipation in water because puddles were only assumed to last one day and, because of the 12-hr time step, no dissipation was assumed to occur while puddles remained on the field. Concentrations of CPY in dew are a function of the concentration in broadleaf foliage and thus a dissipation rate in water is not required for concentration in dew. Because of the 1-hr time step in LiquidPARAM, a rate of dissipation for CPY in water was calculated and incorporated in the model for puddles by use of the same equation used for food items. The half-life in water is 50.8 d (Mackay et al. 2013). Given a half-life of 50.8 d, the dissipation rate of CPY in water is 0.0136 d^{-1} or 0.000568 hr^{-1}.

Body mass. Individual body masses were used to calculate daily rates of ingestion of food and water for each focal species bird. There is a significant difference between masses of bodies of males and females in certain bird species. LiquidPARAM contains distributions for male, female, and combined (assuming 1:1 ratio of males to females) body mass. For this assessment, we assumed a combined distribution.

For each individual bird, a body mass was randomly drawn from a normal distribution that was based on empirical data collected for the focal species assuming combined sexes. The source of body mass data for focal species was Dunning (1993), except for American robin (Howell 1942), and northern bobwhite (Nelson and Martin 1953).

In several cases, a standard deviation (SD) was not reported for males or females of a species. In these cases, the standard deviation was estimated from the coefficient of variation determined for the other sex or for combined males and females. Table SI 5 lists the means and standard deviations for male, female, and combined body masses for each focal bird species.

Food ingestion rate. Free-living birds, unlike captive birds, expend energy foraging for prey, avoiding predators, defending territories, etc. As done by EPA (USEPA 2005), an allometric modeling approach based on free-living birds was used to estimate food intake rate for the focal species rather than the intake rates reported from studies of captive birds. Food intake rate was derived using (Equation SI 11):

Table SI 5 Mean and standard deviation (SD) for body weight of each focal bird species

Common name (scientific name)	Male body weight (g)		Female body weight (g)		Combined body weight (g)	
	Mean	SD	Mean	SD	Mean	SD
Abert's towhee (*Pipilo aberti*)	47.1	3.29	44.8	2.90	46.0	3.1
American crow (*Corvus brachyrhynchos*)	458	27.5	438	35.0	448	35.8
American robin (*Turdus migratorius*)[a]	84.8	1.50	75.0	2.40	77.3	0.36
Blue grosbeak (*Passerina* (*Guiraca*) *caerulea*)	29.3	1.42	27.5	2.20	28.4	1.40
Dickcissel (*Spiza americana*)	29.3	1.76	24.6	1.97	27.0	2.16
Horned lark (*Eremophila alpestris*)	31.9	1.91	30.8	2.46	31.4	2.51
Indigo bunting (*Passerina cyanea*)	14.9	1.39	14.1	1.41	14.5	1.40
Killdeer (*Charadrius vociferus*)	92.1	10.4	101	10.4	96.6	10.4
Mourning dove (*Zenaida macroura*)	123	1.85	115	1.76	119	1.80
Northern bobwhite (*Colinus virginianus*)[b]	173	10.4	170	13.6	172	13.7
Red-winged blackbird (*Agelaius phoeniceus*)	63.6	4.43	41.5	2.74	52.6	3.60
Vesper sparrow (*Pooecetes gramineus*)	26.5	1.59	24.9	1.99	25.7	2.06
Western meadowlark (*Sturnella neglecta*)	112	6.72	89.4	7.15	101	8.06

Source: Dunning (1993)
[a] Howell (1942)
[b] Nelson and Martin (1953)

$$FIR = \frac{FMR}{\sum_{i=1}^{n} AE_i \cdot GE_i} \quad \text{(SI 11)}$$

where,

FMR is normalized free metabolic rate (kcal kg^{-1} bw d^{-1});

AE_i is assimilation efficiency of i^{th} food item (unitless); and

GE_i is gross energy of i^{th} food item (kcal kg^{-1} ww).

The exposure portion of LiquidPARAM used the allometric relationships of Nagy et al. (1999) developed for passerines (e.g., American robin and vesper sparrow), charadriiforms (e.g., killdeer), and galliforms (e.g., northern bobwhite) to estimate the free metabolic rate for focal species in these three orders. The black-legged kittiwake was not included in the charadriiformes data set as it should have been in Nagy et al. (1999). This error was corrected in the regression analyses for free metabolic rate of charadriiformes conducted for this assessment. There were insufficient data to derive free metabolic rates for Columbiformes (e.g., mourning dove). For the mourning dove, the allometric model used was one derived for all bird species. All FMR equations had the general form (Equation SI 12):

$$FMR\left(\frac{kJ}{d}\right) = a \cdot BW(g)^b \quad \text{(SI 12)}$$

In LiquidPARAM, *FMR* was estimated by use of a probabilistic approach by incorporating a distribution for body mass (*BW*), rather than a point estimate, and by incorporating uncertainty resulting from lack of model fit (*LMF*) in the fitted allometric relationship (i.e., a normal distribution parameterized with a mean of zero and a standard deviation calculated as the square root of the unexplained sum of squares from the fitted allometric regression model). The slope (*a*) and power (*b*) parameters and unexplained sum of squares were based on regression analyses of the data reported in Nagy et al. (1999), assuming an underlying normal distribution (*N*) for the latter. The resulting equation for *FMR* for passerines was calculated (Equation SI 13):

$$FMR\ \left(\frac{kJ}{d}\right) = 10^{1.00225}\ x\ BW(g)^{0.69279}\ x\ (LMF = 10^{N(0,0.11212)}) \qquad \text{(SI 13)}$$

where,

N is a normal distribution with parameters mean and standard deviation in brackets.

Equations were developed for galliforms, charadriiforms, and all birds, respectively (Equations SI 14-16):

$$FMR\ \left(\frac{kJ}{d}\right) = 10^{-0.07193}\ x\ BW(g)^{0.96012}\ x\ (LMF = 10^{N(0,0.05020)}) \qquad \text{(SI 14)}$$

$$FMR\ \left(\frac{kJ}{d}\right) = 10^{0.92796}\ x\ BW\ (g)^{0.76852}\ x\ (LMF = 10^{N(0,0.12826)}) \qquad \text{(SI 15)}$$

$$FMR\ \left(\frac{kJ}{d}\right) = 10^{1.01945}\ x\ BW(g)^{0.68079}\ x\ (LMF = 10^{N(0,0.16532)}) \qquad \text{(SI 16)}$$

Assimilation efficiency and gross energy. To calculate rate of ingestion of food (*FIR*) for each bird, gross energy (*GE*) and assimilation efficiency (*AE*) are required for each dietary item. Combined, these two parameters yield the metabolizable energy (*ME* = *GE* x *AE*) of the dietary item. Gross energy content of a dietary item represents the total amount of energy available from a dietary item. Assimilation efficiency represents the proportion of available energy that an organism can obtain from a particular dietary item. Assimilation efficiencies of different dietary items were assigned beta distributions in Monte Carlo simulations. The parameters used to generate the distributions are shown in Table SI 6 and were based upon the measures of centrality and spread reported in the literature (see USEPA 1993 for a summary). As was done by EPA (USEPA 2005), distributions of efficiencies of assimilation were scaled to avoid implausibly small or large values (Equation SI 17):

$$AE_{scaled} = AE_{minimum} + AE_{mean}\ x\ AE_{range} \qquad \text{(SI 17)}$$

Gross energy values for food items were also obtained from the Wildlife Exposure Factors Handbook (USEPA 1993) (Table SI 7). In LiquidPARAM, a lognormal distribution was assumed for gross energy of each food item, as was assumed by EPA (USEPA 2005). Distributions were truncated at the 0.01th and 99.99th centiles to avoid implausibly small and large values, respectively.

Table SI 6 Assimilation efficiencies for birds consuming food items

Item	Statistical parameter							Scaled assimilation efficiency
	Mean	SD	Alpha	Beta	Minimum	Maximum	Range	
Insects	0.72	0.051	55.1	21.4	0.513	0.880	0.367	0.777
Seeds	0.75	0.090	16.6	5.54	0.366	0.970	0.604	0.819
Fruits	0.64	0.150	5.91	3.33	0.118	0.982	0.865	0.671
Grass	0.47	0.096	12.2	13.8	0.156	0.801	0.645	0.459
Broadleaf forage	0.47	0.096	12.2	13.8	0.156	0.801	0.645	0.459

Table SI 7 Gross energies of food items

Item	Gross energy (kcal kg^{-1} ww)			
	Mean	SD	Minimum	Maximum
Insects	1600	260	866	2879
Seeds	4626	998	2045	9995
Fruits	1100	300	391	2873
Grass	1300	130	892	1874
Broadleaf forage	634	74	404	967

Water content. Birds obtain water from their food as well as natural water bodies, puddles and dew. Water contents of food items consumed by birds are the same as used by EPA (USEPA 2005) (Table SI 8).

Table SI 8 Water content of food items

Item	Fractional water content
Insects	0.69
Grass (young)	0.79
Broadleaf forage	0.85
Seeds	0.093
Fruits	0.77

Water ingestion rate (WIR). The daily water requirement of a bird is derived from the daily rate of consumption of water (the daily water flux). A proportion of the daily water flux is obtained from the diet and the remainder through drinking water. The amount of water that a bird obtains from drinking water was estimated (Equation SI 18):

$$WIR\ \left(\frac{mL}{d}\right) = Daily\ Water\ Flux - Food\ Water\ Content \qquad \text{(SI 18)}$$

The water flux used in LiquidPARAM was derived from data reported in Nagy and Peterson (1988). This study developed allometric relationships between bird body mass and daily water flux. From the data reported in Nagy and Peterson (1988), water fluxes were calculated for passerine birds and all birds and an allometric model with a general form (Equation SI 19) was developed for each species:

$$Daily\ Water\ Flux\left(\frac{mL}{d}\right) = a\ x\ BW(g)^{b} \quad \text{(SI 19)}$$

Using a probabilistic approach, a frequency distribution was used for body mass rather than a point estimate and uncertainty resulting from a lack of model fit (LMF) was accounted for. This was done by parameterizing a normal distribution with a mean of zero and a standard deviation calculated as the square root of the unexplained sum of squares from the fitted allometric regression model. The slope (a) and power (b) parameters and unexplained sum of squares were based on the regression analysis of the data reported in Nagy and Peterson (1988), assuming an underlying normal distribution (N) for the latter. The resulting equations for daily water flux for passerines (Equation SI 20) and all birds (Equation SI 21) were:

$$Daily\ Water\ Flux\ \left(\frac{mL}{d}\right) = 10^{-0.21901}\ x\ BW(g)^{1.07296}\ x\ \left(LMF = 10^{N(0,0.16146)}\right) \quad \text{(SI 20)}$$

$$Daily\ Water\ Flux\ \left(\frac{mL}{d}\right) = 10^{0.16994}\ x\ BW(g)^{0.72582}\ x\ \left(LMF = 10^{N(0,0.22933)}\right) \quad \text{(SI 21)}$$

The proportion of daily water requirement obtained from the diet is derived by multiplying the daily fresh mass of each food item by the corresponding fractional water content of the item (Equation SI 22):

$$Food\ Water\ \left(\frac{mL}{d}\right) = TDI\ x\ \sum_{i=1}^{k} P_i\ x\ PWC_i \quad \text{(SI 22)}$$

where,

TDI is the total daily intake (g d^{-1});

P_i is the proportion of total daily intake attributed to the i^{th} food item; and

PWC_i is the proportion water content in the i^{th} food item (unitless).

Diets of focal species are described below.

Rate of metabolism and elimination of chlorpyrifos by birds. Several acute oral and dietary studies have been conducted to determine inhibition of brain AChE activity and recovery in birds following exposure to varying doses of CPY. The response of cholinesterase activity to acute oral CPY exposure has been studied in chickens, northern bobwhite, Japanese quail, red-legged partridge, European starling, and red-winged blackbird (Burn and Leighton 1996; Cairns et al. 1991; Johnston et al. 1994, Maguire and Williams 1987; Meyers et al. 1992; Thompson et al. 1988; Vodela and Dalvi 1995). Survival and brain AChE activity were measured at different times after dosing. Inhibition of brain AChE activity from acute exposure to CPY occurred in dose- and time-dependent manners. Statistically detectable inhibition occurred several hours after dosing and remained detectable for approximately 24 hr following exposure. Mortality occurred when AChE activities approached 40% of the mean activity in brains of control birds. Substantial recovery of brain AChE activity occurred within 24 hr with reactivation of brain AChE, even in dead birds.

A study in which laying hens were exposed to ^{14}C-labeled CPY determined the rate of elimination of CPY by birds (Bauriedel 1986). Single-comb white leghorn laying hens were dosed daily for 10 d with gelatin capsules containing approximately 2.26 mg ^{14}C-CPY with an average of 164 μCi of radioactivity. Body masses and rates of consumption of feed did not differ from controls and egg production ranged from 80 to 100% of the production observed in controls. In addition, no gross abnormalities were observed during necropsy. Replicates of excreta, egg yolk, egg white, whole blood, contents of the gastrointestinal tract, thigh muscle, breast muscle, liver, kidney, fat, skin, gizzard, heart, and ova were pooled by subset to facilitate quantitative analyses. Concentrations of CPY, as determined by ^{14}C in tissues measured 12 hr following the last dose, ranged from 0.010 mg ai kg^{-1} ww in the breast muscle to 0.198 mg ai kg^{-1} ww in the fat. Greatest concentrations of CPY were found in the gastrointestinal tract contents (up to 0.393 mg ai kg^{-1} ww). Excreta consisted primarily of TCP and contained 88.4 to 94.5% of the administered dose. A single compartment elimination model was used to obtain an elimination rate constant of 0.512 d^{-1} or a half-life of approximately 1 d. A half-life of 1 d for metabolism and elimination of CPY in birds was assumed for this assessment.

Temporal foraging behavior. Chlorpyrifos is often applied when birds are nesting in or near treated fields. The time and energy demands on birds are greater during nesting due to the requirements of the nestlings and the environmental factors affecting the adults (Best 1977; Heagy and Best 1983). As a result, nesting birds in agro-ecosystems, particularly small passerines, must make frequent foraging trips for food throughout the daylight hours. Male and female field sparrows (*Spizella pusilla*) make approximately 3 to 6 feeding trips per hr (Best 1977). Eastern bluebirds (*Sialia sialis*) average 4.8 to 6.5 feeding trips per hr, depending on brood size and sex of the parent (Pinkowski 1978). Gray catbirds (*Dumetella carolinensis*) make approximately 10 to 13 feeding trips per hr (Johnson and Best 1982). For great tits (*Parus major*), the number of feeding trips per nest (males and females combined) varies from about 10 to 40 per hr (Kluijver 1950). The combined number of feeding trips for male and female brown thrashers (*Toxostoma rufum*) varies from 6 to 10 per hr (Heagy and Best 1983). The average number of feedings per hr during care of nestlings is 9.6 for yellow-headed blackbirds, *Xanthocephalus xanthocephalus* (Fautin 1941).

Feeding typically begins about sunrise and continues to sunset with the most active feeding occurring in the early morning and early evening for a variety of passerine species including European starling, *Sturnus vulgaris* (Kessel 1957), field sparrow (Best 1977), gray catbird (Johnson and Best 1982), yellow-headed blackbird (Fautin 1941), and great tit (Kluijver 1950). The feeding rate of eastern bluebirds is relatively constant throughout the day with females having a peak rate early in the day and males having a peak rate later in the day (Pinkowski 1978). Brown thrashers tend to have a relatively constant feeding rate throughout the day but with a peak in the evening hours (Heagy and Best 1983).

LiquidPARAM has three options that the user may choose from for temporal foraging pattern: 1) equal feeding throughout the daylight hours, 2) feeding only during the first two hr and last two hr of daylight (a gorge-feeding scenario), or 3) bimodal feeding with slightly more feeding in the early morning and evening (**Error! Reference ource not found.**).

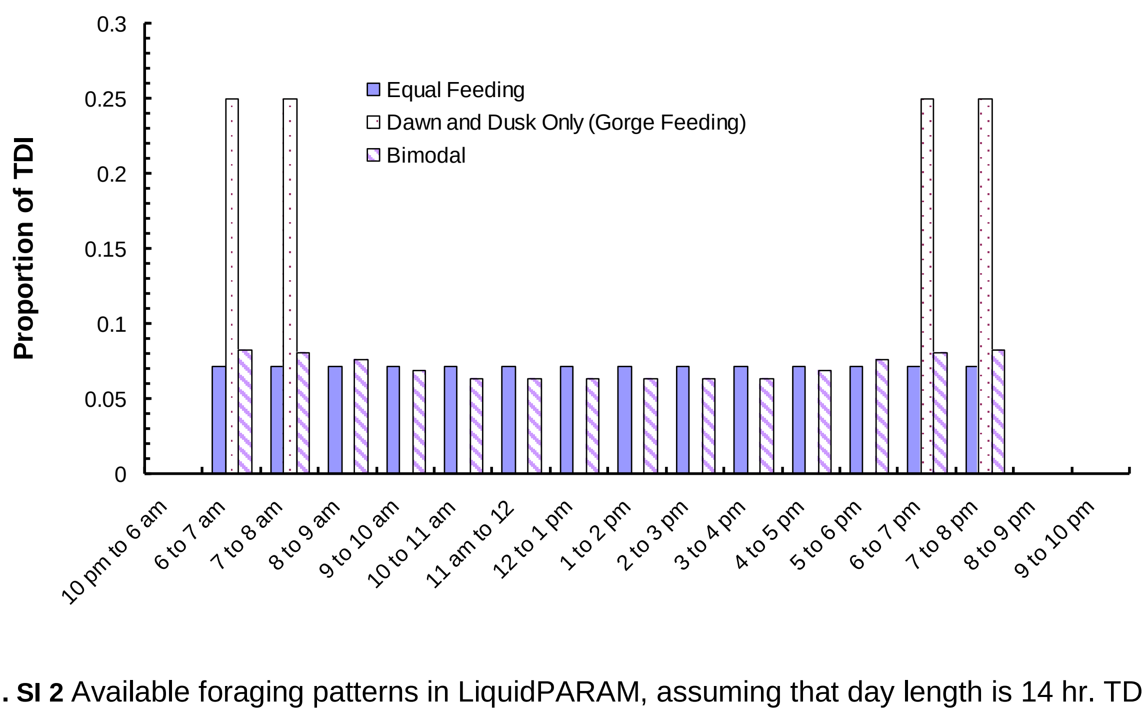

Fig. SI 2 Available foraging patterns in LiquidPARAM, assuming that day length is 14 hr. TDI is total daily intake

The relative proportions of daily intake of food remain constant for different lengths of daylight. However, to ensure that the total of all the daylight time steps is always one (i.e., is equal to the total daily intake) the absolute values are adjusted for length of day. Thus, if there are 12 daylight hr and equal feeding throughout the day is assumed, the proportion of total daily intake for each hourly time step will be 0.0833 (i.e., 1/12). Most nesting bird species have relatively constant feeding activity throughout the day with slight peaks shortly after sunrise and shortly before dusk. This pattern is referred to as a “bimodal feeding pattern” and was the pattern selected for all species in this assessment. This pattern is the typical foraging pattern for bird species, except in a few instances (e.g., waterfowl may gorge feed during migration).

Proportion time on field. Risks to birds from exposure to flowable CPY are linked to the proportion of time individual birds spend on treated fields. A review of the literature found few studies on foraging behavior of birds on agricultural fields. Most studies on this topic reported abundances of different bird species in edge habitats and in row or field crops (see summary by Best and Murray 2003).

The available studies generally reported a habitat preference in one of the following categories: outside of agricultural fields, edge of fields, or center of fields (Best et al. 1995; Best and Murray 2003; Boutin et al. 1999; Crocker et al. 1998; Parnell 2002, Prosser 1999). Foraging by birds typically occurs near the perimeter of agricultural fields. These areas provide a greater abundance and diversity of food than the interior of the field and offer greater protection (Best et al. 1995). Exceptions to this habitat preference have been reported. For example, horned larks in southern Ontario were observed more often in the interior of soybean fields (Boutin et al. 1999). Horned larks have been observed to selectively nest and use tilled row crops and sparsely vegetated areas (Best et al. 1995).

Although some species use agricultural habitats, they usually occur in relatively small numbers (Best et al. 1995). Bird species will be more attracted to fields with crops that they consume (e.g., red-winged blackbirds and corn) (Boutin et al. 1999). Birds also demonstrate a preference according to the height of the crop. Horned larks are more abundant in soybean than late-stage corn fields, because they prefer to forage in fields with limited cover (Boutin et al. 1999).

For proportion of time that birds spend foraging in treated fields (PT), there are three major sources of variation: variation among populations due primarily to differences in quality of habitat among locations, variation among individuals within each population due to, for example, proximity of territories to the treated field or fields, and temporal variation in foraging behavior of individuals. LiquidPARAM explicitly accounts for the first two sources of variation in proportion of time foraging in treated fields (Fig. SI 3). To account for among-population (= among-field) variation in PT for a given focal species, LiquidPARAM randomly samples from a beta distribution that represents variation in most likely *PT* among fields (Fig. SI 3A). The output from this step is 1000 values for most likely population *PT*, i.e., one value per field. The next step is to determine individual *PT*s for the 20 birds that occur in each field in the model. In LiquidPARAM, a betapert distribution is created for each field using the most likely population *PT* for that field and a minimum value of zero and maximum value of one as the inputs for the distribution (Fig. SI 3B). The betapert distribution is useful for modeling situations in which a variable is bounded with minimum and maximum values and for which a "most likely value" is known or can be estimated (Vose 1996). In this regard, the betapert distribution is essentially a smoother version of a triangular distribution. When the minimum and maximum values for a betapert distribution are zero and one, respectively, the following formulae may be used to convert between a betapert and a beta distribution (Equations SI 23 and 24):

$$\alpha = 6 \text{ x } c, \text{ min } \alpha > 0.3, \text{ max } \alpha < 5.7 \qquad \text{(SI 23)}$$

$$\beta = 1 - \alpha \qquad \text{(SI 24)}$$

where α and β are beta distribution parameters and c is the most likely value.

No quantitative information is available on variation in *PT* among individuals within a field. However, several studies indicate that this variation can be high (Crocker et al. 2002; Knapton and Mineau 1995). To maximize uncertainty for the estimate of variation in *PT* among individuals, a minimum value of zero and a maximum value of one were used for each field distribution (Fig. SI 3B). The output of this step is 20 values of *PT*, i.e., one *PT* value for each individual in the field (Fig. SI 3C).

During nesting, short-term (i.e., hour by hour) variation in *PT* for a given individual certainly occurs but has not been quantified in agro-ecosystems in the US. Small passerines typically have small territories and make frequent foraging trips even within an hourly time step (see preceding section). As a result, there will be temporal averaging of *PT* within each hourly time step. Thus, hourly temporal variation should be relatively minor for most territorial individuals during nesting. LiquidPARAM does not account for hourly variation in *PT*.

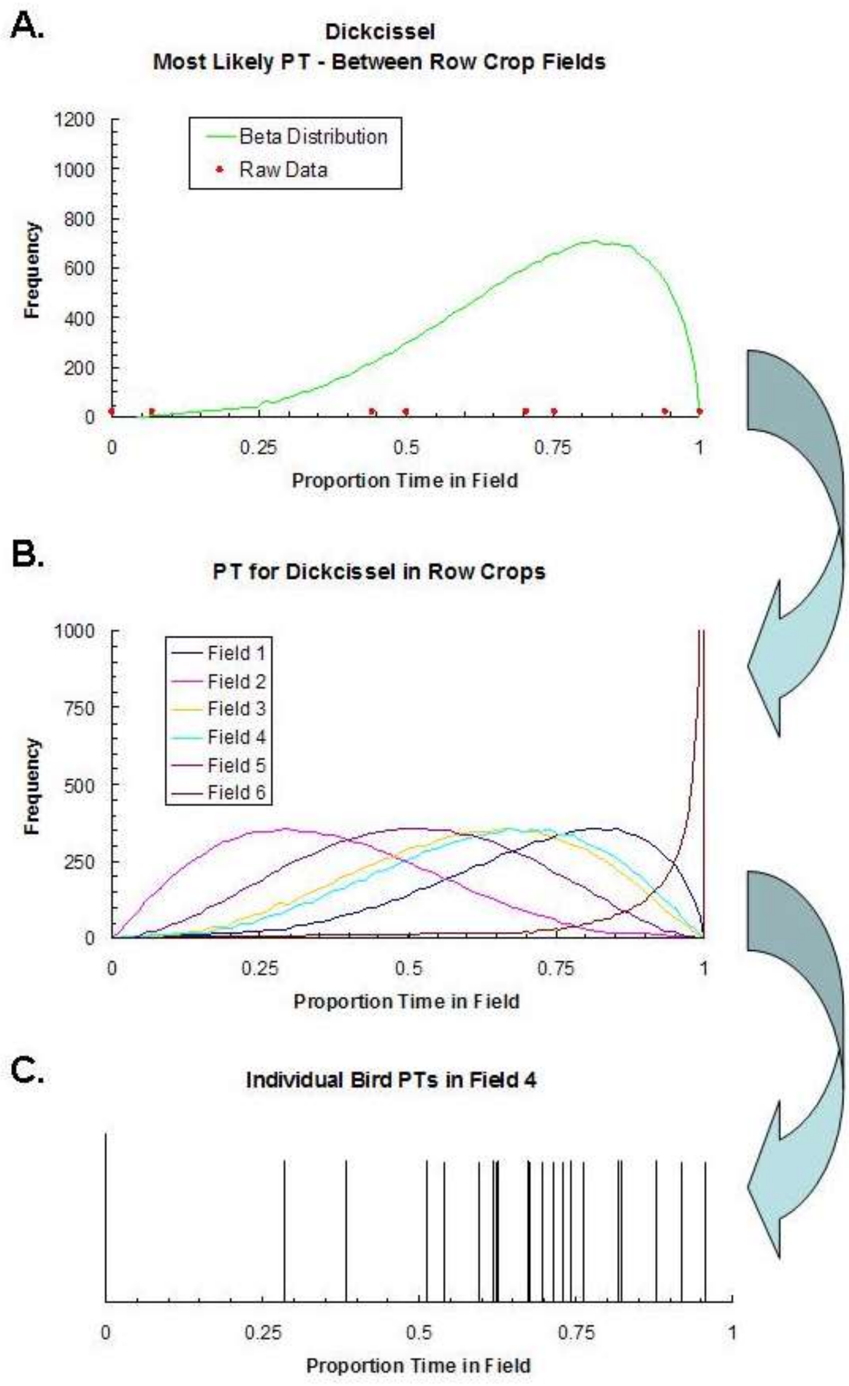

Fig. SI 3 Approach to estimate proportion of time foraging in fields. The first step is to sample from a beta distribution (A) to generate a most likely *PT* value for each of 1000 fields. The most likely *PT* value, a minimum of 0 and a maximum of 1 are used as inputs to derive a betapert distribution for each field (B). The final step is to generate a *PT* value for each of 20 individual birds on each field (C) by sampling from the field betapert distribution

The proportion of individual birds observed in crop fields versus field edges for species that frequent corn and cotton fields in different states and with different surrounding habitats has been determined from published studies on birds (Best and Murray 2003). For any given field, the proportion of observations of birds in crop fields versus field edges is an indication of most likely population PT. A similar compendium was prepared by Dr. Louis Best (raw data from Booth et al. 1989) for alfalfa. Values of PT calculated from the data presented by Best and Murray (Best and Murray 2003) were used as the basis for deriving beta distributions for each focal bird species. This exercise was done separately for row crops (e.g., corn and cotton combined to represent row crops) and alfalfa. Beta distributions are approximate fits to the data because sample size was insufficient to fit the data using the maximum likelihood method. In all cases, the chosen beta distributions had a greater arithmetic mean PT than did the corresponding data. Thus, distributions for most likely population PT are somewhat conservative (see Fig. SI 4 and Fig. SI 5). Input parameters for the beta distributions that represent among population (= among field) variability in proportion of time foraging in fields are provided (Table SI 9).

Table SI 9 Beta distribution parameters for between-field variability in PT

Species	Crop	Beta distribution parameters			
		Alpha	Beta	Min	Max
Abert's towhee	Orchard	10	6	0	0.8
American crow	Row/Orchard	1.1	10	0	1
American robin	Row	1.3	7	0	0.6
Blue grosbeak	Row/Orchard	1.2	3	0	1
Dickcissel	Alfalfa	2	7	0	0.8
Dickcissel	Row	4	1.6	0	1
Horned lark	Row	3	0.8	0.1	1
Indigo bunting	Row	1.2	4	0	1
Killdeer	Row	1.9	1.1	0	1
Mourning dove	Alfalfa	1.2	15	0	1
Mourning dove	Row/Orchard	1.2	3	0	1
Northern bobwhite	Row/Orchard	1.7	9	0	0.75
Red-winged blackbird	Alfalfa	1.2	5.5	0	1
Red-winged blackbird	Row/Orchard	1.1	1.1	0	1
Vesper sparrow	Alfalfa	2	3.2	0	1
Vesper sparrow	Row	10	15	0	0.7
Western meadowlark	Alfalfa	1.7	4.5	0	1

Diet. The diets of the focal bird species are reported in Table SI 10. Fractions are based on averages calculated from available data. Diets were calculated primarily from the observed diets during the breeding season or summer months to focus on the time period when CPY is most likely to be applied. Diet was assumed to be constant throughout the application period for all birds within a species.

Table SI 10 Proportions of food items in the diet by mass of focal bird species during the spring and summer

Species	Food type					References
	Insects	Seeds	Fruits	Grasses	Broadleaf forage	
Abert's towhee (*Pipilo aberti*)	0.97	0.03	0	0	0	Rosenberg et al. 1991, Rosenberg and Rosenberg 1982
American crow (*Corvus brachyrhynchos*)	0.45	0.50	0.05	0	0	Imler 1939, Martin et al. 1961
American robin (*Turdus migratorius*)	0.80	0.20	0	0	0	Martin et al. 1961)
Blue grosbeak (*Passerina caerulea*)	0.73	0.27	0	0	0	Martin et al. 1961, Rosenberg and Rosenberg 1982
Dickcissel (*Spiza americana*)	0.70	0.30	0	0	0	Gross 1921, Martin et al. 1961
Horned lark (*Eremophila alpestris*)	0.64	0.36	0	0	0	Martin et al. 1961, Rotenberry 1980
Indigo bunting (*Passerina cyanea*)	0.78	0.22	0	0	0	Payne 2006
Killdeer (*Charadrius vociferus*)	1	0	0	0	0	Fair et al. 1995
Mourning dove (*Zenaida macroura*)	0	1	0	0	0	Martin et al. 1961, Mirarchi and Baskett 1994
Northern bobwhite (*Colinus virginianus*)	0.44	0.56	0	0	0	Peoples et al. 1994
Red-winged blackbird (*Agelaius phoeniceus*)	0.40	0.60	0	0	0	Martin et al. 1961
Vesper sparrow (*Pooecetes gramineus*)	0.41	0.59	0	0	0	Martin et al. 1961
Western meadowlark (*Sturnella neglecta*)	0.81	0.19	0	0	0	Martin et al. 1961

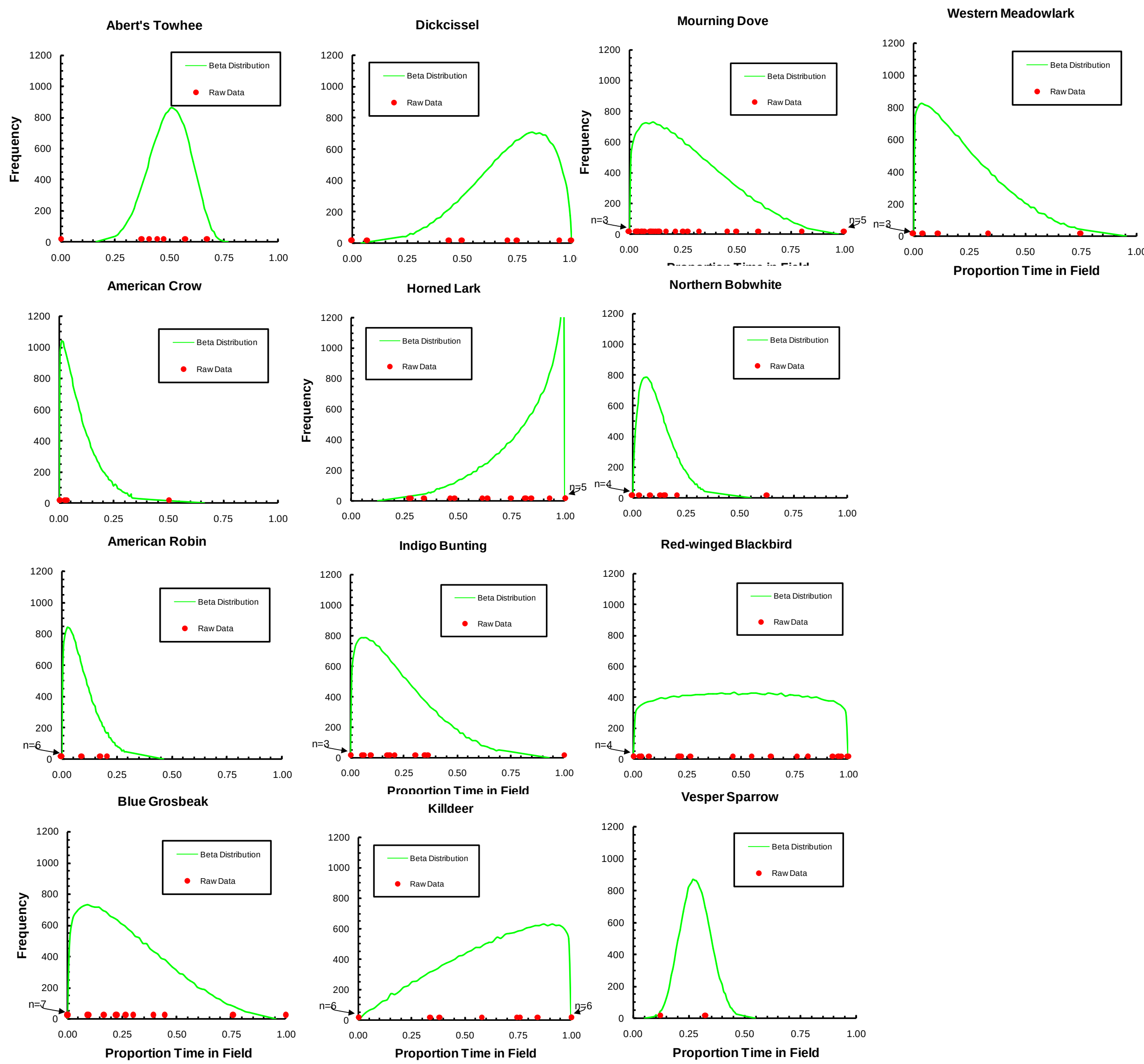

Fig. SI 4 Beta distributions for between-field variation in most likely PT for row crops

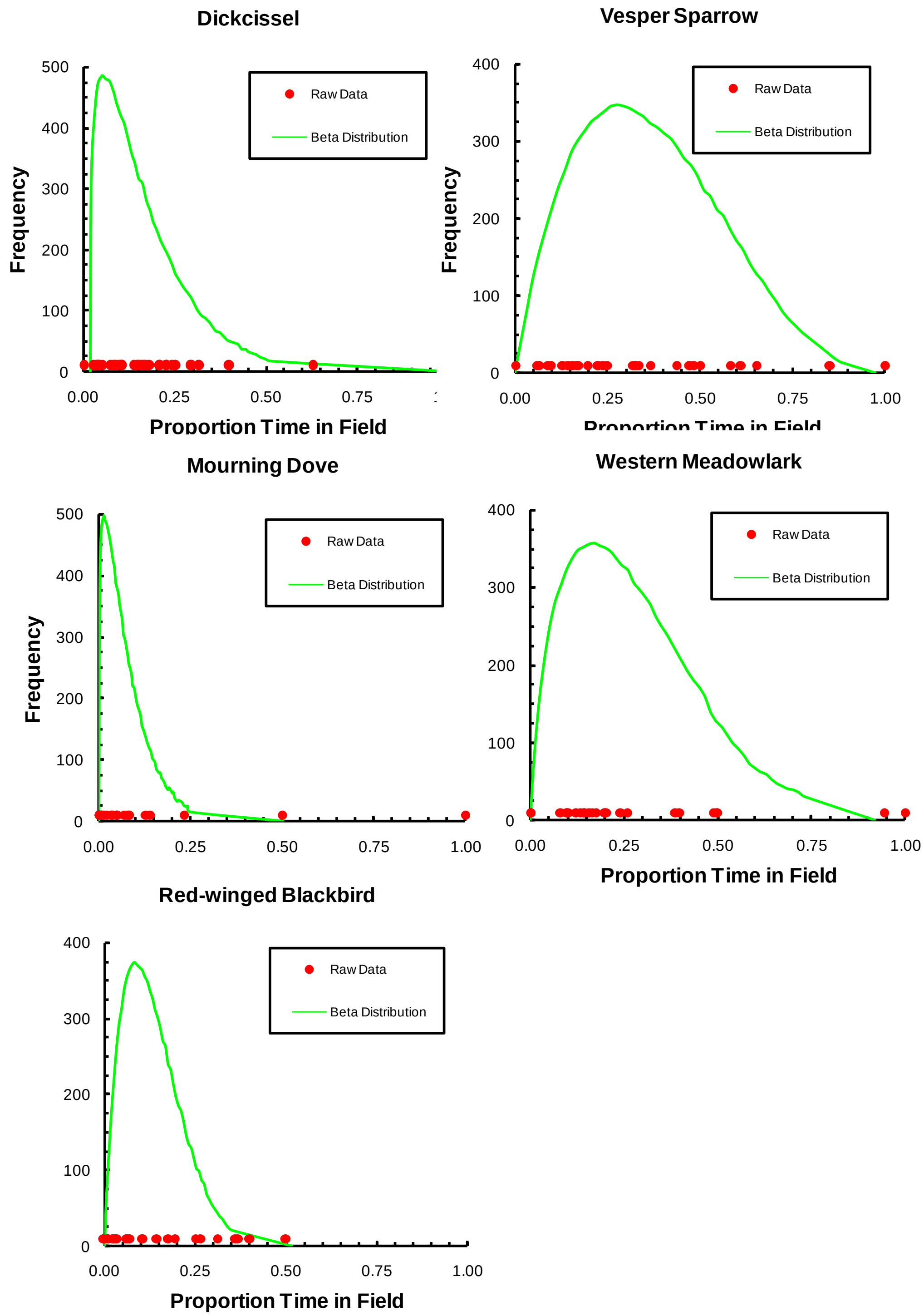

Fig. SI 5 Beta distributions for between-field variation in most likely PT for alfalfa

Avoidance. A bird's ability to detect CPY and subsequently avoid consuming contaminated food impacts the potential for toxicity. The smaller the detection threshold, the fewer adverse effects that will be experienced. A dietary choice test was conducted to determine the ability of northern bobwhites (*Colinus virginianus*) to detect and avoid food treated with CPY by Bennett (1989). Three scenarios were investigated: 1) birds were offered a feeder of treated and a feeder of untreated food simultaneously, 2) birds were offered 5 feeders with treated and 5 feeders with untreated food simultaneously, and 3) birds were offered 9 feeders with treated and 1 feeder with untreated food simultaneously. Fourteen-day old northern bobwhite chicks were presented with the test diets for 5 d, and the feeders were randomly re-positioned each day. The discrimination threshold was determined by comparing the volumes of food consumed among the feeders. In the first scenario, birds consumed significantly more untreated food than treated food at and above the discrimination threshold of 63 mg ai kg^{-1} diet. Total food intake rates were unaffected compared to control birds that were only fed untreated food. Thresholds for discrimination for the second and third scenarios were 26 and 71 mg ai kg^{-1} diet, respectively. Mortality was only observed at concentrations exceeding the discrimination thresholds. Scenario three required the birds to sample more food trays to discriminate between treated and untreated food sources, and as a result, increased mortality was observed.

A study on mallard (*Anas platyrhynchos*) chicks exposed to both untreated food and food treated with CPY (Wildlife International (1978) was conducted as described in Kenaga et al. (1978). When offered food treated with CPY in corn oil and untreated food simultaneously, mallard ducklings preferentially chose untreated food at all concentrations tested (112 to 1124 mg ai kg^{-1} diet) and body masses did not decrease, indicating that the chicks could distinguish between treated and untreated food (Kenaga et al. 1978; Wildlife International 1978)

A study on northern bobwhite adults was conducted to determine whether the concentration of CPY in the diet affected food intake rate. In this study, birds were offered both treated and untreated diet simultaneously for 6 d (Stafford 2010). No reduction in body mass was observed in any of the treatment groups (0 to 240 mg ai kg^{-1} diet). There did not appear to be any indication that birds preferred untreated food or reduced food intake rate as concentration of CPY increased.

To determine the relationship between exposure and avoidance, we calculated reduction in CPY exposure due to aversion (i.e., preference for untreated diet versus treated diet) in all 3 studies (Equation SI 25):

$$PRE_{av} = (0.5 - PTD) x\ 2 \qquad \text{(SI 25)}$$

where PRE_{av} is the proportion reduction in exposure due to aversion, and PTD_t is the proportion of treated diet consumed. If there was no aversion or attraction to treated diet, *PTD* would be 0.5 and PRE_{av} would be 0. If birds only consumed untreated diet,

PRE_{av} would be 1 and if birds only consumed treated diet, PRE_{av} would be -1. For each of the three avoidance studies described above, a regression analysis was conducted to determine the relationship between concentration of CPY in the diet and proportion reduction in exposure due to aversion (Fig. SI 6). The results indicate strong relationships between PRE_{av} and concentration in the diet for bobwhite (Bennett 1989) and mallard (Wildlife International 1978). The relationship between PRE_{av} and concentration of CPY in the diet of bobwhite (Stafford 2010), however, was weak likely due to the lower concentrations of CPY used. For the aversion component of LiquidPARAM, we selected the regression model fitted to the bobwhite results (Bennett 1989) (Equation SI 26):

$$PRE_{av} = 0.1868 \times \ln(C_{diet}) - 0.5224 \qquad \text{(SI 26)}$$

where C_{diet} is dietary concentration (mg ai kg^{-1} diet). The regression models from the Wildlife International (1978) and Bennett (1989) studies are similar but the latter was chosen because it had more data points, a greater coefficient of determination (r^2 of 0.895 vs. 0.798) and was the more conservative model (i.e., greater concentrations required to cause the same level of aversion).

The following steps were used to determine the reduction in exposure due to aversion in LiquidPARAM: 1) at each hourly time step, a weighted dietary residue concentration was calculated by summing the products of the concentration and proportion in diet of each food item, 2) we then entered the weighted concentration of CPY in the diet into the regression model (Equation SI 26) to determine the proportion exposure reduction due to aversion, 3) proportion aversion was corrected such that all negative values were converted to zero (no aversion) and all values above 1 were equal to 1, and 4) hourly residue concentrations were multiplied by one minus the corrected proportion aversion values.

In addition to aversion, birds can also reduce exposure by reducing food intake rate. The latter might occur because birds feel sick following initial exposure. However, no relationship between average daily dose and intake of food intake was observed in any of the avoidance studies (Bennett 1989; Stafford 2010; Wildlife International 1978) (Fig. SI 7). Thus, the food reduction component of LiquidPARAM was turned off for analyses of exposure to CPY.

Averaging Period for Chronic Exposure. For CPY, number of eggs laid per hen was the most important factor leading to reduced reproductive success in the chronic reproduction study of mallard used to generate the chronic effects metrics for this assessment (Fink 1978a,b). See section 5 for additional details.

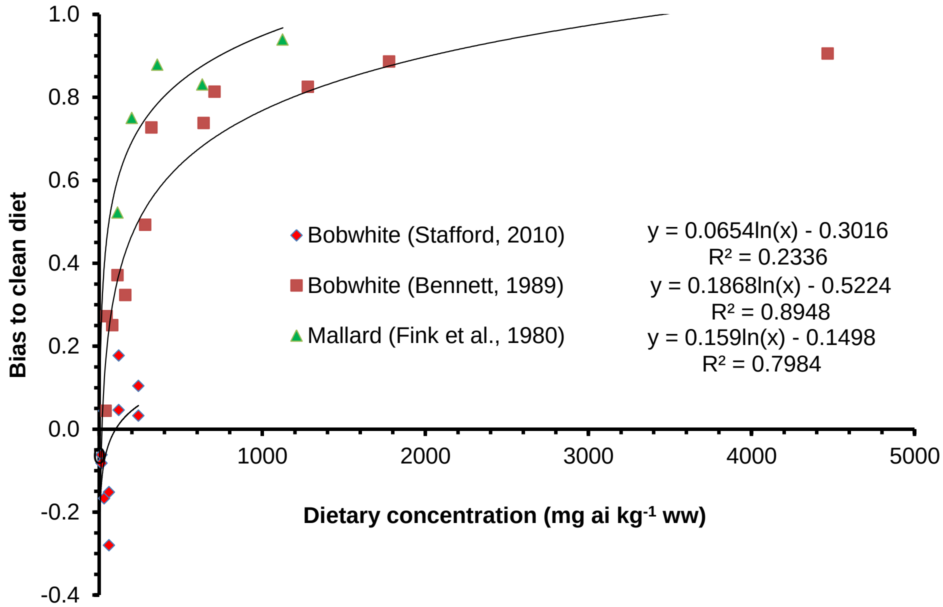

Fig. SI 6 Proportion reduction in exposure due to aversion versus dietary concentration of chlorpyrifos

This endpoint suggests that exposure during gestation was the critical period of exposure. The gestation period for mallards ranges from 23 to 30 d with a typical gestation period of 28 d (Dmitrieva and Gottlieb 1992; Palmer 1976). Therefore, a 28-d average total daily intake (TDI) was calculated for each day in the 60-d model runs for chronic exposure. The maximum 28-d average TDI that occurred during the 60-d simulation was compared to the NOEL and LOEL for each bird in each simulation.

1.3 Results of Exposure Modeling

The results of the acute and chronic simulations of exposure (Table SI 11 and Table SI 12, respectively) illustrate some of the major trends that emerged from the analyses. These include:

- Acute and chronic exposure estimates were variable within a species in each of the use patterns considered. Ratios of 75th to 25th centile exposure estimates differed by as little as several fold to as much as several orders of magnitude apart (Table SI 11 and Table SI 12).
- Species that have a large PT (e.g., horned lark, red-winged blackbird) had greater estimates of acute and chronic exposure than did species with smaller PT values (e.g., mourning dove, northern bobwhite).
- The crop with the greatest single rate of application (oranges) also produced the highest exposure estimates. Multiple applications only caused a modest increase in acute exposure (e.g., compare results for apple/cherry versus almond in Table SI 11), likely due to the relatively short half-life of CPY on dietary items. Multiple applications had a more pronounced influence on estimates of chronic

exposure because the application interval (i.e., 10 or 14 d depending on the crop) is shorter than the chronic averaging period of 28 d (Table SI 12).

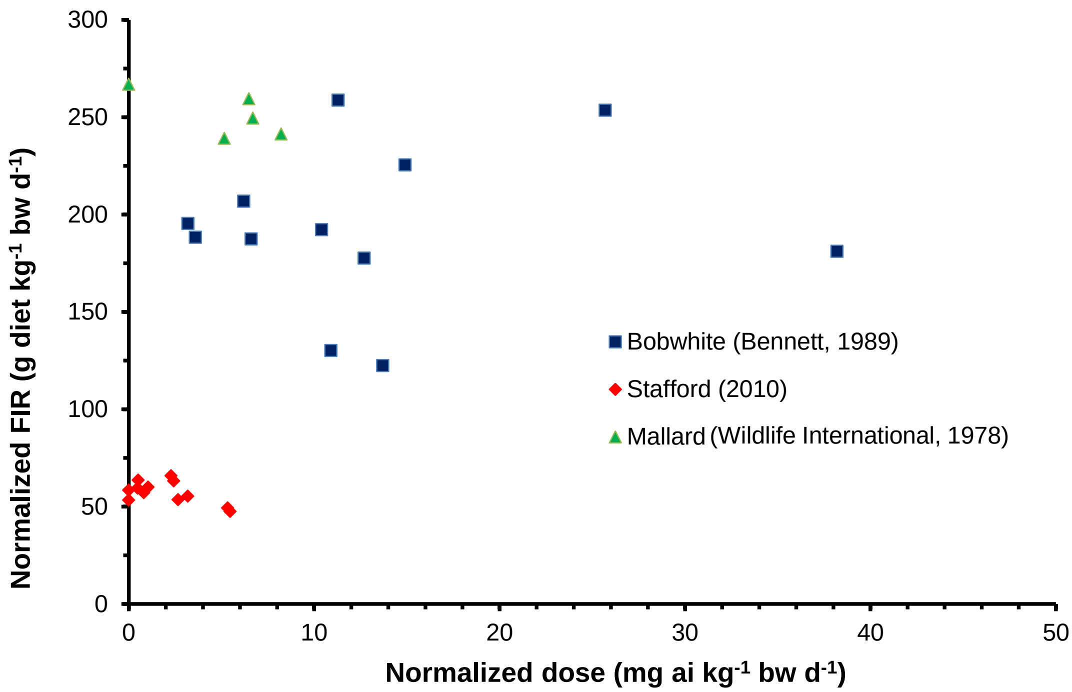

Fig. SI 7 Normalized food intake rate versus dietary dose of chlorpyrifos.

1.4 Sensitivity Analyses of LiquidPARAM

The sensitivity analyses for the avian risk assessment model for flowable CPY relied on "what if" analyses using a "one-at-a-time" design. Two baseline scenarios, a lesser and a greater exposure scenario, were used in the sensitivity analyses for acute and chronic exposure (Table SI 13). The lesser exposure scenario was for mourning doves in pecan orchards treated with CPY 3 times at rates of 1.05 kg ha^{-1} (0.94 lb A^{-1}) using the broadcast application technique. The greater exposure scenario was for blue grosbeak in orange orchards treated with CPY once at a rate of 6.3 kg ha^{-1} (5.6 lb ai A^{-1}) using the airblast application technique. This scenario was considered to be a greater exposure scenario because of the greater rate of application and because blue grosbeaks spend a greater proportion of their time in the treated area than do mourning doves. For each of the scenarios, one variable was altered at a time to explore the influence that variable had on the output variable (i.e., percent bird mortality for acute exposure, probability of exceeding NOEL and LOEL for chronic exposure).

Table SI 11 Estimated maximum acute exposure for birds exposed to flowable chlorpyrifos

Crop	Use pattern	Appl. rate		Species	Maximum dose retained (mg ai kg^{-1} bw)					
		kg ha^{-1}	lb A^{-1}		Mean	25th centile	50th centile	75th centile	Minimum	Maximum
Alfalfa	Southern plains - applied broadcast 4X with 10 d interval	1.05	0.94	Dickcissel	4.08	1.87	3.05	4.97	4.29E-03	59.6
				Mourning dove	0.100	0.00446	0.0323	0.121	6.85E-16	3.09
				Red-winged blackbird	3.73	1.19	2.75	5.03	7.22E-10	48.0
				Vesper sparrow	6.14	2.27	4.91	8.58	9.86E-09	59.3
				Western meadowlark	1.37	0.281	0.786	1.68	1.52E-10	29.9
Almond	California - applied airblast post-plant 2X (May, hull-split) with 10 d interval	2.07	1.88	Abert's towhee	0.135	0.00836	0.0541	0.177	2.47E-18	3.95
				Blue grosbeak	8.17	1.44	4.60	10.7	1.01E-11	179
				American crow	0.239	0.0154	0.0990	0.317	2.54E-12	4.14
				Mourning dove	0.0199	0.00433	0.0140	0.0292	1.63E-15	0.224
				Red-winged blackbird	6.48	1.88	4.67	8.72	1.99E-10	107
Apple / Cherry	Northwest - applied airblast during dormant season / Michigan applied broadcast post-plant	2.07	1.88	Blue grosbeak	5.55	0.817	2.78	6.92	2.70E-14	144
				American crow	0.186	0.0133	0.0764	0.240	3.87E-14	4.25
				Mourning dove	0.00987	0.00191	0.00599	0.0132	7.55E-16	0.236
				Red-winged blackbird	4.27	1.09	2.72	5.45	3.39E-10	94.1
Broccoli	California - applied band at-plant and post-plant 3X with 10 d interval	2.36	2.11	American crow	0.115	0.00704	0.0457	0.151	9.20E-17	2.83
				Horned lark	0.932	0.570	0.809	1.16	4.23E-04	6.95
				Mourning dove	0.195	0.0414	0.127	0.270	1.20E-13	3.32
				Red-winged blackbird	0.624	0.234	0.531	0.897	1.23E-12	4.64
Corn	Midwest - applied broadcast at-plant and band post-plant 3X with 10 d interval	1.12	1	American robin	0.439	0.0299	0.176	0.561	4.60E-13	8.89
				Horned lark	5.78	2.63	4.23	6.94	4.39E-02	114
				Killdeer	4.35	2.16	3.68	5.71	2.49E-07	54.7
				Mourning dove	0.366	0.0724	0.227	0.497	8.28E-13	7.44
				Northern bobwhite	0.255	0.0258	0.132	0.360	8.95E-12	5.32
				Red-winged blackbird	4.51	1.68	3.76	6.41	1.79E-09	60.0
				Vesper sparrow	4.66	1.88	3.67	6.36	8.68E-05	53.5
Grape	California - applied airblast	2.07	1.88	Blue grosbeak	5.91	1.09	3.72	8.31	3.89E-10	78.9
				American crow	0.187	0.0128	0.0760	0.244	1.85E-13	4.56

Crop	Use pattern	Appl. rate		Species	Maximum dose retained (mg ai kg^{-1} bw)					
		kg ha^{-1}	lb A^{-1}		Mean	25^{th} centile	50^{th} centile	75^{th} centile	Minimum	Maximum
	prior to bud break			Mourning dove	0.426	0.0734	0.239	0.547	3.18E-15	17.1
				Northern bobwhite	0.334	0.0327	0.165	0.456	3.16E-15	7.32
				Red-winged blackbird	5.85	1.92	4.67	8.23	5.78E-10	59.5
Grapefruit	Florida - applied airblast post-plant (Apr-Jun)	2.80	2.5	Blue grosbeak	7.70	1.12	3.86	9.46	1.26E-10	382
				American crow	0.256	0.0176	0.113	0.346	1.28E-12	4.14
				Mourning dove	0.0133	0.00252	0.00802	0.0176	2.87E-15	0.328
				Northern bobwhite	0.312	0.0266	0.132	0.380	2.56E-14	9.90
				Red-winged blackbird	6.15	1.50	3.89	8.03	3.82E-12	175
Orange	California - applied airblast post-plant (May-Aug)	6.28	5.6	Abert's towhee	2.74	1.22	2.12	3.53	1.98E-02	32.2
				Blue grosbeak	18.4	2.46	9.24	22.5	1.32E-10	384
				American crow	0.548	0.0305	0.218	0.728	5.28E-13	10.7
				Mourning dove	0.0285	0.00487	0.0160	0.0365	7.57E-14	0.519
				Red-winged blackbird	26.8	6.90	17.3	34.3	6.78E-10	427
Pecan	Georgia - applied airblast 3X with 10 d interval	1.05	0.94	Blue grosbeak	4.08	0.674	2.30	5.37	1.38E-11	163
				American crow	0.142	0.00895	0.0590	0.190	1.49E-16	2.75
				Mourning dove	0.00970	0.00172	0.00623	0.0137	1.82E-12	0.122
				Northern bobwhite	0.165	0.0150	0.0715	0.205	2.30E-16	5.11
				Red-winged blackbird	3.16	0.913	2.20	4.27	3.52E-10	62.3
Soybean	Louisiana - applied broadcast post-plant 3X with 14 d interval (May-Aug)	1.05	0.94	Blue grosbeak	3.93	0.932	2.82	5.65	3.47E-11	47.3
				Dickcissel	0.832	0.453	0.710	1.06	3.39E-05	7.81
				Horned lark	4.67	2.07	3.37	5.64	1.15E-02	62.5
				Indigo bunting	0.304	0.0170	0.106	0.341	1.34E-14	28.6
				Mourning dove	0.296	0.0538	0.176	0.398	7.27E-11	5.17
				Red-winged blackbird	3.71	1.30	3.04	5.18	2.34E-14	51.3
Sweet corn	Florida - applied broadcast at-plant and band post-plant 3X with 10 d interval	1.12	1	American crow	0.108	0.00717	0.0449	0.148	1.83E-13	1.97
				Mourning dove	0.296	0.0538	0.176	0.398	7.27E-11	5.17
				Northern bobwhite	0.252	0.0246	0.124	0.348	1.20E-11	6.17
				Red-winged blackbird	4.58	1.73	3.84	6.56	5.83E-14	41.4

Table SI 12 Estimated maximum chronic exposure for birds exposed to flowable chlorpyrifos

Crop	Use pattern	Appl. rate		Species	Maximum 28-d average TDI (mg ai kg^{-1} bw d^{-1})					
		kg ha^{-1}	lb A^{-1}		Mean	25th centile	50th centile	75th centile	Minimum	Maximum
Alfalfa	Southern plains - applied broadcast 4X with 10 d interval	1.05	0.94	Dickcissel	0.289	0.0437	0.154	0.371	3.83E-13	4.57
				Mourning dove	0.0317	0.00151	0.0104	0.0377	4.32E-15	0.761
				Red-winged blackbird	0.499	0.0693	0.296	0.729	2.69E-14	7.53
				Vesper sparrow	1.72	0.604	1.38	2.46	1.60E-09	11.2
				Western meadowlark	0.346	0.0830	0.219	0.445	2.70E-09	7.27
Almond	California - applied airblast post-plant 2X (May, hull-split) with 10 d interval	2.07	1.88	Abert's towhee	0.294	0.149	0.243	0.381	3.28E-03	3.32
				Blue grosbeak	1.71	0.265	0.989	2.29	1.52E-13	24.8
				American crow	0.0642	0.00416	0.0270	0.0872	3.15E-13	0.961
				Mourning dove	0.000819	0.0000339	0.000256	0.000961	1.34E-15	0.0287
				Red-winged blackbird	1.35	0.465	1.04	1.85	6.58E-12	22.9
Apple / Cherry	Northwest - applied airblast during dormant season / Michigan applied broadcast post-plant	2.07	1.88	Blue grosbeak	0.977	0.130	0.464	1.19	6.32E-11	22.3
				American crow	0.0328	0.00211	0.0138	0.0442	8.38E-15	0.623
				Mourning dove	0.00617	0.00114	0.00360	0.00821	2.69E-14	0.0910
				Red-winged blackbird	0.661	0.174	0.428	0.876	3.96E-10	9.95
Broccoli	California - applied band at-plant and post-plant 3X with 10 d interval	2.36	2.11	American crow	0.444	0.0216	0.141	0.492	8.46E-14	16.2
				Horned lark	1.04	0.616	0.911	1.33	1.18E-02	6.98
				Mourning dove	0.240	0.0451	0.148	0.325	5.84E-13	3.21
				Red-winged blackbird	0.583	0.189	0.475	0.836	2.55E-10	4.19
Corn	Midwest - applied broadcast at-plant and band post-plant 3X with 10 d interval	1.12	1	American robin	0.383	0.0183	0.118	0.404	8.68E-14	16.8
				Horned lark	0.865	0.458	0.688	1.04	1.06E-02	11.8
				Killdeer	0.478	0.232	0.397	0.621	3.38E-07	4.56
				Mourning dove	0.114	0.0211	0.0704	0.158	2.17E-12	2.29
				Northern bobwhite	0.0360	0.00420	0.0188	0.0508	1.60E-14	0.501
				Red-winged blackbird	0.665	0.244	0.566	0.958	3.09E-12	6.03
				Vesper sparrow	0.612	0.242	0.483	0.824	5.76E-06	5.31
Grape	California - applied airblast prior to bud break	2.07	1.88	Blue grosbeak	0.918	0.184	0.607	1.30	5.04E-11	12.5
				American crow	0.180	0.00824	0.0521	0.181	8.72E-13	9.46
				Mourning dove	0.0766	0.0116	0.0408	0.100	1.31E-12	1.66
				Northern bobwhite	0.0536	0.0058	0.0266	0.0734	4.81E-17	0.692

Crop	Use pattern	Appl. rate		Species	Maximum 28-d average TDI (mg ai kg^{-1} bw d^{-1})					
		kg ha^{-1}	lb A^{-1}		Mean	25^{th} centile	50^{th} centile	75^{th} centile	Minimum	Maximum
				Red-winged blackbird	0.934	0.299	0.722	1.32	6.61E-12	10.1
Grapefruit	Florida - applied airblast post-plant (Apr-Jun)	2.80	2.5	Blue grosbeak	1.23	0.165	0.592	1.46	1.16E-12	45.8
				American crow	0.041	0.003	0.018	0.055	2.56E-14	0.644
				Mourning dove	0.00196	0.000321	0.00107	0.00253	4.99E-13	0.0419
				Northern bobwhite	0.0497	0.00365	0.0197	0.0609	1.19E-14	1.98
				Red-winged blackbird	0.945	0.250	0.598	1.21	9.62E-09	15.5
Orange	California - applied airblast post-plant (May-Aug)	6.28	5.6	Abert's towhee	0.433	0.189	0.330	0.559	3.52E-03	5.37
				Blue grosbeak	2.62	0.421	1.39	3.19	8.78E-12	74.1
				American crow	0.0980	0.00651	0.0408	0.130	7.60E-13	1.76
				Mourning dove	0.00414	0.000664	0.00227	0.00534	5.65E-18	0.0874
				Red-winged blackbird	2.12	0.559	1.34	2.71	2.15E-08	34.6
Pecan	Georgia - applied airblast 3X with 10 d interval	1.05	0.94	Blue grosbeak	1.25	0.203	0.714	1.74	1.73E-11	20.1
				American crow	0.0433	0.00293	0.0191	0.0598	2.40E-13	0.604
				Mourning dove	0.00193	0.000394	0.00124	0.00271	2.55E-13	0.0314
				Northern bobwhite	0.0538	0.00554	0.0272	0.0750	4.34E-12	0.907
				Red-winged blackbird	1.02	0.314	0.796	1.46	3.23E-09	9.32
Soybean	Louisiana - applied broadcast post-plant 3X with 14 d interval (May-Aug)	1.05	0.94	Blue grosbeak	0.224	0.0360	0.125	0.294	1.82E-11	4.67
				Dickcissel	0.222	0.0333	0.119	0.295	7.60E-14	5.24
				Horned lark	1.14	0.577	0.890	1.38	2.71E-03	15.6
				Indigo bunting	0.955	0.167	0.626	1.41	2.97E-10	9.33
				Mourning dove	0.0859	0.0168	0.0536	0.117	7.72E-11	1.15
				Red-winged blackbird	0.387	0.0534	0.230	0.554	5.04E-11	5.00
Sweet corn	Florida - applied broadcast at-plant and band post-plant 3X with 10 d interval	1.12	1	American crow	0.225	0.0120	0.0778	0.260	3.03E-13	5.15
				Mourning dove	0.117	0.0212	0.0718	0.162	4.80E-14	2.58
				Northern bobwhite	0.0397	0.00421	0.0204	0.0567	4.85E-14	0.740
				Red-winged blackbird	0.669	0.230	0.553	0.951	3.96E-13	9.18

Table SI 13 Baseline exposure scenarios for the LiquidPARAM sensitivity analyses

Parameter	Low exposure scenario	High exposure scenario
Pesticide	Lorsban® Advanced	
Bird species	Mourning dove	Blue grosbeak
Bird sex	Combined	
Region and crop	Georgia, pecan	California, orange
Application rate	1.05 kg ha^{-1} (0.94 lb ai A^{-1}) applied 3X with 10-d intervals	6.28 kg ha^{-1} (5.6 lb ai A^{-1})
Application method	Broadcast	
Application time	9 am	
Day length (hr)	14	
Dew duration (hr)	4	
Drinking water scenario	Dew and puddles day after application	
K_{oc}	8216	
F_{oc}	0.4	
Half-lives for residues (d)	Grass, seeds and fruits = 2.92, Broadleaf foliage = 2.09, Insects = 2.86, Water = 50.8	
Foraging behavior	Bimodal feeding pattern	
Half-life for elimination (d)	1	
Avoidance behavior	On	
Aversion component	a = -0.5224, b = 0.1868	
Reduced FIR component	a = 0, b = 0	
Toxicity adjustment factor for dietary matrix	1	
RUDs	Chlorpyrifos-specific RUDs for orchards	
Puddle concentrations (mg L^{-1} lb^{-1} A^{-1})	Mean = 0.0429, SD = 0.0576	Mean = 0.0243, SD = 0.0170
Acute toxicity metrics (mg kg^{-1} bw)	5^{th}, 50^{th} and 95^{th} centile LD50s = 7.03, 30.9 and 136, Probit slope = 3.45	
Chronic toxicity metrics (mg kg^{-1} bw d^{-1})	NOEL = 2.88, LOEL = 18.7	
Chronic exposure duration (d)	28	

In this sensitivity analysis, effects of several factors were determined. These included: 1) changing the drinking water scenario from dew and puddles 1 d after application to dew only, 2) changing from a bimodal foraging pattern to an equal feeding pattern throughout the day (see Fig. SI 2), 3) changing from CPY-specific RUDs (Table SI 3) to the standard Fletcher et al. (1994) RUDs (see Table SI 2 and Table SI 3) and turning the avoidance behavior component off instead of on. These sensitivity analyses were done for acute and chronic exposures for each of the lesser and greater exposure scenarios. In addition, we investigated the influence of changing the averaging period for chronic exposure from 28 d to 14 d. Durations of exposure shorter than 14 d would not likely lead to the observed reproductive effects in the studies by Fink (1978a,b). The results of the sensitivity analyses indicate that none of the changes to the model input parameters had a significant influence on estimated acute risk to the mourning dove in pecan (the lesser exposure scenario) or blue grosbeak in orange orchards (the greater exposure scenario) (Table SI 14). Similar results were observed for chronic risk except that reducing the chronic averaging period led to moderately higher risk estimates for blue grosbeaks in orange orchards.

1.5 Evaluation of the Model

LiquidPARAM was originally developed to assess the acute risks of flowable carbofuran to birds. As part of the carbofuran assessment, model predictions were compared to the results of in-depth and quantitative field studies. Although avian field studies are available for flowable CPY (see section 6 in Moore et al. 2013), the best available field studies for evaluating performance of LiquidPARAM involved application of carbofuran. Therefore, this section evaluates model performance of LiquidPARAM by using carbofuran as an example AChE-inhibiting insecticide.

LiquidPARAM has not been previously evaluated or calibrated, nor has TIM. As such, there is some uncertainty regarding the model structure and predictive power of both LiquidPARAM and TIM. Although models are simplified abstractions of natural systems, it is possible to delineate circumstances in which model results are consistent with empirical data (Mankin et al. 1975). A variety of methods have been developed for comparing model results with data (e.g., Mankin et al. 1975; Moore et al. 2003; Moore et al. 2010). The simplest way to evaluate the predictive power of models is to compare predictions of the simulation model with field observations, which is the approach used here. The most useful field studies for evaluating performance of LiquidPARAM were conducted on carbofuran by Jorgensen et al. (1989) and Booth et al. (1989). These quantitative studies are described below as are several other less quantitative studies. The latter are used as part of a weight-of-evidence evaluation of the performance of LiquidPARAM.

Table SI 14 Results of the sensitivity analysis conducted for LiquidPARAM. For chronic exposure, the values represent the percentage of birds with TDIs below the NOEL and LOEL

Variable	Value	Exposure scenario	Birds protected (%)		
Acute Exposure			***5th centile***	***50th centile***	***95th centile***
RUDs	Kenaga nomograms	Low (Mourning dove in pecan)	100	100	100
	Chlorpyrifos nomograms		100	100	100
	Kenaga nomograms	High (Blue grosbeak in orange)	46.9	81.0	97.9
	Chlorpyrifos nomograms		45.4	79.7	97.5
Drinking water scenario	Dew only	Low (Mourning dove in pecan)	100	100	100
	Dew + 1 d puddles		100	100	100
	Dew only	High (Blue grosbeak in orange)	47.5	81.9	97.9
	Dew + 1 d puddles		45.4	79.7	97.5
Foraging behavior	Uniform	Low (Mourning dove in pecan)	100	100	100
	Bimodal		100	100	100
	Uniform	High (Blue grosbeak in orange)	46.6	81.3	97.8
	Bimodal		45.4	79.7	97.5
Avoidance behavior	On	Low (Mourning dove in pecan)	100	100	100
	Off		100	100	100
	On	High (Blue grosbeak in orange)	46.9	81.0	97.9
	Off		45.4	79.7	97.5
Chronic Exposure			***NOEL***	***LOEL***	
RUDs	Kenaga nomograms	Low (Mourning dove in pecan)	100	100	
	Chlorpyrifos nomograms		100	100	
	Kenaga nomograms	High (Blue grosbeak in orange)	72.5	99.2	
	Chlorpyrifos nomograms		71.9	98.9	
Drinking water scenario	Dew only	Low (Mourning dove in pecan)	100	100	
	Dew + 1 d puddles		100	100	
	Dew only	High (Blue grosbeak in orange)	70.5	98.9	
	Dew + 1 d puddles		71.9	98.9	
Foraging behavior	Uniform	Low (Mourning dove in pecan)	100	100	
	Bimodal		100	100	
	Uniform	High (Blue grosbeak in orange)	72.2	100	

Variable	Value	Exposure scenario	Birds protected (%)	
	Bimodal		71.9	98.9
Avoidance behavior	Off	Low (Mourning dove in pecan)	100	100
	On		100	100
	Off	High (Blue grosbeak in orange)	73.2	98.5
	On		71.9	98.9
Chronic averaging period (days)	14	Low (Mourning dove in pecan)	100	100
	28		100	100
	14	High (Blue grosbeak in orange)	53.0	94.7
	28		71.9	98.9

Quantitative Field Studies for Carbofuran. Field studies were conducted in Nebraska and Texas/New Mexico to determine if the use of Furadan® 4F (44.4% carbofuran) to control corn borers had a significant effect on birds that frequent treated fields (Jorgensen et al. 1989). Similar field studies were conducted in Kansas and Oklahoma, where Furadan® 4F was used to control insects in alfalfa crops (Booth et al. 1989). The field studies included surveys of abundances of bird species, carcass search-efficiencies, studies to determine rates of removal of dead bird carcasses by predators or scavengers, carcass searches, and residue analysis of carcasses. Fifteen paired corn plots (7 controls, 8 Furadan® 4F treatments) were studied in south-central Nebraska (Buffalo and Dawson Counties). Sixteen paired corn plots (8 controls, 8 Furadan® 4F treatments) were studied on three farm complexes in the Texas panhandle (Dallam County) and adjacent northeast New Mexico (Union Co). Sixteen paired alfalfa plots (8 controls, 8 Furadan® 4F treatments) in each of two locations were studied in Nemaha County in northeastern Kansas and in Kingfisher County in central Oklahoma.

The spray program for the corn studies in Nebraska and Texas/New Mexico consisted of 2 aerial applications of Furadan® 4F at 1.12 kg ai ha^{-1} (1 lb ai A^{-1}) each to control corn borers. The second applications took place 2 weeks after the first application. The spray program for the alfalfa studies in Kansas and Oklahoma consisted of 1 aerial application at 1.12 kg ai ha^{-1} (1 lb ai A^{-1}) prior to the first cutting. The second applications in the alfalfa studies occurred 5 to 7 weeks after the first application (2^{nd} cutting), but, in accordance with the label at the time of the studies, was applied at 0.56 kg ai ha^{-1} (0.5 lb ai A^{-1}). Furadan® 4F was generally applied as a foliar spray at the maximum recommended US label use rates at the time of the studies.

Animal carcasses and feather spots found on the plots were analyzed for carbofuran residues. Searches for dead birds occurred 2 to 6 hr following application, then each day for 7 d following application. All searches in the field habitats and edges were done on approximately 2.3 ha (5 A) areas for each field and were performed by foot. Some observers were accompanied by dogs. To determine search efficiencies, carcasses were placed on the field on application day and searches were conducted 2 and 3 hr after spray.

The Search Efficiency Index was determined for all species for which at least two dead birds were found during the respective application periods. Because the relative abundances of most bird species were low, we pooled species to achieve adequate sample sizes for statistical comparisons. The guild approach was chosen because it combines species on the basis of similarities in the way they use the environment.

Jorgensen et al. (1989) and Booth et al. (1989) determined the number of live birds observed for each dead bird found for each species (the RLDBP approach). These values can be converted to a percentage of dead birds (Equation SI 27):

$$P = \frac{1}{Ratio\ of\ Live\ to\ Dead\ Birds} \times 100 \qquad \text{(SI 27)}$$

It could be argued that estimates of mortality based on equation S1 27 would be biased in favor of demonstrating decreased effect because live birds may be observed repeatedly. However, the estimated number of live birds over the duration of the experiment was used in the calculation, and each time the same bird was counted, it was at risk of being exposed to Furadan® 4F. It has been argued that, although a definitive determination of formula bias could not be made, the bias was likely in favor of the number of birds found dead (i.e., worst-case mortality rate, Booth et al. 1989, Jorgensen et al. 1989). The above equation was used in evaluating the performance of LiquidPARAM.

Estimates of mortality in treated fields were based upon the timed counts census method for live birds because this was the only method used in both alfalfa and corn. The numbers of live birds estimated by transect and timed count census methods were very similar in corn (Jorgensen et al. 1989). Estimates of mortality of birds in treated fields were also corrected for the search efficiencies determined in the studies as determined on a per plot basis for all birds. Three estimates of mortality of birds in treated fields were determined for alfalfa and corn: 1) no correction for mortality observed prior to application in treated fields or in control fields, 2) corrected for mortality observed prior to application in treated fields, and 3) corrected for mortality observed both prior to application in treated fields and mortality observed in control fields. The corrections for both pre-application mortality and control field mortality were done using Abbot's formula (Newman 1995) (Equation SI 28):

$$p_c = \frac{p - p_0}{1 - p_0} \qquad \text{(SI 28)}$$

where p_c, p and p_0 are the corrected, original, and pre-application mortalities of controls, respectively.

Uncorrected mortality values in treated fields likely overestimated mortality due to carbofuran because other sources of mortality due to natural causes, machinery, other pesticides, etc. are included in the calculations. Correcting for mortality in control fields, however, might underestimate mortality due to carbofuran because other pesticides were applied to control fields or in nearby fields that were not applied to treated fields. The 3 estimates of percent mortality on treated fields for both corn and alfalfa are summarized in Fig. SI 8.

LiquidPARAM was run using scenarios that replicate the application dates, rates and methods described in the Booth et al. (1989) and Jorgensen et al. (1989) except that scenarios run in LiquidPARAM included 1 application only. This was done because: 1) the intervals between applications in the field studies were widely spaced, and 2) mortality was rarely observed after the second application. Thus, to ensure a fair comparison, percent mortality estimates from the field study were calculated for the period following the first application only. For comparison, TIM v1 was also run for these scenarios.

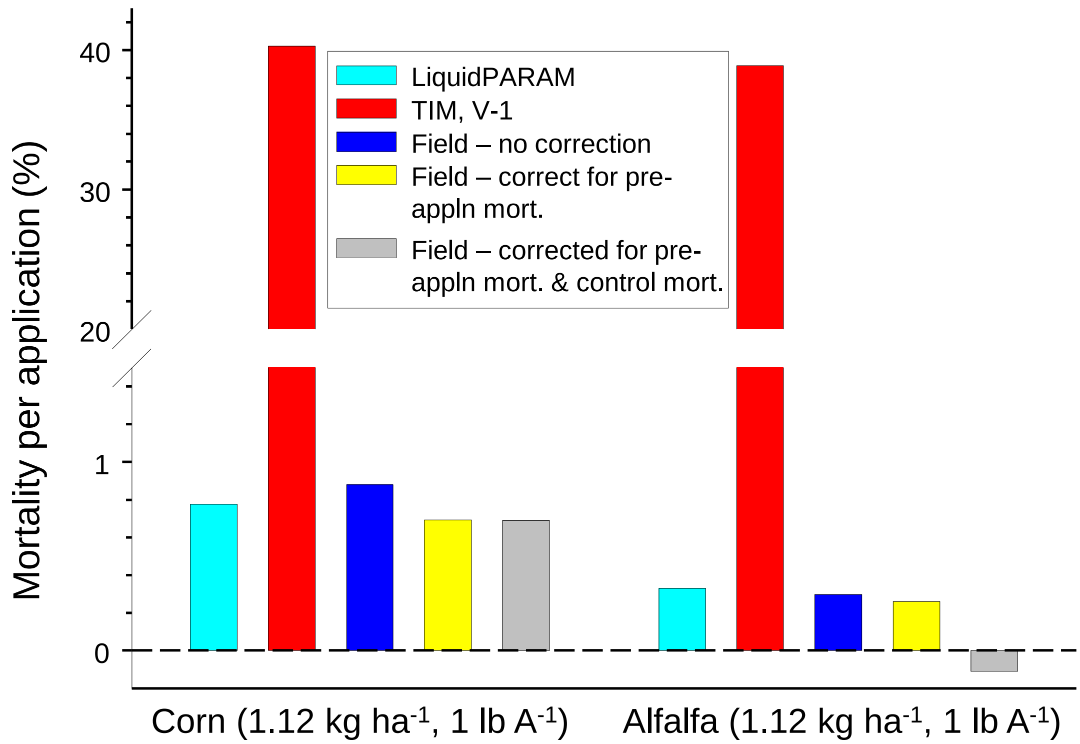

Fig. SI 8 Percent mortality per application of Furadan® 4F in corn and alfalfa as estimated by LiquidPARAM, TIM (v1), and observed in field studies by Booth et al. (1989) and Jorgensen et al. (1989)

The model estimates from LiquidPARAM and TIM v1 are compared to the results of the field studies in Fig. SI 8. The results indicate that observed mortality of birds in Furadan® 4F-treated fields was small (<1%) for both corn and alfalfa even when there was no correction for mortality occurring prior to application of carbofuran in treated fields or for mortality observed in control fields. In alfalfa, mortality in control fields slightly exceeded mortality in treated fields which led to a negative value for estimated mortality of birds on treated fields following correction for mortality observed on control fields (Fig. SI 8). Estimates of mortality from LiquidPARAM were remarkably similar to the field estimates of mortality for corn and alfalfa (Fig. SI 8), indicating excellent model performance. Estimates of mortality from TIM v1 were much greater (>45-fold for corn,

>130-fold for alfalfa) than the field estimates of mortality for both corn and alfalfa (Fig. SI 8).

There are several limitations to the evaluation of model performance described here. First, comparison of model performance to field observations was limited to one pesticide in two field studies (Booth et al. 1989; Jorgensen et al. 1989). However, these studies did include a large number of plots (n = 15 or 16 plots in each of 2 states for each crop) which reduces this concern somewhat. Nevertheless, it would be useful to extend the evaluation of model performance to other pesticides (including CPY), geographic areas, and other crops should appropriate field studies become available in the future. Second, the field studies conducted by Booth et al. (1989) and Jorgensen et al. (1989) were conducted at a time of the year when birds had completed nesting and thus had reduced site fidelity. There was also considerable plot-to-plot variation in observed abundances of birds. In other respects, however, the field studies were state-of-the-art as exhibited by the high search efficiencies, use of paired control and treated plots, measurement of pre-application mortality, and high sample sizes. Further, other field studies and monitoring studies, though less quantitative, consistently indicated that birds experience very low mortality following application of flowable carbofuran to corn, cotton and alfalfa fields (see below).

Other Field Studies. Several other studies have also found that Furadan® 4F had little effect on birds. When all bird species were combined, there were no Furadan® 4F treatment effects in alfalfa fields in Utah even when pre-treatment densities were used as a covariate (Jorgensen et al. 1983). Application of Furadan® 4F did not significantly reduce the number of savannah sparrows when compared with the control (Jorgensen et al. 1983). In 1995 and 1996, monitoring programs were conducted in several states including Texas, Oklahoma, California, Mississippi, Arkansas, Tennessee, and Louisiana to investigate the effects to wildlife from use of Furadan® 4F for cotton aphid control (Smith 1997). These studies showed that Furadan® 4F had little or no effect on bird species. In one case, EPA requested that a survey in Texas be carried out using stricter search guidelines. No dead or dying avian wildlife were found in treated fields after the study was carried out with the stricter guidelines (Smith 1997).

Conclusions of Model Evaluation. The available evidence indicates that the lack of avian mortality predicted by LiquidPARAM for carbofuran are corroborated by a wide variety of field studies including two studies in corn and alfalfa that can could be considered state-of-the-art (Booth et al. 1989; Jorgensen et al. 1989). EPA’s TIM (v1), however, overestimated avian mortality by a wide margin (Fig. SI 8).

2 Detailed description of the structure of the exposure portion of GranPARAM

2.1 Input variables for GranPARAM

This section begins by presenting details on the Granular Pesticide Avian Risk Assessment Model and inputs for estimating availability of Lorsban® 15G granules in fields relative to natural grit. Subsequently, details on how the exposure model estimated bird uptake of natural grit and Lorsban® 15G granules are provided. Many of the assumptions described below for model input parameters were explored in the sensitivity analyses described in Section 2.3.

Relative field areas. In the banded and in-furrow application scenarios commonly employed for granular CPY, the granules are not spread evenly throughout the field. The purpose of banded and in-furrow application is to direct a more concentrated application of granules to the planted rows themselves. In addition, the rows do not extend all the way to the ends of the field. These factors were accounted for by considering the size and geometry of the field and the application bands to define specific field zones (e.g., within the pesticide band, between pesticide bands, within a spill area) and calculating the fraction of the total field area composed of each zone, along with their corresponding granule availabilities.

For all scenarios, a square, 18 ha (40 A) field was assumed. The field margin was assumed to be 9 m (30 ft) wide and the remainder of the field was defined as the field center. There are two reasons why a field margin was required in the model. Because many bird species prefer field edge habitat, these species likely spend more time in the margins of the field than in the center of the field. The margin area provides a greater abundance and diversity of food than does the field interior, and offers greater protection from predators (Best et al. 1995; Best et al. 1990). Thus, the exposure model has the option to have birds forage preferentially in the four side margin areas, as opposed to the field center. The second reason why a margin was required is because at the ends of rows, the machinery must turn around. The pesticide applicator must often be lifted out of the ground during turning. Thus, the potential for spills is highest in the two end-of-row margin areas (Fischer and Best 1995). Exposure due to spills in end-of-row margin areas was modeled for each of the exposure scenarios. However, spills that occurred elsewhere in the field (e.g., due to machines hitting bumps in the field) were not modeled. Although such spills are infrequent, not including mid-field spills is a limitation of the model.

The default margin width of 9 m (30 ft) was somewhat arbitrary because different machines have different spatial requirements for making turns. However, 9 m (30 ft) is likely a reasonable estimate for many types of machinery. Similarly, the distance to which bird species forage away from the edge varies by species. Some species such as the common pheasant and northern bobwhite rarely stray more than a few feet from the field edge, while others such as the red-winged blackbird and horned lark commonly occur in the field center (Best et al. 1990). Thus, 9 m (30 ft) was only a very approximate estimate of what constituted a field margin to a bird species.

Spill sizes were assumed to be 25 cm^2 (4 sq in) in size and only occurred at the row ends, where the planter machines turned around. Pesticide granules may be spilt from machinery at row ends by a variety of mechanisms, including:

- The landwheel continues to rotate after it is lifted clear of the ground.
- The landwheel catches on the ground as the machine moves over bumpy terrain.
- Pipes linking granule applicator rotors to delivery spouts or fishtails have corrugations, joints or kinks in them. Granules accumulate in these obstructions as the machinery moves along the row, and are released as the machinery turns on the headland due to the machinery being lifted, the tractor bumping over bumpy terrain on the headland, or as the pipes straighten while the drill is being lowered back into the soil for the start of the next row (Prosser 2005).

Any of these problems tends to cause distinctive, long, thin “trails” of granules. The trails are variable in length but are generally not longer than 30 cm (1 ft). Assuming a trail width of 8 mm (0.3 in), a likely overestimate, produces a spill size estimate of 22 cm^2 (3.6 sq in). For this assessment, the default spill size was rounded up to 25 cm^2 (4 sq in).

Distances between crop rows are a function of crop type and method of application. For banded applications of CPY, the band width and distance between rows on center were assumed to be:

- Broccoli = 10 cm (4 in) wide bands, 0.76 m (30 in) spacing between rows;
- Corn and sweet corn = 15 cm (6 in) wide bands, 0.91 m (36 in) spacing between rows;
- Peanut = 15 cm (6 in) wide bands, 0.91 m (36 in) spacing between rows; and
- Sunflower = 15 cm (6 in) wide bands, 0.76 m (30 in) spacing between rows.

For in-furrow applications, the furrow width was 7.5 cm (3 in) and distance between rows on center was 0.46 m (18 in) for onions and 0.91 m (36 in) for corn and sweet corn.

Available grit. Available natural grit in a crop field is a function of soil texture and correlates directly to sand content. The more sandy the soil, the greater the number of natural grit particles available to birds. Best (1992) found that the size range of granules for the five insecticide formulations most frequently used in cornfields was 0.2 to 1.6 mm in diameter. GranPARAM estimates the number of natural grit particles in this size range present in soils of different texture and sand content in different regions of the United States. To make these estimations, distributions of surface soil textures within areas of the continental United States were determined for crops to which Lorsban® 15G is applied, followed by estimations of numbers of grit particles within the 0.2 to 1.6 mm size range for soils of different textures.

For this assessment, an investigation of the soil textures was undertaken to determine soil texture statistics by crop and area for the contiguous United States. The Cropland Data Layer (NASS CDL) (USDA 2012) rasters for each crop were used to identify the crop footprint. The crop footprints were then joined and overlaid with soil texture data from the Soil Survey Geographic Database (SSURGO) and aggregated by each region for each crop. SSURGO is a nationwide layer of digital soil data produced by the Natural Resources Conservation Service (USDA 1994).

The CDL data layer is comprised of numerous classes of use patterns. In many cases, there is not a 1:1 relationship between a CPY use pattern and a CDL class. Table SI 15 outlines a lookup table between CPY use patterns and CDL crop classes.

Table SI 15 Lorsban® 15G use pattern and CDL database crop class lookup

Use pattern	Corresponding CDL crop (CDL numeric code)
Broccoli	Broccoli (214)
Citrus	Citrus (72), Oranges (212)
Corn	Corn (1), Sweet Corn (12), Popcorn or ornamental corn (13), Double crops: Winter Wheat/Corn (225), Oats/Corn (226), Barley/Corn (237), Corn/Soybeans (241)
Cotton	Cotton (2), Double crops: Lettuce/Cotton (232), Winter Wheat/Cotton (238)
Onion	Onions (49)
Peanut	Peanuts (10)
Potato	Potatoes (43)
Sugar beet	Sugar beets (41)
Sunflower	Sunflowers (6)
Tobacco	Tobacco (11)

In some cases, a crop class area may be under represented when compared to the National Agricultural Survey Statistics (NASS) Cropland Data Layer data due to, for example, error in interpretation of satellite imagery. To account for this potential under representation, several additional vegetable and ground fruit classes were added to the crop footprints as required. The results are shown in Table SI 16.

Table SI 16 Lorsban® 15G use pattern lookup table

Use pattern	CDL crop or crop group
Broccoli	Crop group: Vegetables/ground fruit
Citrus	Crop: Citrus, oranges
Corn	Crop: Corn, double crop(s) corn
Cotton	Crop: Cotton
Onion	Crop: Onions
Peanut	Crop group: Other row crops
Potato	Crop: Potato
Sugar beet	Crop: Sugar beet
Sugar beet in California	Crop group: Other row crops
Sunflower	Crop: Sunflower
Tobacco	Crop group: Other row crops
Other row crops	Peanuts, Sunflower, Tobacco, Mint, Canola, Flaxseed, Rapeseed, Mustard, Sugar beets, Sugarcane
Vegetables and ground fruit	Dry beans, Potatoes, Sweet potatoes, Misc vegs & fruits, Watermelons, Onions, Cucumbers, Chick peas, Lentils, Peas, Tomatoes, Caneberries, Carrots, Asparagus, Garlic, Cantaloupes, Honeydew melons, Broccoli, Peppers, Greens, Strawberries, Squash, Lettuce, Pumpkins, Double crop Lettuce/Cantaloupe, Blueberries, Cabbage, Cauliflower, Celery, Radishes, Turnips, Eggplants, Gourds, Cranberries

The fundamental spatial unit of SSURGO data is the map unit, a polygon with a defined collection of soil types. Each map unit has a unique ID that links to more data about that individual soil type, e.g., map unit components, horizons, soil textures, etc. The area of each SSURGO map unit was tabulated in the final dataset, and exported to a Microsoft Access database to join to additional soil texture data. The SSURGO data were then used to generate a table containing the soil surface soil horizon by component percentage. Soil texture area was then summed generating tables containing soil texture, acreage area, and percent of area for each crop and region of interest. Table SI 17 shows the results for onions in the Pacific Northwest.

The natural particles used by birds are the mineral components of soil that fall into the size classification for sands. According to the U.S. Department of Agriculture (USDA) soil classification scheme, these size ranges are 1.0 to 0.5 mm in diameter for coarse sand (average diameter = 0.75 mm) and 0.5 to 0.25 mm in diameter for medium sand (average diameter = 0.375 mm). The NRCS publishes the National Soils Characterization database (often called the "pedons" database) in relational form which contains USDA particle size distributions for representative pedons of a large number of soils. The information contained in the database was transferred into a Microsoft Access database and then moved into the GranPARAM workbook. Using this information, data expressed as weight percentages of the soil mineral fraction were grouped by sand size classification and soil texture to yield medium- and coarse-sized weight percentage distributions for each soil texture.

Table SI 17 Summary table for onions in the Pacific Northwest

Soil texture	Area (A)	Area (%)
Clay	7,849	4.24
Clay loam	8,744	4.73
Coarse sand	4	0.00216
Coarse sandy loam	1,848	1.00
Fine sand	7,449	4.03
Fine sandy loam	13,039	7.05
Loam	5,134	2.77
Loamy coarse sand	58	0.0313
Loamy fine sand	33,728	18.2
Loamy sand	4,681	2.53
Loamy very fine sand	1,103	0.595
Sand	2,170	1.17
Sandy clay loam	23	0.0124
Sandy loam	4,324	2.34
Silt loam	69,615	37.6
Silty clay	5,086	2.75
Silty clay loam	4,428	2.39
Very fine sandy loam	15,767	8.52

To convert the soil texture information into a number of natural grit particles available for ingestion by birds per unit area, conversion from the mass fraction to a number of particles was required. Because the sand particles in soil are primarily composed of silica, the mass fraction of the various sand sizes was assumed to be equivalent to their volume fractions (i.e., the sand particles all have the same density). Therefore, the mass fraction is related to the volume fraction by a factor of the cube of the grit particle radius. The resulting volume fraction can be reduced to a number of particles per unit area by conceptualizing the unit area as a slice through the equators of particles of differing size arranged as a surface monolayer. This approach assumed that the depth of the surface layer was not important, i.e., the unit area of field was viewed from above in two dimensions and there was a monolayer of particles available for grit consumption on the surface. With this assumption, the number of particles was calculated from equations SI 29 and 30:

$$MVol = \frac{4}{3} \cdot \pi \cdot {M_r}^3 \qquad \text{(SI 29)}$$

$$CVol = \frac{4}{3} \cdot \pi \cdot {C_r}^3 \qquad \text{(SI 30)}$$

where,

$MVol$ is the average volume of a single medium-sized sand particle in mm^3;

M_r is the average radius of a single medium-sized sand particle in mm;

$CVol$ is the average volume of a single coarse-sized sand particle in mm^3; and

C_r is the average radius of a single coarse-sized sand particle in mm.

and equations SI 31 and 32:

$$MAvlGrt = \frac{\frac{MMassfrac}{100}}{MVol}\ x\ 10^{10} \quad \text{(SI 31)}$$

$$CAvlGrt = \frac{\frac{CMassfrac}{100}}{CVol}\ x\ 10^{10} \quad \text{(SI 32)}$$

where,

$MAvlGrt$ is the number of medium-sized sand particles per hectare;

$MMassfrac$ is the mass percentage of mineral fraction occupied by medium-sized sand for a given soil pedon;

$CAvlGrt$ is the number of coarse-sized sand particles per hectare;

$CMassfrac$ is the mass percentage of mineral fraction occupied by coarse-sized sand for a given soil pedon; and

10^{10} is the conversion from mm^3 to hectare.

The above calculations produced estimates of the numbers of particles of natural grit similar in size to medium- and coarse-sized pesticide granules according to measurements of sand fractions in a soil pedon from the pedons database.

To include variation in mass fraction of the sand sizes within a texture classification, Crystal Ball was used to sample the “pedons” database uniformly so that the entire range of the mass fractions was included in the natural grit calculations.

Determining availabilities of natural grit and pesticide granules. The Granule:Grit Ratio (GGR) determines the probabilities of a bird choosing either a Lorsban® 15G granule or a natural piece of grit with each peck a bird makes in search of grit. The methodology for estimating GGR is presented in the following sections.

Available granules. The number of Lorsban® 15G granules available on the soil surface ($AvlGnl$) was calculated from the application rate (App) (**Error! Reference ource not found.**), the proportion of granules applied to the field that remain on the surface (Sur), the weight of an individual granule ($GnlWt$), and the section of the field where the bird feeds. Lorsban® 15G granules were categorized into coarse- (1.0-0.5 mm) and medium-sized (0.5-0.25 mm) granules to correspond with the natural grit ranges for coarse sand and medium sand. To estimate numbers of each on the soil surface, the pesticide formulation was characterized in terms of the fraction that each size category occupied, granule weight within each size category, and availability of granules for the particular section of the field (Equation SI 33):

$$AvlGnl = \frac{App\ x\ 10^6\ x\ Sur}{fM\ x\ MGnlWt + fC\ x\ CGnlWt} \qquad \text{(SI 33)}$$

where,

$AvlGnl$ are the granules on the soil surface per unit area in selected part of the field;

App is the rate of application (kg ai ha^{-1});

Sur is the fraction of granules applied remaining on the soil surface;

fM is the fraction of medium-sized granules in the formulation (0.5-0.25 mm);

$MGnlWt$ is the average weight (mg) of medium-sized granules in the formulation;

fC is the fraction of coarse-sized granules in the formulation (1.0-0.5 mm);

$CGnlWt$ is the average weight (mg) of coarse-sized granules in formulation; and

10^6 is the conversion from kg to mg.

For Lorsban® 15G, fM and fC are 0.79 and 0.21, respectively. Average $MGnlWt$ and $CGnlWt$ are 0.037 and 0.27 mg, respectively (ECOFRAM 1999).

The numbers of medium and coarse-sized granules were then calculated as follows (Equations SI 34 and SI 35):

$$MGnl = fM\ x\ AvlGnl \qquad \text{(SI 34)}$$

$$CGnl = fC\ x\ AvlGnl \qquad \text{(SI 35)}$$

where,

$MGnl$ is the number of available medium-sized granules per unit area (hectare); and

$CGnl$ is the number of available coarse-sized granules per unit area (hectare).

For the CPY assessment, application rate was a user-defined parameter and was set at the maximum label rates listed in Table SI 18 The other input parameters required to estimate the numbers of medium and coarse Lorsban® 15G granules on the soil surface of the field are described below.

Table SI 18 Exposure scenarios for Lorsban® 15G

Crop	Use pattern	Appl. rate		Focal bird species
		kg ha^{-1}	lb A^{-1}	
Broccoli	California - applied T-band at-plant	2.52	2.25	Horned lark, Red-winged blackbird, Mourning dove
Corn and sweet corn	Midwest - applied T-band or in-furrow at-plant; applied broadcast or in-furrow post-plant	1.45 1.12	1.3 1	Horned lark, Red-winged blackbird, Mourning dove, Northern bobwhite, Common pheasant
Onion	Pacific northwest - applied in-furrow at-plant	1.12	1	Horned lark, Red-winged blackbird, Mourning dove
Peanut	Southeast - applied band post-plant	4.48	4	Horned lark, Red-winged blackbird, Mourning dove, Northern bobwhite
Sugarbeet	Midwest - applied broadcast at-plant	1.12	1	Horned lark, Red-winged blackbird, Mourning dove, Northern bobwhite, Common pheasant
Sunflower	Midwest - applied T-band at-plant	1.45	1.3	Horned lark, Red-winged blackbird, Mourning dove, Northern bobwhite, Common pheasant
Tobacco	Southeast - applied broadcast preplant with incorporation	2.24	2	Horned lark, Red-winged blackbird, Mourning dove, Northern bobwhite

The numbers of medium and coarse-sized granules were then calculated as follows (Equations SI 34 and SI 35):

$$MGnl = fM \ x \ AvlGnl \quad \text{(SI 34)}$$

$$CGnl = fC \ x \ AvlGnl \quad \text{(SI 35)}$$

where,

$MGnl$ is the number of available medium-sized granules per unit area (hectare); and

$CGnl$ is the number of available coarse-sized granules per unit area (hectare).

The other input parameters required to estimate the numbers of medium and coarse Lorsban® 15G granules on the soil surface of the field are described below.

Available Granules in the End-row. Crop end-rows tend to have greater numbers of granules on the soil surface due to spills and the turning of equipment. In a study by Fischer and Best (1995), end-row granule counts were taken within a 930 cm^2 (1 sq ft) area centered on the largest visible spill at the end of randomly selected rows. Comparison to midfield counts indicated that end-row spill areas have 15 (mean = 15.5±12.9) times the number of granules compared to midfield. Thus, the number of Lorsban® 15G granules per unit area at end rows ($EAvlGnl$) was estimated in GranPARAM by multiplying the number of granules at midfield ($AvlGnl$) by the average value of 15.

Application Incorporation Efficiency. Several researchers have studied granule incorporation efficiency into soil during the application of granular insecticide formulations to corn (Erbach and Tollefson 1983; Fischer and Best 1995; Hummel et al. 1992; Idema et al. 1993; Tollner and Cryer 1997). These studies characterized the proportion of pesticide granules that remained on the soil surface with band, T-band, and in-furrow application methods with or without further incorporation. Their results are summarized in Table SI 19.

Table SI 19. Percentage of corn rootworm formulation granules remaining on the soil surface after application by a variety of methods (see Moore et al. 2010)

Method of application	% of applied granules on surface		Sample size
	Mean ± SD	Median	
Band/T-Band + press wheel	7.3±7.3	4.4	26
T-Band + press wheel + tines/chains	5.8±1.6		5
In-furrow + press wheel	0.57±0.2		3

Method of application	% of applied granules on surface		Sample size
	Mean ± SD	Median	
Band behind press wheel	40.2		1
Band behind press wheel + tines/chains	11.7±6.1		2

Four options exist in GranPARAM to estimate proportion of pesticide granules remaining on the soil surface following application: a distributional approach, use of arithmetic means, use of maximum or 95th centiles, and use of EPA default values. The EPA default values are 0.15 (i.e., 15% of applied granules remain on the soil surface immediately after application) for band and T-band application methods, and 0.01 for the in-furrow application method. We used the distributional approach in the CPY exposure assessment to capture the full range of the available measured data. We assumed a beta distribution for each of T-band, band, and in-furrow application. The distributions were parameterized by combining the results in Table SI 19 (first 2 rows for T-band, last 2 rows for band, and 3rd row for in-furrow) and choosing distribution parameters that approximated a fit to the data. The following were the parameters selected:

- T-band – minimum = 2, maximum = 40, alpha = 0.3, beta = 2.0;
- Band – minimum = 0, maximum = 80, alpha = 10, beta = 25; and
- In-furrow - minimum = 0, maximum = 8.6, alpha = 35, beta = 500.

Granule ingestion rate. The first step to estimate Lorsban® 15G granule ingestion rate (GIR) was to calculate the probability p of a bird choosing a Lorsban® 15G granule over a natural grit particle according to the availability of medium- and coarse-sized granules and natural grit particles (Equations SI 36 and SI 37):

$$p_{medium} = \frac{GGPF\ x\ MGnl}{GGPF\ x\ MGnl + MAvlGrt} \qquad \text{(SI 36)}$$

$$p_{coarse} = \frac{GGPF\ x\ CGnl}{GGPF\ x\ CGnl + CAvlGrt} \qquad \text{(SI 37)}$$

where,

p_{medium} is the probability a particle ingested is a medium-sized pesticide granule;

p_{coarse} is the probability a particle ingested is a coarse-sized pesticide granule; and

$GGPF$ is the granule:grit preference factor (see below).

Once N, the number of particles ingested and p, the probability that an ingested particle was a pesticide granule, were estimated, the number of granules ingested was determined by randomly sampling from a binomial distribution. This was done for each field zone and each particle size class (Equation SI 38):

$$X_{sij} = Binomial(N_{sij}, p_{sj}) \quad \text{(SI 38)}$$

where,

X_{sij} is the number of granules of size s ingested by bird i in field zone j during the day following application;

N_{sij} is the number of particles of size s ingested by bird i in field zone j during the day following application; and

p_{sj} is the probability that a particle of size s being ingested in zone j is a pesticide granule.

The total number of pesticide granules ingested by bird i was then determined by summing across field zones for medium and coarse granules (Equations SI 39 and SI 40):

$$MGIR_i = \sum_{j=1}^{N_j} mediumX_{ij} \quad \text{(SI 39)}$$

$$CGIR_i = \sum_{j=1}^{N_j} coarseX_{ij} \quad \text{(SI 40)}$$

where,

$MGIR_i$ is the number of medium-sized granules ingested by bird i during the day following application;

$CGIR_i$ is the number of coarse-sized granules ingested by bird i during the day following application;

$mediumX_{ij}$ is the number of medium-sized granules ingested by bird i in field zone j during the day following application; and

$coarseX_{ij}$ is the number of coarse-sized granules ingested by bird i in field zone j during the day following application.

Once the number of Lorsban® 15G granules consumed by a bird per day was estimated, the one remaining factor needed to calculate the amount of pesticide ingested was the pesticide loading on each ingested granule. This is discussed in the next section.

Estimation of pesticide ingestion rate. Pesticide ingestion rate from granules ($PIRG$) is the measure of dose to a bird in mg ai/kg bw/day. PIRG was calculated for each size of granule (Equations SI 41 and SI 42):

$$MDose_i = MMG\ x\ MGIR_i \quad \text{(SI 41)}$$

$$CDose_i = CMG \ x \ CGIR_i \quad \text{(SI 42)}$$

where,

MMG is the mass of pesticide on single medium-sized granule (mg granule^{-1});

CMG is the mass of pesticide on single coarse-sized granule (mg granule^{-1});

$MDose_i$ is the pesticide dose due to medium-sized granules (mg d^{-1}) by bird i; and

$CDose_i$ is the pesticide dose due to coarse-sized granules (mg d^{-1}) by bird i.

For Lorsban® 15G, average MMG and CMG are 0.00555 and 0.0405 mg ai granule^{-1}, respectively.

Total pesticide daily dose from ingestion of granules was calculated as the sum of pesticide doses from ingestion of medium and coarse-sized granules, normalized to bird body weight (Equations SI 43):

$$PIRG_i = \frac{MDose_i + CDose_i}{BW_i} \quad \text{(SI 43)}$$

where,

$PIRG_i$ is the pesticide ingested as a result of granule ingestion (mg ai kg^{-1} bw d^{-1}) for bird i; and

BW_i is the body weight for bird i in kg.

Particle ingestion rate. Counts of grit in bird gizzards are available for many avian species associated with agroecosystems. The most extensive database is that of Gionfriddo and Best (1996) which includes gizzard grit count information for 35 North American bird species. The sample sizes vary among species, but all have at least 5 gizzard samples. The original database for this study was used to develop particle ingestion rate distributions for 29 of the original 35 species (Gionfriddo and Best, unpublished data). The gizzard count data are included along with the size preference distributions in the Excel workbook “Grit Data by Species.xls”. The workbook provides data on total number of birds sampled for each species, the number that contained no grit particles in their gizzards, the number of birds that had grit, plus the total number of grit particles in each bird’s gizzard. In the GranPARAM simulations, gizzard grit counts for medium and coarse-sized grit were randomly selected from the “Grit Data by Species” workbook for the bird species of interest. This random selection was done for each of the 20 birds in a randomly chosen field, and then the process was repeated until 1000 fields had been sampled.

Counts of grit particles are snapshots of what is in a bird’s gizzard and are not a direct assessment of particle consumption rate. Unfortunately, there is little information on the particle ingestion rate (PIR) for birds. In the CPY assessment, PIR was calculated as follows (Equation SI 44):

$$PIR = \frac{GrtObsv}{GrtRtnd} \quad \text{(SI 44)}$$

where,

PIR is the grit ingestion rate (particles per day);

$GrtObsv$ is the grit count in bird gizzard; and

$GrtRtnd$ is the proportion of grit retained from t_0 to end of a day (default = 0.24).

Gizzard count data were divided by $GrtRtnd$ to correct for the continuous clearance of grit particles from a bird's gizzard. Proportion of grit retained over a day in a bird species depends on grit availability (Alonso 1985; Lienhart 1953; May and Braun 1973; McCann 1939; Smith and Rastall 1911; Stafford and Best 1999; Walter and Aitken 1961), ingestion rate (McCann 1939; Smith and MacIntyre 1959; Tagami 1974;, Trost 1981), grit size (Roland et al. 1972; Stafford and Best 1999; Tagami 1974) and diet (Stafford and Best 1999; Trost 1981). When birds have unlimited access to grit, they tend to take up and eliminate more of it (i.e., retain less grit) than they do when grit is scarce or absent (Alonso 1985; Kraup 1924; Lienhart 1953; May and Braun 1973; Smith and Rastall 1911; Stafford and Best 1999; Walter and Aitken 1961). Coarse, hard diets (e.g., seeds and hard animal parts) are also thought to decrease elimination of grit because of the need for additional grinding (less grinding action is needed on a soft diet) (Norris et al; 1975, Trost 1981).

In the few grit retention studies that have been performed, the results differed considerably. The studies demonstrated, however, an approximate negative exponential relationship between test grit remaining in the gizzard and time, suggesting that a more or less consistent percentage of grit is replaced daily. The study with the most conservative (i.e., smallest) value for daily grit retention was one by Fischer and Best (1995). They found that house sparrows fed a controlled number of granules and canned dog food had gizzard granule counts that were strongly correlated with the number of granules consumed daily. The data indicated that gizzard granule counts averaged 24% of the total number of granules consumed daily. Thus, birds were consuming four times the gizzard grit count per day (i.e., 1/0.24 = 4.17). In another study with house sparrows and northern bobwhites, Stafford and Best (1999) found that gizzard grit counts were approximately equal to the amount ingested each day, with the exception of sparrows on a soft diet. In GranPARAM, a conservative daily grit retention value of 24% was used in calculating daily grit consumption. Given the limited data available for this variable, the use of a conservative value for daily grit retention was considered reasonable. The focal species used in this risk assessment generally have "hard" diets, further supporting the use of a conservative value for daily grit retention.

Proportion of time spent in treated fields. GranPARAM assumes that the proportion of total particle intake arising from treated fields is equal to the proportion of time birds spend foraging in treated fields (PT). The methods used to estimate PT in GranPARAM were the same as in LiquidPARAM (see Section 1.2).

Field margin utilization factor. Even when a bird is on the field, it will not feed randomly across the entire field. For example, most species preferentially use the edges of the fields (Best et al. 1990), perhaps to reduce their vulnerability to predators. The behavior is accounted for by a simple ratio expressed as a Field Margin Utilization Factor ($FMUF$). A study by Best et al. (1990) in Illinois and Iowa cornfields indicated that about 5 times more birds were recorded during transect counts in cornfield perimeters than in cornfield centers. Red-winged blackbird, mourning dove, ring-necked pheasant and northern bobwhite all showed a strong preference for cornfield perimeters over cornfield centers. Conversely, horned larks were observed in the centers and perimeters of cornfields, and showed no clear preference for either. Based on the Best et al. (1990) study and others (Beason and Franks 1974; Best 1986), $FMUF$ was set at 5 for all focal species, except the horned lark for which $FMUF$ was set at 1 (i.e., latter species had equal preference for field center and field edge).

Grit size preference. The size of grit found in bird gizzards increases with bird body mass (Best and Gionfriddo 1991; Gionfriddo and Best 1996). The grit-size distribution profiles of most species have definite peaks, with the grit found in gizzards declining abruptly on either side of the modal grit size. Although the grit sizes found in gizzards of some larger bird species exceed the upper size range of pesticide granules, almost all species typically have some grit in their gizzards that overlap with the particle sizes used for granular pesticides, including Lorsban® 15G (Best and Gionfriddo 1991; Gionfriddo and Best, unpubl. data). Thus, on the basis of grit size, there is the potential for many common farmland birds to consume Lorsban® 15G granules for grit.

The best source of data on grit size used by North American birds is that reported in Gionfriddo and Best (1996), wherein they presented information for 35 North American bird species. Although the published account only reported mean grit size for each bird species, information on the grit size distributions within gizzards of individual birds of each species is available from the original database (Gionfriddo and Best, unpubl. data). Data from the original database were used to provide grit size preference and grit counts for 29 of the 35 species in Gionfriddo and Best (1996). Species with less than 5 gizzard samples were excluded from consideration. The mean grit size varied considerably (0.3 to 2.9 mm) and increased linearly with the common logarithm of the bird body mass. The size range of grit for these species corresponds with medium sand particles through to very coarse sand and fine gravel, and overlaps with the size ranges of Lorsban® 15G granules. This information is contained in the Excel workbook “Grit Data by Species.xls”, which was constructed by re-grouping the original 0.2 mm size fractions of the database into fractions fitting more closely with the USDA groupings, and then by recalculating grit percentage size distributions according to the numbers of grit in each new fraction. This workbook includes grit size and numbers for the 5 focal species selected for this assessment (i.e., common pheasant, horned lark, mourning dove, northern bobwhite, and red-winged blackbird). Although the fractions in the spreadsheet do not agree completely with the USDA classification, they are very close: fine sand = 0.1 to 0.2 mm; medium sand = 0.2 to 0.6 mm; coarse sand = 0.6 to 1.0 mm; and very coarse sand = 1.0 to 2.0 mm. Crystal Ball® was used to sample uniformly from the grit percentages for medium- and coarse-sized particles from the spreadsheet for a given bird species. All individual sets of values in a species dataset were assumed to be equally probable.

Granule:Grit preference factor. When given a choice between naturally occurring grit and particles of a granular pesticide, birds may preferentially select one over the other. Such preferential consumption should be considered when estimating granule consumption rates. Granule:Grit Preference Factor ($GGPF$) is a dimensionless number that relates the frequency that birds given equal access to pesticide granules and natural grit particles will select granules. If a bird has no preference or aversion to pesticide granules compared to natural grit, $GGPF$ would be 1. If a bird prefers granules to natural grit, then $GGPF$ would be >1, and if a bird prefers natural grit to granules, then $GGPF$ would be <1. For example, if birds were shown through empirical tests to prefer natural grit over pesticide granules by a 3:1 margin, then $GGPF$ would be defined as 0.33.

Birds strongly avoid Lorsban® 15G granules and this has been attributed to the formulation characteristics of the granules (Best and Gionfriddo 1994; Best et al. 1996; Gionfriddo and Best 1996). The clay-based (e.g., montmorillonite, bentonite) carrier comprises most of the volume of a Lorsban® 15G granule and provides the surface to which the active ingredient is applied. Most of the natural grit consumed by birds is either quartz or feldspar (Korschgen 1964; May and Braun 1973), both of which are silicon-rich minerals.

Preferences for $GGPF$ in house sparrows were studied by Best and Gionfriddo (1994). Birds were given pairwise choices between silica granules and five other carrier types. The silica granules were composed of a material (quartz) that birds normally consume for grit and could be considered a reasonable surrogate for natural grit. The five carrier types included heat-treated montmorillonite clay, a bentonite form of montmorillonite clay, gypsum, corncob, and cellulose complex. Preference was documented in several ways, and included the number of trips birds made to trays containing each of the particle types being compared, the number of pecks at particles within the trays, and the number of pecks per trip. In all cases, the sparrows preferentially consumed silica granules over the alternative granule carriers, although the degree of preference differed among carriers. The mean number of trips per bird to the trays containing silica granules ranged from 2.3 to 21.0 times greater than that to trays containing pesticide carriers, and the mean number of pecks per trip was from 5.7 to 36.6 times greater. The percentage of pecks made to ingest silica granules as opposed to the alternatives ranged from 92.8 to 99.9% of all pecks. The $GGPF$ for the clay-based carriers was 0.078 in this study and this was the factor used in the CPY assessment.

Preferences of birds for granule types are not likely to be constant and may vary under different environmental conditions (e.g., Stafford and Best 1997; Stafford et al. 1996). Caution should be exercised in relying too heavily on the results from a single study or protocol. However, it is clear from the Best and Gionfriddo (1994) study that $GGPF$ is an important factor in reducing exposure of birds to CPY applied using a clay-based carrier.

Spill Attraction Factor. Variation in consumption of pesticide granules by house sparrows was associated with availability and configuration (Fischer and Best 1993). In testing aviaries, blank silica granules were arranged in bands and “spills” with an equivalent number of granules per square foot. Ten birds per aviary (and treatment) were allowed access to the granules over a 2-d period. Gizzard grit counts showed that birds exposed to “spills” tended to consume more granules than those exposed to bands with the same number of granules per square foot. On average over 3 trials, birds exposed to “spills” consumed approximately twice the number of granules than birds exposed to bands consumed. These results suggest that birds in agricultural fields may be more inclined to consume pesticide granules from spills than they would be to consume granules that were appropriately applied to the field. Thus, spill attraction should be taken into account when considering avian exposure to granular pesticides. The largest difference between band and “spill” applications occurred in the first trial. Results of the first trial showed a 4.21-fold increase in consumption of granules from “spills” compared to bands. In GranPARAM, this ratio was used as a conservative estimate of spill attraction factor. A conservative approach was deemed appropriate because of the limited data available for this variable and because such data have only been collected for 1 bird species.

2.2 Results of Exposure Modeling

Some of the major trends that emerged from the analyses (Table SI 20) include:

- For all bird species and use patterns, the 25th, 50th and 75th centile exposure estimates were zero indicating that most birds never ingest a CPY granule.
- Horned larks consistently had the highest exposure estimates. This species frequently forages in crop fields (Best and Murray 2003), has a coarse, hard diet (Martin et al. 1961; Rotenberry 1980) and has high grit counts in their gizzards (Gionfriddo and Best 1996).
- Rate of application only had a modest influence on mean exposure estimates in birds. More important was the application method. When application rates were comparable (e.g., the three corn and sweet corn scenarios), in-furrow and banded application led to lower exposure estimates than for broadcast application. Also important was the region modelled. Horned larks had a lower exposure in broccoli than in corn and sweet corn when CPY was T-band applied. This result occurred despite a much higher application rate in broccoli (2.52 kg ha^{-1}; 2.25 lb ai A^{-1}) than in corn and sweet corn (1.43 kg ha^{-1}; 1.3 lb ai A^{-1}). This anomaly can be explained by the fact that soils in California where broccoli is grown have higher medium- and coarse-sized particle counts than do soils in the corn belt.

2.3 Sensitivity analyses

For the sensitivity analysis, we varied the following input variables: 1) field sizes of 4.54 and 45.4 ha (10 and 100 A) were investigated and compared to the standard 18 ha (40 A) field, 2) spill size was increased to 6,542 cm^2 (1000 sq in) from the standard 26 cm^2 (4 sq in), 3) spill concentration factor was increased to 1000 from the standard 15 value, 4) granule availabilities on the soil surface of 0.8%, 1% and 5% were compared to the standard approach of sampling from the distributions of measured values, 5) proportion of time in the field was increased to the maximum possible value of 100%, 6) gizzard grit counts were increased to the 95th centile measured values, 7) daily grit retention was increased to 75% from the standard 24% value, and 8) the granule:grit preference factor was adjusted to 1 (i.e., no preference) from the standard value of 0.078. In all cases, the sensitivity analysis changes were designed to investigate the influence of selecting worst-case or near worst-case values for the input parameter of interest. As with LiquidPARAM, the sensitivity analyses for GranPARAM included 2 baseline scenarios: 1) Lesser – mourning dove in onion fields (Pacific Northwest – 1.12 kg ha^{-1} (1 lb A^{-1}) applied in-furrow at-plant (7.5 cm; 3 in in furrow, 46 cm (18") row spacing), and 2) Greater – horned lark in corn fields (Corn Belt - 1.12 kg ha^{-1} (1 lb A^{-1}) applied broadcast post-plant).

The results of the sensitivity analysis indicated that none of the changes to the input parameters had any effect on estimated risk to mourning doves in onion fields, the low exposure scenario (Table SI 21). For horned larks in corn fields, changing gizzard grit count or granule:grit preference factor to near worst-case values led to slight increase in predicted mortality if horned larks are of high sensitivity (Table SI 21). Otherwise, assuming worst-case input parameter values had little to no influence on estimated avian risk.

2.4 Evaluation of the Model

The most useful study for evaluating performance of GranPARAM was conducted by Fischer and Best (1995). In their study, consumption of pesticide granules by free-ranging birds was quantified by applying blank silica granules to Iowa cornfields at known application rates and examining gizzards from birds collected from these fields for the presence of granules. Data were collected for 13 bird species, of which 3 were judged to have sufficient data (i.e., n >20) to evaluate model performance. The 3 species were: brown-headed cowbird, red-winged blackbird, and vesper sparrow. A scenario was selected in GranPARAM to match, as closely as possible, the conditions in the field study by Fischer and Best (1995). The details of the model evaluation exercise are described in Moore et al. (2010). The model predictions for 2 of the species, red-winged blackbird and vesper sparrow, agreed with field observations. In the case of brown-headed cowbird, the model somewhat under predicted exposure compared to field observations. Fischer and Best (1995) stated that their field study results were likely biased towards overestimation of number of granules/bird.

Overall, GranPARAM performed reasonably well for bird species exposed to blank silica granules in Iowa cornfields and performed well when compared to the results of several semi-quantitative studies (Moore et al. 2010). Although the available field studies for evaluating GranPARAM are limited, the analyses conducted to date indicate that GranPARAM performs well. Thus, the model can be used with reasonable confidence for estimating the risks of Lorsban® 15G to birds in treated fields.

Table SI 20 Estimated maximum acute exposure for birds exposed to granular chlorpyrifos

Crop	Use Pattern	Appl. rate		Species	Maximum dose retained (mg ai kg^{-1} bw)					
		kg ha^{-1}	lb A^{-1}		Mean	25^{th} centile	50^{th} centile	75^{th} centile	Minimum	Maximum
Broccoli	California - applied T-band at-plant (10 cm (4") band, 75 cm (30") row spacing)	2.52	2.25	Horned lark	0.142	0	0	0	0	16.0
				Mourning dove	0.00973	0	0	0	0	1.70
				Red-winged blackbird	0.0223	0	0	0	0	8.97
Corn and sweet corn	Corn belt - applied T-band (15 cm (6") band, 91 cm (36") row spacing)	1.46	1.3	Horned lark	0.208	0	0	0	0	18.1
				Common pheasant	0.00823	0	0	0	0	4.42
				Mourning dove	0.00377	0	0	0	0	2.04
				Northern bobwhite	0.0228	0	0	0	0	13.7
				Red-winged blackbird	0.0553	0	0	0	0	40.5
Corn and sweet corn	Corn belt - applied in-furrow at-plant (7.5 cm (3") furrow, 91 cm (36") row spacing)	1.46	1.3	Horned lark	0.215	0	0	0	0	5.34
				Common pheasant	0.00290	0	0	0	0	1.75
				Mourning dove	0.00471	0	0	0	0	3.39
				Northern bobwhite	0.0106	0	0	0	0	11.7
				Red-winged blackbird	0.0228	0	0	0	0	20.1
Corn and sweet corn	Corn belt - applied broadcast post-plant	1.12	1	Horned lark	1.30	0	0	0	0	280
				Common pheasant	0.0346	0	0	0	0	24.2
				Mourning dove	0.0265	0	0	0	0	12.0
				Northern bobwhite	0.0827	0	0	0	0	121
				Red-winged blackbird	0.0105	0	0	0	0	0.876
Onion	Pacific northwest - applied in-furrow at-plant (7.5 cm (3")	1.12	1	Horned lark	0.0322	0	0	0	0	20.7
				Mourning dove	0.00125	0	0	0	0	2.38
				Red-winged blackbird	0.0235	0	0	0	0	6.36

Crop	Use Pattern	Appl. rate		Species	Maximum dose retained (mg ai kg^{-1} bw)					
		kg ha^{-1}	lb A^{-1}		Mean	25th centile	50th centile	75th centile	Minimum	Maximum
	furrow, 45 cm (18") row spacing)									
Peanut	Southeast - applied band post-plant (15 cm (6") band, 91 cm (36") row spacing)	4.48	4	Horned lark	0.355	0	0	0	0	24.0
				Mourning dove	0.00907	0	0	0	0	2.38
				Northern bobwhite	0.0249	0	0	0	0	16.5
				Red-winged blackbird	0.106	0	0	0	0	39.5
Sugar beet	Midwest - applied broadcast at-plant	1.12	1	Horned lark	0.458	0	0	0	0	86.7
				Common pheasant	0.000131	0	0	0	0	0.0406
				Mourning dove	0.0138	0	0	0	0	11.2
				Northern bobwhite	0.0329	0	0	0	0	77.8
				Red-winged blackbird	0.0688	0	0	0	0	3.96
Sunflower	Midwest - applied T-band at-plant (15 cm (6") band, 75 cm (30") row spacing)	1.46	1.3	Horned lark	0.126	0	0	0	0	19.4
				Common pheasant	0.00544	0	0	0	0	3.62
				Mourning dove	0.00326	0	0	0	0	2.72
				Northern bobwhite	0.0152	0	0	0	0	17.1
				Red-winged blackbird	0.0361	0	0	0	0	34.9
Tobacco	Southeast - applied broadcast preplant with incorporation	2.24	2	Horned lark	0.583	0	0	0	0	86.9
				Mourning dove	0.0142	0	0	0	0	12.3
				Northern bobwhite	0.0399	0	0	0	0	45.3
				Red-winged blackbird	0.0114	0	0	0	0	0.876

Table SI 21 Results of the sensitivity analysis conducted for GranPARAM

Variable	Value	Exposure scenario	Birds protected (%)		
			5th centile	50th centile	95th centile
Field size	4.54 ha (10 A)	Low (Mourning dove in onion)	100	100	100
	18.18 ha (40 A)		100	100	100
	45.4 ha (100 A)		100	100	100
	4.54 ha (10 A)	High (Horned lark in corn)	95.5	98.7	99.8
	18.18 ha (40 A)		95.9	98.9	99.9
	45.4 ha (100 A)		95.5	99.0	99.8
Spill size	26 cm^2 (4 sq in)	Low (Mourning dove in onion)	100	100	100
	6,542 cm^2 (1000 sq in)		100	100	100
	26 cm^2 (4 sq in)	High (Horned lark in corn)	95.9	98.9	99.9
	6,542 cm^2 (1000 sq in)		96.7	99.0	99.8
Spill concentration factor	15	Low (Mourning dove in onion)	100	100	100
	1000		100	100	100
	15	High (Horned lark in corn)	95.9	98.9	99.9
	1000		95.9	98.8	99.8
Granule availability	0.8%	Low (Mourning dove in onion)	100	100	100
	1%		100	100	100
	5%		100	100	100
	Sample from distribution		100	100	100
	100%	High (Horned lark in corn)	96.5	99.1	99.9
Proportion time in field	100%	Low (Mourning dove in onion)	100	100	100
	Sample from distribution		100	100	100
	100%	High (Horned lark in corn)	96.1	99.0	99.8
	Sample from distribution		95.9	98.9	99.9
Gizzard grit count	95th centile	Low (Mourning dove in onion)	100	100	100
	Sample from distribution		100	100	100
	95th centile	High (Horned lark in corn)	91.7	94.1	99.3
	Sample from distribution		95.9	98.9	99.9
Grit retention	24%	Low (Mourning dove in onion)	100	100	100
	75%		100	100	100
	24%	High (Horned lark in corn)	95.9	98.9	99.9

Variable	Value	Exposure scenario	Birds protected (%)		
			5th centile	50th centile	95th centile
	75%		97.9	99.7	100
Granule:Grit preference factor	0.078	Low (Mourning dove in onion)	100	100	100
	1		100	100	100
	0.078	High (Horned lark in corn)	95.9	98.9	99.9
	1		91.4	98.2	99.8

SI Appendix 4. Avian Incident Reports for Chlorpyrifos

There are two primary sources of incident reports in the United States. The first source is Section 6(a)(2) of FIFRA, where pesticide registrants or manufacturers are required to report to EPA any information on known adverse effects to the environment caused by registered pesticides. Before 1998, registrants were required to submit any information on all ecological incidents to their knowledge. However, registrants are now only required to submit information on "major" incidents (USEPA 2012). Incident reports submitted from other sources, such as the States, also are included in EIIS. One of the issues with the development of the EIIS is lack of proper tracking and quality control. Within the EIIS, each incident is assigned a unique incident number. However, in the EIIS reports for CPY, there appear to be two duplicate incidents (see Table 22):

EIIS data for CPY was requested through the Freedom of Information Act (FOIA) on June 4th, 2013 (USEPA 2013). There were 69 incidents involving birds and CPY from 1974 to 2009 (Table 22), however, for one of these incidents (I021729-033), no information regarding the date and location of the incident or its relation to CPY use was provided. Therefore, this incident was omitted in the analysis below.

The EIIS report provides general information on the incident location, certainty, legality, end use product, application method and total magnitude. Certainty is ranked on a scale from 0 to 4 where a 0 indicates that the incident was unrelated to application of CPY and a 4 indicates that it is highly probable that CPY was responsible. Of the 68 avian incidents, 32 were considered highly probable, 17 were probable, 15 were possible, and four were unlikely to be related to CPY application. A legality code indicates whether the incident was due to a registered use, misuse (not applied as per label), accidental misuse (e.g., spill), intentional misuse (e.g., baiting), or unknown. Of the 68 incidents reported, 11 were classified as occurring with registered uses of CPY, 50 were unknown, and seven were due to misuse. Incidents involving the misuse of CPY (accidental or intentional) are not considered further in this assessment. In some incident reports, information was also available describing the affected species, responses observed (e.g., mortality, behavioral), and the identified route of exposure. Additional information on application rate and type, and local meteorological conditions was not provided. There is also a significant amount of descriptive information missing for many of the reported incidents, making it difficult to interpret the information in some cases.

Of the Code 4 incidents, seven were associated with a registered use, while the rest were either unknown or the result of misuse. Of the two incidents reported since changes in labeled uses for CPY in 2002, one incident was associated with an accidental misuse (in 2006) but there was no information for the other (in 2009). In the avian incident in 2009, mortalities were observed in one eastern meadowlark and ten brown headed cowbirds as a result of ingestion of CPY (I021453-001). The most common routes of exposure for birds were through ingestion and perching (the database does not define how birds are exposed during perching). There was insufficient detail for many of the reported incidents to determine the end use product involved or the method of application.

Overall, the EIIS data suggest that incidents resulting from the legal, registered uses of CPY have been very infrequent since 2002. The small number of recent incidents suggests that the current labels for CPY are generally protective of birds. However, this line of evidence has a high level of uncertainty because of the difficulties associated with finding dead birds in the field and linking any mortality observed to CPY.

Table 22. Summary of avian incidents for chlorpyrifos obtained from the Ecological Incident Information System (EIIS)

Incident#	Date	County, state	Certainty code	Legality code	End-use product	Application method	Taxon affected	Magnitude	Response	Route of exposure
Terrestrial										
I021729-033[a]							Red kite (*Milvus milvus*)	1	mortality	bait consumption
							Red kite (*Milvus milvus*)	1	mortality	bait consumption
I003131-001	05/30/1974	Suffolk, NY	3	UN		N/R	Canada goose (*Branta canadensis*)	43	mortality	ingestion
B0000-501-23	07/09/1974	NY	2	UN	N/R	N/R	Canada goose (*Branta canadensis*)	12	mortality	ingestion
B0000-400-21	01/01/1981	FL	3	UN		N/R	American robin (*Turdus migratorius*)	unknown	mortality	ingestion
B0000-501-11	10/05/1983	Hartford, CT	2	UN		N/R	Brown-headed cowbird (*Molothrus ater*)	60	mortality	ingestion
I003131-002	05/24/1985	Albany, NY	4	RU			American robin (*Turdus migratorius*)	unknown	mortality	ingestion
I003131-003	04/14/1986	Monroe, NY	4	RU		N/R	American robin (*Turdus migratorius*)	2	mortality	ingestion
I000103-015	09/15/1988	Floyd, GA	3	UN	N/R	N/R	Rock dove (*Columba livia*)	1	mortality	ingestion
							Rock dove (*Columba livia*)	1	mortality	ingestion
I003131-006	08/02/1989	Albany, NY	4	RU		Spray	American robin (*Turdus migratorius*)	2	mortality	ingestion
I005417-009	10/26/1989	Solano, CA	4	RU			Duck (*Anatidae*)	6	mortality	ingestion
I000097-007	02/20/1990	San Juan	3	MI	N/R	N/R	Domestic pigeon (*Columba livia*)	40	mortality	
B0000-502-82	02/23/1990		3	MI	N/R	Bait	Pigeon (*Columbidae*)	40	mortality	ingestion
I000103-007	03/01/1990	Taliaferro, GA	4	UN	N/R	N/R	American robin (*Turdus migratorius*)	7	mortality	ingestion

Incident#	*Date*	*County, state*	*Certainty code*	*Legality code*	*End-use product*	*Application method*	*Taxon affected*	*Magnitude*	*Response*	*Route of exposure*
B0000-400-66	05/03/1990	Erie, NY	2	UN		N/R	Mallard (*Anas platyrhynchos*)	2	mortality	ingestion
I000504-024	03/04/1991	Gwinnett, GA	4	UN	N/R	N/R	American robin (*Turdus migratorius*)	16	mortality	N/R
I003184-001	03/04/1991	Virginia Beach CI, VA	4	MI		N/R	American robin (*Turdus migratorius*)	3	Incapaci-tation	ingestion
							American robin (*Turdus migratorius*)	43	mortality	ingestion
I004169-040 **(duplicate of the above?)**	03/04/1991	Virginia Beach CI, VA	4	UN	N/R	N/R	American robin (*Turdus migratorius*)	43	mortality	ingestion
I003176-003	05/15/1991	Prince William, VA	2	RU			Unknown bird	22	mortality	ingestion
I000015-001	06/03/1992	Montgomery, MD	2	RU		Spray	Bluebird (*Turdidae*)	1	mortality	ingestion
B000177-001	07/08/1992	Arlington, VA	2	UN	N/R	N/R	Bluebird (*Turdidae*)	1	mortality	N/R
I000504-002	02/01/1993	Santa Rosa, FL	4	UN	N/R	N/R	American robin (*Turdus migratorius*)	15	mortality	ingestion
							American robin (*Turdus migratorius*)	100	mortality	ingestion
I003654-001	02/16/1993	Yancey, NC	4	UN		N/R	American robin (*Turdus migratorius*)	1	mortality	ingestion
I003351-001	12/17/1993	San Joaquin, CA	4	UN			Red-tailed hawk (*Buteo jamaicensis*)	1	mortality	ingestion
I000724-001	09/22/1993	Glynn, GA	1	RU			Boat-tailed grackle (*Cassidix mexicanus*)	3	mortality	ingestion
							Common yellow-throat (*Geothlypis trichas*)	1	mortality	ingestion
I002993-	09/28/1993	Grant, WI	3	MA		N/R	Cedar waxwing	18	mortality	ingestion

Incident#	Date	County, state	Certainty code	Legality code	End-use product	Application method	Taxon affected	Magnitude	Response	Route of exposure
009							(*Bombycilla cedrorum*)			
I005042-005	01/02/1994	Stanislaus, CA	4	UN		N/R	Red-tailed hawk (*Buteo jamaicensis*)	1	mortality	perching
							Red-tailed hawk (*Buteo jamaicensis*)	1	mortality	N/R
							Red-tailed hawk (*Buteo jamaicensis*)	2	mortality	perching
I005042-009	01/19/1994	Stanislaus, CA	2	UN		N/R	Barn owl (*Tyto alba*)	1	incapaci-tation	perching
I003351-012	01/27/1994	Stanislaus, CA	3	UN			Red-tailed hawk (*Buteo jamaicensis*)	1	mortality	N/R
							Red-tailed hawk (*Buteo jamaicensis*)	1	mortality	N/R
I005042-008 **(duplicate of the above?)**	01/27/1994	Stanislaus, CA	4	UN	N/R	N/R	Red-tailed hawk (*Buteo jamaicensis*)	2	mortality	perching
I005042-014	01/29/1994	Butte, CA	1	UN		N/R	Red-tailed hawk (*Buteo jamaicensis*)	1	incapaci-tation	perching
I003351-018	01/29/1994	Butte, CA	3	UN			Red-tailed hawk (*Buteo jamaicensis*)	1	mortality	N/R
I005042-013	01/30/1994	San Joaquin, CA	2	UN		N/R	Red-tailed hawk (*Buteo jamaicensis*)	1	incapaci-tation	perching
I005042-010	02/03/1994	Merced, CA	3	UN		N/R	Red-tailed hawk (*Buteo jamaicensis*)	1	mortality	N/R
I005042-003	02/06/1994	Merced, CA	4	UN	N/R	N/R	Red-tailed hawk (*Buteo jamaicensis*)	1	mortality	drift
I005042-011	02/07/1994	Stanislaus, CA	1	UN		N/R	Red-tailed hawk (*Buteo jamaicensis*)	1	incapaci-tation	perching
I003351-006	02/12/1994	Stanislaus, CA	3	UN			Red-tailed hawk (*Buteo jamaicensis*)	1	mortality	ingestion
							Red-tailed hawk	1	mortality	unknown

Incident#	Date	County, state	Certainty code	Legality code	End-use product	Application method	Taxon affected	Magnitude	Response	Route of exposure
							(*Buteo jamaicensis*)			
I005042-007	02/15/1994	Merced, CA	2	UN		N/R	Red-tailed hawk (*Buteo jamaicensis*)	1	mortality	drift, spray
I001815-001	12/06/1994	Escambia, FL	3	UN	N/R	N/R	Common grackle (*Quiscalus quiscula*)	most of 800	mortality	ingestion
							Unknown bird	some of 800	mortality	
I005042-001	12/17/1994	San Joaquin, CA	4	UN	N/R	N/R	Red-tailed hawk (*Buteo jamaicensis*)	2	mortality	unknown
I005042-015	12/23/1994	Stanislaus, CA	2	UN		N/R	Red-tailed hawk (*Buteo jamaicensis*)	1	incapaci-tation	perching
I002243-002	02/10/1995	Houston, GA	4	UN	F	N/R	American robin (*Turdus migratorius*)	23	mortality	ingestion
							Blue jay (*Cyanocitta cristata*)	1	mortality	ingestion
I002243-001	02/14/1995	Richmond, GA	4	RU	F	N/R	American robin (*Turdus migratorius*)	N/R	mortality	ingestion
							Grackle (*Quiscalus sp.*)	N/R	mortality	ingestion
I002074-001	02/15/1995	Citrus, FL	4	UN	N/R	N/R	American robin (*Turdus migratorius*)	60	mortality	ingestion
I002074-002	02/18/1995	Citrus, FL	4	UN	N/R	N/R	American robin (*Turdus migratorius*)	1	mortality	ingestion
I001884-001	03/03/1995	Santa Rosa, FL	4	RU		N/R	Grackle (*Quiscalus sp.*)	1000	mortality	ingestion
I005294-001	01/01/1996	Stanislaus, CA	4	UN		N/R	Cooper's hawk (*Accipiter cooperii*)	1	mortality	ingestion
I004993-005	01/20/1996	Tuolumne, CA	2	UN		N/R	Red-tailed hawk (*Buteo jamaicensis*)	1	mortality	N/R
							Red-tailed hawk (*Buteo jamaicensis*)	1	mortality	N/R
I004993-013	08/09/1996	Fresno, CA	3	UN		N/R	American kestrel (*Falco sparverius*)	1	mortality	N/R
I005037-	10/22/1996	NC	4	UN	N/R	N/R	Common grackle	7	mortality	

Incident#	*Date*	*County, state*	*Certainty code*	*Legality code*	*End-use product*	*Application method*	*Taxon affected*	*Magnitude*	*Response*	*Route of exposure*
002							(*Quiscalus quiscula*)			
1004701-001	11/01/1996	Charleston, SC	4	RU	N/R	N/R	Grackle (*Quiscalus sp.*)	7	mortality	ingestion
I004934-001	02/24/1997	Okaloosa, FL	4	UN		N/R	American robin (*Turdus migratorius*)	4	mortality	ingestion
I007107-006	07/19/1997	Santa Cruz, CA	4	UN	N/R	N/R	Goose (*Anserinae*)	3	mortality	N/R
I006595-001	01/09/1998	Charleston, SC	4	UN	N/R	N/R	Pelican (*Pelecansus sp.*)	1	mortality	ingestion
I008164-001	07/26/1998	Roscommon, MI	4	UN	N/R	N/R	Mallard (*Anas platyrhynchos*)	2	mortality	ingestion
I008454-001	01/13/1999	Alameda, CA	2	UN		Spray	American robin (*Turdus migratorius*)	100	mortality	
							Unknown bird	dozens	mortality	ingestion
I010002-001	01/14/1999	Contra Costa, CA	3	UN	N/R	N/R	American robin (*Turdus migratorius*)	9	mortality	N/R
							Cedar waxwing (*Bombycilla cedrorum*)	3	mortality	N/R
							House finch (*Carpodacus mexicanus*)	1	mortality	N/R
I009337-001	10/22/1999	Suffolk, NY	2	UN	N/R	N/R	Duck (*Anatidae*)	2	mortality	ingestion
							Swan (*Anatidae*)	1	mortality	ingestion
I018980-033	01/15/2000	Benton, OR	4	UN			Cackling goose (*Branta hutchinsii*)	22	mortality	
I018980-023	01/26/2000	East Baton Rouge, LA	2	UN			American robin (*Turdus migratorius*)	1	mortality	
							Blue jay (*Cyanocitta cristata*)	2	mortality	
							Brown-headed cowbird (*Molothrus ater*)	151	mortality	
							Cardinal	22	mortality	

Incident#	Date	County, state	Certainty code	Legality code	End-use product	Application method	Taxon affected	Magnitude	Response	Route of exposure
							(*Richmondena cardinalis*)			
							Mourning dove (*Zenaida macroura*)	1	mortality	
							Red-winged blackbird (*Agelaius phoeniceus*)	unknown	mortality	
I011532-001	01/10/2001	Westchester, NY	3	UN	N/R	N/R	Blue jay (*Cyanocitta cristata*)	1	mortality	ingestion
I011300-002	01/13/2001	Effingham, GA	4	UN	N/R	N/R	American robin (*Turdus migratorius*)	10	mortality	ingestion
I011131-001	01/22/2001	Morgan, GA	3	UN	N/R	N/R	Common grackle (*Quiscalus quiscula*)	large number	mortality	ingestion
I011879-001	03/24/2001	Orange, NY	3	UN	N/R	N/R	American crow (*Corvus brachyrhynchos*)	1	mortality	ingestion
I013385-001	06/16/2001	Bergen, NJ	2	RU			Canada goose (*Branta canadensis*)	4	mortality	N/R
I012661-001	11/13/2001	Onondaga, NY	4	UN		Bait	Rock dove (*Columba livia*)	1	mortality	ingestion
I017850-008	3/17/2006	Noble, OK	1	MA			Blackbird (*Icteridae*)	100	mortality	ingestion
							Red-tailed hawk (*Buteo jamaicensis*)	2	mortality	secondary poisoning
I021453-001	11/06/2009	Wayne, GA	4	UN			Brown-headed cowbird (*Molothrus ater*)	10	mortality	ingestion
							Eastern meadowlark (*Sturnella magna*)	1	mortality	ingestion
Terrestrial/Aquatic										
I000103-016	10/09/1988	Highlands, FL	4	MA	N/R	Spill	Boat-tailed grackle (*Cassidix mexicanus*)	unknown	mortality	spill
							Turkey vulture	unknown	incapaci-	spill

Incident#	Date	County, state	Certainty code	Legality code	End-use product	Application method	Taxon affected	Magnitude	Response	Route of exposure
							(*Cathartes aura*)		tation	
							Unknown bird	142	mortality	spill
							White ibis (*Eudocimus albus*)	unknown	mortality	spill
							Wood stork (*Mycteria Americana*)	unknown	incapaci-tation	spill
I000962-001	03/01/1994		3	MA	F	Broad-cast, unincorp	American robin (*Turdus migratorius*)	1	mortality	runoff

[a]No General Information report was provided for this incident.
Certainty Code: 0 = Unrelated, 1 = Unlikely, 2 = Possible, 3 = Probable, 4 = Highly Probable
Legality Code: RU = Registered Use, M = Misuse, MA = Misuse (Accidental), MI = Misuse (Intentional), UN = Unknown.

References

Aldrich JW (1993) Classification and Distribution. In: Baskett TS, Sayre MW, Tomlinson RE, Mirarchi RE (eds), Ecology and Management of the Mourning Dove. Stackpole Books, Harrisburg, PA pp 47-54.

Alonso JC (1985) Grit in the gizzard of Spanish sparrows (*Passer hipaniolensis*). Vogelwarte 33:135-143.

American Ornithologists' Union (1998) Check-list of North American Birds. American Ornithologists' Union, Washington, DC, 829 pp.

Arch AM (2006) Dursban WG: Test to assess short-term effects on wigeon (*Anas penelope*) of a grass application of a 75% WG formulation of chlorpyrifos. Dow Chemical Company (Unpublished Report), Midland, MI.

Baehr CH, Habig C (2001) Statistical Evaluation of UTAB database for Use in Terrestrial Nontarget Organism Probabilistic Risk Assessments. In: Greenberg BM, Hull RN, Roberts MH, Jr, Gensemer RW (eds), Environmental Toxicology and Risk Assessment: Science, Policy and Standardization – Implications for Environmental Decisions. American Standards for Testing Materials (ASTM), West Conshohocken, PA pp 96-112.

Barrows WB (1912) Michigan Bird Life. Special Bulletin of the Department of Zoology and Physiology, Michigan Agricultural College, East Lansing, MI, 822 pp.

Basili GD, Temple SA (1999) Winter ecology, behavior, and conservation needs of dickcissels in Venezuela. Stud Avian Biol-Ser 19:289-299.

Bauriedel WR (1986) Fate of ^{14}C-Chlorpyrifos Administered to Laying Hens. Dow Chemical, USA (Unpublished Report), Midland, MI.

Beason RC, Franks EC (1974) Breeding behavior of the horned lark. Auk 91:65-74.

Bennett RS (1989) Role of dietary choices in the ability of bobwhite to discriminate between insecticide-treated and untreated food. Environ Toxicol Chem 8:731-738.

Bent AC (1968) The blue grosbeak (*Passerina caerulea*). In: Austin OL (ed), Life Histories of North American Cardinals, Grosbeaks, Towhees, Finches, Sparrows, and Allies (Part 1). Vol. 237, US National Natural History Museum Bulletin, Washington, DC.

Best LB (1972) First-year effects of sagebrush control on two sparrows. J Wildl Manage 36:534-544.

Best LB (1977) Nestling biology of the field sparrow. Auk 94:308-319.

Best LB (1986) Conservation tillage: Ecological traps for nesting birds? Wildl Soc Bull 14.

Best LB, Whitmore RC, Booth GM (1990) Use of cornfields by birds during the breeding season: The importance of edge habitat. Am Midl Nat 123:84-99.

Best LB, Gionfriddo JP (1991) Characteristics of grit use by cornfield birds. Wilson Bull 103:68-82.

Best LB (1992) Characteristics of corn rootworm insecticide granules and the grit used by cornfield birds: Evaluating potential avian risks. Am Midl Nat 128:126-138.

Best LB, Gionfriddo JP (1994) House sparrow preferential consumption of carriers used for pesticide granules. Environ Toxicol Chem 13:919-925.

Best LB, Freemark DF, Dinsmore JJ, Camp M (1995) A review and synthesis of habitat use by breeding birds in agricultural landscapes of Iowa. Am Midl Nat 134:1-29.

Best LB, Stafford TR, Mihaich EM (1996) House sparrow preferential consumption of pesticide granules with different surface coatings. Environ Toxicol Chem 15:1763-1768.

Best LB, Murray LD (2003) Estimating the proportion of diet birds take from treated agricultural fields. CropLife America, Washington, DC.

Bird RD, Smith LB (1964) The food habits of the red-winged blackbird, *Agelaius phoeniceus*, in Manitoba. Can Field-Nat 78:179-186.

Black CT (1941) Ecological and Economic Relations of the Crow, with Special Reference to Illinois, PhD Thesis, University of Illinois, Urbana, IL.

Booth GM, Best LB, Carter MW, Jorgensen CD (1989) Effects of Furadan 4F on Birds Associated with Kansas and Oklahoma Alfalfa Fields. FMC Corporation (Unpublished Report), Philadelphia, PA.

Booth GM, Mortensen SR, Carter MW, Schaalje BG (2005) Hazard evaluation for northern bobwhite quail (*Colinus virginianus*) exposed to chlorpyrifos-treated turf and seed. Ecotoxicology and Environmental Safety 60:176-187.

Boutin C, Freemark KE, Kirk DA (1999) Farmland birds in southern Ontario: Field use, activity patterns and vulnerability to pesticide use. Agric Ecosyst Environ 72:239-254.

Brennan LA, Hurst GA (1995) Summer diet of northern bobwhite in eastern Mississippi: implications for management. Proc Annu Conf Southeast Assoc Fish and Wildl Agencies 49:516-524.

Brewer BS (1987) The Degradation of Three Chlorpyrifos and two Diazinon Formulations When Exposed to North Central Texas Environmental Conditions. Dow Chemical Company (Unpublished Report), Midland, MI.

Brown KC, Sprosen R, Forster A (2006) Chlorpyrifos Residues in Invertebrates Following Autumn and Summer Applications to Cereals. Dow AgroSciences (Unpublished Report), Abingdon, OX, UK.

Bryant HC (1914) A determination of the economic status of the western meadowlark in California. University of California Publications in Zoology 11:377-510.

Burn JD, Leighton FA (1996) Further studies of brain cholinesterase: Cholinergic receptor ratios in the diagnosis of acute lethal poisoning of birds by anticholinesterase pesticides. J Wildl Dis 32:216-224.

Butler AW (1897) The Birds of Indiana. In: Blatchley WS (ed), Twenty-Second Annual Report. Indiana Department of Geology and Natural Resources, Indianapolis, IN pp 515-531.

Cadman MD, Eagles PFJ, Helleiner FM (1987) Atlas of the Breeding Birds of Ontario. University of Waterloo Press, Waterloo, ON, 706 pp.

Cairns MA, Maguire CC, Williams BA, Bennett JK (1991) Brain cholinesterase activity of bobwhite acutely exposed to chlorpyrifos. Environ Toxicol Chem 10:657-664.

Campbell RW, Dawe NK, McTaggart-Cowan I, Cooper JM, Kaiser GW (2001) The Birds of British Columbia, Vol 4. Royal British Columbia Museum, Victoria, BC, 773 pp.

Cannings RA, Cannings RJ, Cannings SG (1987) Birds of the Okanagan Valley, British Columbia. Royal British Columbia Museum, Victoria, BC, 420 pp.

Chambers GD, Wight HM, Baskett TS (1962) Characteristics of wintering flocks of mourning doves in Missouri. J Wildl Manage 26:155-159.

Crocker DR, Prosser P, Tarrant KA, Irving PV, Watola G, Chandler-Morris SA, Hart J, Hart ADM (1998) Improving the Assessment of Pesticide Risks to Birds in Orchards. Objective 1: Use of Radio-Telemetry to Monitor Birds' Use of Orchards. Central Science Laboratory, UK Ministry of Agriculture, Fisheries and Food, York, UK. EH18/02

Crocker DR, Prosser P, Irving PV, Bone P, Hart ADM (2002) Estimating Avian Exposure to Pesticides on Arable Crops. In: Boatman ND, Carter N, Evans AD, Grice PV, Stoate C, Wilson JD (eds), Birds and Agriculture. Association of Applied Biologists, Wellesbourne, UK pp 237-244.

Davis SK, Lanyon WE (2008) Western meadowlark (*Sturnella neglecta*). In: Poole A (ed), The Birds of North America Online. Cornell Laboratory of Ornithology, Ithaca, NY pp 104.

Dawson J (1986a) Residues of Chlorpyrifos in Leatherjackets Following Application of Dursban 4 to Grassland - United Kingdom, Devon 1985. Dow Chemical Company (Unpublished Report), Norfolk, UK.

Dawson J (1986b) Residues of Chlorpyrifos in Leatherjackets Following Application of Dursban 4 to Grassland - United Kingdom, Yorkshire 1985. Dow Chemical Company, Norfolk (Unpublished Report), Norfolk, UK.

Dawson J (1987) Chlorpyrifos Residues in Grass and Hay Following Application of Dursban 4 - Germany, Spring 1986. Dow Chemical Company, Ltd (Unpublished Report), Letcombe Regis, UK.

Day S (1986) Chlorpyrifos Residues in Grass and Hay Following Application of Dursban 4 - Germany, 1985. Dow Chemical Company, Ltd (Unpublished Report), Letcombe Regis, UK.

Dmitrieva L, Gottlieb G (1992) Development of brainstem auditory pathway in mallard duck embryos and hatchlings. J Comp Physiol A Sens Neural Behav Physiol 171:665-671.

Dolbeer RA (1982) Migration patterns for sex and age classes of blackbirds and starlings. J Field Ornithol 53:28-46.

Dunning JB, Jr (1984) Body Weights of 686 Species of North American Birds. Eldon Publishing, Cave Creek, AZ, 38 pp.

Dunning JB, Jr (1993) CRC Handbook of Avian Body Masses. CRC Press, Boca Raton, FL, 371 pp.

ECOFRAM (1999) Terrestrial Draft Report. United States Environmental Protection Agency, Washington, DC. http://www.epa.gov/oppefed1/ecorisk/terrreport.pdf

Erbach DC, Tollefson JJ (1983) Granular insecticide application for corn rootworm control. Trans Am Soc Ag Eng 26.

Fair JM, Kennedy PL, McEwen LC (1995) Effects of carbaryl grasshopper control on nesting killdeer in North Dakota. Environ Toxicol Chem 14:881-890.

Fautin RW (1941) Development of nestling yellow-headed blackbirds. Auk 58:215-232.

Feist FG (1968) Breeding Bird Populations in Relation to Proposed Sagebrush Control in Central Montana, Department of Zoology, MSc Thesis, Montana State University, Bozeman, MT, 41 pp.

Fink R (1978a) The Effect of Chlorpyrifos During a One-Generation Reproduction Study on Bobwhite. Dow Chemical (Unpublished Report), Midland MI.

Fink R (1978b) One-Generation Reproduction Study – Mallard Duck: Chlorpyrifos. Dow Chemical (Unpublished Report), Midland MI.

Fischer DL, Best LB (1993) Avian consumption of pesticide granules in relation to granule availability, SETAC National Conference, Society of Environmental Toxicology and Chemistry, Houston, TX, pp.

Fischer DL, Best LB (1995) Avian consumption of blank pesticide granules applied at planting to Iowa cornfields. Environ Toxicol Chem 14:1543-1549.

Fletcher JS, Nellessen JE, Pfleeger TE (1994) Literature review and evaluation of the EPA food-chain (Kenaga) nomogram, an instrument for estimating pesticide residues on plants. Environ Toxicol Chem 13:1383-1391.

Forbes SA (1883) The regulative action of birds upon insect oscillation. Ill State Nat Hist Surv Bull 1.

Frese I, Schneider K, Wilkens S (2008) Residues of Chlorpyrifos in Arthropods After Spray Application of Dursban 75 WG in Pome Fruit Orchards – Magnitude and Time Course of Residue Decline. Dow AgroSciences (Unpublished Report), Abingdon, OX, UK.

Frey LT, Krueger HO, Palmer DA (1994) Lorsban Insecticide: An Evaluation of its Effects Upon Avian and Mammalian Species on and Around Corn Fields in Iowa. Wildlife International Ltd., Easton, MD, Project 103-366.

Gale D (1997) Residues of Chlorpyrifos in Established Grassland at Intervals Following Two Applications of DURSBAN 480 (EF-1042) or DURSBAN WG (EF-1315), Germany – 1995. DowElanco Company, Ltd (Unpublished Report), Letcombe Regis, UK.

Gallagher SP, Palmer DA, Krueger HO (1994) Lorsban Insecticide A Pilot Year Evaluation of its Effects upon Avian and Mammalian Species on and Around Citrus Groves in California. DowElanco (Unpubished Report), Indianapolis, IN.

Gauvreau C, Alvo R (1996) Killdeer. In: Gauthier J, Aubry Y (eds), The Breeding Birds of Quebec: Atlas of the Breeding Birds of Southern Quebec. Association Quebecoise des Groupes d'Ornithologues, Province of Quebec Society for the Protection of Birds. Canadian Wildlife Service, Environment Canada, Quebec Region, Montreal, PQ.

Gilligan J, Smith M, Rogers D, Contreras A (1994) Birds of Oregon: Status and Distribution. Cinclus Publications, McMinnville, OR, 360 pp.

Gionfriddo JP, Best LB (1996) Grit-use patterns in North American birds: The influence of diet, body size, and gender. Wilson Bull 108:685-696.

Godfrey WE (1986) The Birds of Canada. National Museums of Canada, Ottawa, ON, 600 pp.

Gomez LE (2009) Use and Benefits of Chlorpyrifos in U.S. Agriculture. Dow AgroSciences (Unpublished Report), Indianapolis, IN, USA. NA

Gross A (1921) The dickcissel of the Illinois prairies. Auk 38:163-184.

Heagy PA, Best LB (1983) Factors affecting feeding and brooding of brown thrasher nestlings. Wilson Bull 95:297-303.

Hoerger FD, Kenaga EE (1972) Pesticide Residues on Plants: Correlation of Representative Data as a Basis for Estimation of Their Magnitude in the Environment. In: Coulston F, Korte F (eds), Environmental Quality and Safety – Global Aspects of chemistry, Toxicology and Technology as Applied to the Environment. Academic Press, New York, NY pp 9-23.

Howell JC (1942) Notes on the nesting habits of the American robin (*Turdus migratorius* L.). Am Midl Nat 28:529-603.

Howell SNG, Webb S (1995) A Guide to Birds of Mexico and Northern Central America. Oxford University Press, Oxford, UK, 1010 pp.

Hummel JW, Wax LM, Edwards DI (1992) Incorporation and fate of granular soil insecticides. Trans Am Soc Ag Eng 35:773-779.

Idema PF, Kolaszar T, Perritt JE, Palmer DA, Krueger HO (1993) AZTEC 2.1% Granular Insecticide: An Evaluation of its Effects upon Avian Species in and Around Corn Fields in Central Iowa. Bayer Crop Protection (Unpublished Report), Kansas City, MO.

Imler RH (1939) Comparison of the food of the white-necked raven and crows in Oklahoma. Wilson Bull 51:121-122.

Iwata Y, O'Neal JR, Barkley JH, Dinoff TM, Dusch MR (1983) Chlorpyrifos applied to California citrus: Residue levels on foliage and on and in fruit. J Agric Food Chem 31:603-610.

Johnsgard PA (1988) The Quails, Partridges, and Francolins of the World. Oxford University Press, New York, NY, 264 pp.

Johnson EJ, Best LB (1982) Factors affecting feeding and brooding of gray catbird nestlings. Auk 99:148-156.

Johnston DW (1961) The Biosystematics of American Crows. University of Washington Press, Seattle, WA, 119 pp.

Johnston G, Walker CH, Dawson A (1994) Interactive effects between EBI fungicides (prochloraz, propiconazole and penconazole) and OP insecticides (dimethoate, chlorpyrifos, diazinon and malathion) in the hybrid red-legged partridge. Environ Toxicol Chem 13:615-620.

Jones SL, Cornely JE (2002) Vesper sparrow (*Pooecetes gramineus*). In: Poole A (ed), The Birds of North America Online. Cornell Laboratory of Ornithology, Ithaca, NY pp 624.

Jorgensen CD, Booth GM, Carter MW, White CM, Whitmore RC (1983) Effects of Furadan ® 4F on Avian and Insect Populations in Alfalfa (*Medicago sativa*). FMC Corporation (Unpublished Report), Philadelphia, PA.

Jorgensen CD, Whitmore RC, Booth GM, Carter MW, Smith HD (1989) Effects of Furadan® 4F on Birds Associated with Nebraska and Texas/New Mexico Corn Fields. FMC Corporation (Unpublished Report), Philadelphia, PA.

Kenaga EE (1973) Factors to be considered in the evaluation of the toxicity of pesticides to birds in the environment. Environ Qual Safe 2:166-181.

Kenaga EE, Fink RJ, Beavers JB (1978) Dietary Toxicity Tests With Mallards Simulating Residue Decline of Chlorpyrifos and Avoidance of Treated Food. Dow Chemical Company (Unpublished Report), Midland, MI.

Kessel B (1957) A study of the breeding biology of the European starling (*Sturnus vulgaris* L.) in North America. Am Midl Nat 58:257-331.

Kluijver HN (1950) Daily routines of the great tit, *Parus m. major* L. Ardea 38:99-135.

Knapton RW, Mineau P (1995) Effects of granular formulations of terbufos and fonofos applied to cornfields on mortality and reproductive success of songbirds. Ecotoxicol 4:138-153.

Korschgen L (1964) Foods and nutrition of Missouri and Midwestern pheasants. Trans N Am Wildl Nat Resour Conf 29.

Kraup BF (1924) The digestive organs of the fowl. Vet Med US 19:522-523.

Lawrence A (2006) Quantification of Residues on Arthropod Communities Following Summer Application of Chlorpyrifos to Orchards. Cambridge Environmental Assessments, Cambridge, UK, Study No XCE-1411. Dow Chemical Company (Unpublished Report), Midland, MI.

Lewis JC (1993) Foods and Feeding Ecology. In: Baskett TS, Sayre MW, Tomlinson RE, Mirarchi RE (eds), Ecology and Management of the Mourning Dove. Stackpole Books, Harrisburg, PA pp 181-204.

Lienhart R (1953) Recherches sur le role des cailloux contenus dans le gesier des oiseaux granivores. Bull Soc Sci Nancy 12:5-9.

Ligon JS (1961) New Mexico Birds and Where to Find Them. University of New Mexico Press, Albuquerque, NM, 360 pp.

Livingstone K (2006a) Residues of Chlorpyrifos in Sugar Beet at Intervals and Harvest Following a Single Application of EF-726 Followed by Two Applications of EF-1551 - Northern Europe. Dow AgroScience (Unpublished Report), Milton Park, UK.

Livingstone K (2006b) Residues of Chlorpyrifos in Sugar Beet at Intervals and Harvest Following a Single Application of EF-726 Followed by Two Applications of EF-1551 - Central Europe 2005. Dow AgroScience (Unpublished Report), Milton Park, UK.

Long JL (1981) Introduced Birds of the World: The Worldwide History, Distribution, and Influence of Birds Introduced to New Environments. Universe Books, New York, NY, 528 pp.

Mackay D, Giesy JP, Solomon KR (2013) Fate in the environment and long-range atmospheric transport of the organophosphorus insecticide, chlorpyrifos and its oxon. Rev Environ Contam Toxicol 231 ???.

Maguire CC, Williams BA (1987) Response of thermal stressed bobwhite to organophosphorus exposure. Environmental Pollution 47:25-39.

Maher WJ (1974) Birds III: Food Habits. University of Saskatchewan (Matador Project), University of Saskatchewan, Saskatoon, SK. Technical Report # 52

Mankin JB, O'Neill RV, Shugart HH, Rust BW (1975) The Importance of Validation in Ecosystem Analysis. In: Innis GS (ed), New Directions in the Analysis of Ecological Systems. Simulation Council Proceedings Series pp 63-71.

Martin AC, Zim HS, Nelson AL (1961) American Wildlife and Plants. McGraw Hill, New York, NY, 500 pp.

May TA, Braun CE (1973) Gizzard stones in adult white-tailed ptarmigan (*Lagopus leucurus*) in Colorado. Arctic Alpine Res 5:49-57.

McAtee WL, Beal FEL (1924) Some Common Game, Aquatic, and Rapacious Birds in Relation to Man. US Department of Agriculture, Washington DC.

McAtee WL (1926) The relation of birds to woodlots in New York State. Roosevelt Wild Life Bull 4:154.

McCall PJ, Oliver GR, McKellar R (1984) Modeling the Runoff Potential and Behavior of Chlorpyrifos in a Terrestrial-aquatic Watershed. Dow Chemical (Unpublished Report), Midland, MI.

McCann LJ (1939) Studies of the grit requirements of certain upland game birds. J Wildl Manage 3:31-41.

McNicol DK, Robertson RJ, Weatherhead PJ (1982) Seasonal, habitat, and sex-specific food habits of red-winged blackbirds: Implications for agriculture. Can J Zool 60:3282-3289.

McQuillen HL, Brewer LW, Tank SL, Stafford JM (1998a) Determination of Residues of Chlorpyrifos in Insects, Soil Invertebrates and Seed After a Single Application of Lorsban 4E Insecticide to Alfalfa. Ecotoxicology & Biosystems Associates, Inc., Snow Camp, NC, Study No. 079716.

McQuillen HL, Brewer LW, Tank SL, Stafford JM (1998a) Determination of Residues of Chlorpyrifos in Insects, Soil Invertebrates and Seed After a Single Application of Lorsban 4E Insecticide to Citrus. Ecotoxicology & Biosystems Associates, Inc., Snow Camp, NC, Study No. 079717.

Meyers SM, Marden BT, Bennett RS, R B (1992) Comparative response of nestling European starlings and red-winged blackbirds to an oral administration of either dimetholate or chlorpyrifos. J Wildl Dis 28:400-406.

Mirarchi RE (1993) Energetics, Metabolism and Reproductive Physiology. In: Baskett TS, Sayre MW, Tomlinson RE, Mirarchi RE (eds), Ecology and Management of the Mourning Dove. Stackpole Books, Harrisburg, PA pp 143-160.

Mirarchi RE, Baskett TS (1994) Mourning dove (*Zenaida macroura*). In: Poole A, Gill F (eds), The Birds of North America, No 117. The Academy of Natural Sciences, Philadelphia, PA.

Monroe BL, Jr (1968) A Distributional Survey of Birds of Honduras. Ornithology Monograph No. 7. The American Ornithologists' Union, Farmington, NM, 458 pp.

Moore DRJ, Teed RS, Greer C, Solomon KR, Giesy JP (2013) Refined avian risk assessment for flowable and granular formulations of chlorpyrifos in North America. Rev Environ Contam Toxicol 231 ????.

Moore DRJ, Breton RL, MacDonald DB (2003) A comparison of model performance for six quantitative structure-activity relationship packages that predict acute toxicity to fish. Environ Toxicol Chem 22:1799-1809.

Moore DRJ, Fischer DL, Teed RS, Rodney SI (2010) Probabilistic risk assessment model for birds exposed to granular pesticides. Integr Environ Assess Manag 6:260-272.

Myers CM, Lewallen LL, Nobe B (1976) Residue Studies of Fenthion (Baytex®) and Dursban® in Central California Pastures. Bureau of Vector Control, California State Department of Public Health, Fresno, CA. DN10637.

Nagy K, Peterson C (1988) Scaling of Water Flux Rate in Animals. University of California Press, Berkeley, CA, 172 pp.

Nagy KA, Girard IA, Brown TK (1999) Energetics of free-ranging mammals, reptiles, and birds. Ann Rev Nutrit 19:247-277.

Nelson AL, Martin AC (1953) Gamebird weights. J Wildl Manage 17:36-42.

Newman MC (1995) Quantitative Methods in Aquatic Ecotoxicology. Lewis Publishers, Boca Raton, FL, 426 pp.

Norris E, Norris C, Steen JB (1975) Regulation and grinding ability of grit in the gizzard of Norwegian willow ptarmigan (*Lagopus lagopus*). Poult Sci 54:1839-1843.

Old J (2005) Residues of Chlorpyrifos in Sugar Beet at Intervals and Harvest Following a Single Application of EF-726 Followed by Two Applications of EF-1551 - Central Europe - 2004. Dow AgroScience (Unpublished Report), Milton Park, UK.

Old J (2006) Residues of Chlorpyrifos in Sugar Beet at Intervals and Harvest Following a Single Application of EF-726 Followed by Two Applications of EF-1551 - Northern Europe - 2004. Dow AgroScience (Unpublished Report), Milton Park, UK.

Olsen DW (1977) A Literature Review of Pheasant Habitat Requirements and Improvement Methods. Utah State Department of Natural Resources, Salt Lake City, UT. Publ No. 77-7

Orians GH (1985) Blackbirds of the Americas. University of Washington Press, Seattle, WA, pp.

Otis DL, Schulz JH, Miller D, Mirarchi RE, Baskett TS (2008) Mourning dove (*Zenaida macroura*). In: Poole A (ed), The Birds of North America Online. Cornell Laboratory of Ornithology, Ithaca, NY pp 117.

Owens RA, Myres MT (1973) Effects of agriculture upon populations of native passerine birds of Alberta fescue grassland. Can J Zool 51:697-713.

Palmer RS (1976) Handbook of North American Birds, Volume II: Waterfowl, Part 1. Yale University Press, New Haven, CT, 566 pp.

Parnell IB (2002) Northern Bobwhite Habitat Use and Nesting Ecology in a Forest- and Agriculture-Dominated System, MSc Thesis, University of Georgia, Athens, GA, 75 pp.

Payne RB (2006) Indigo Bunting (*Passerina cyanea*). In: Poole A (ed), The Birds of North America Online. Cornell Laboratory of Ornithology, Ithaca, NY pp 104.

Peck GK, James RD (1987) Breeding Birds of Ontario, Nidiology and Distribution, Vol 2: Passerines. Royal Ontario Museum, Toronto, ON, 851 pp.

Peoples AD, Lochmiller RL, Leslie DM, Boren JC, Jr, Engle DM (1994) Essential amino acids in northern bobwhite foods. J Wildl Manage 58:167-175.

Phillips AR, Marshall JT, Jr, Monson G (1964) The Birds of Arizona. University of Arizona Press, Tuscon, AZ, 212 pp.

Pinkowski BC (1978) Feeding of nestling and fledgling eastern bluebirds. Wilson Bull 90:84-98.

Portwood D, Williams M (1995) Residues of Chlorpyrifos in Pasture at Intervals Following Two Applications of Dursban 480 (EF-1042) or Dursban WG (EF-1300), Belgium – 1994. DowElanco Company, Ltd (Unpublished Report), Letcombe Regis, UK.

Prosser P (1999) Potential Exposure of Birds to Treated Seeds. Central Science Laboratory, UK Ministry of Agriculture, Fisheres and Food, York, UK. EH18/02

Prosser P (2005) Field Monitoring of Temik 10G Usage in Commercial Fields and Effects on Wildlife in Britain: Final Report. Central Science Laboratory, York, UK.

Racke KD, Robb CK (1993a) Dissipation of Chlorpyrifos in Cool-season Turfgrass and Fallow Soil in Indiana. DowElanco (Unpublished Report), Indianapolis, IN.

Racke KD, Robb CK (1993a) Dissipation of Chlorpyrifos in Cool-season Turfgrass and Fallow Soil in Florida. DowElanco (Unpublished Report), Indianapolis, IN.

Racke KD, Robb CK (1994) Field Evaluation of Chlorpyrifos Runoff Potential From Turfgrass. DowElanco (Unpublished Report), Indianapolis, IN.

Raffaele H, Wiley J, Garrido O, Keith A, Raffaele J (1998) A Guide to the Birds of the West Indies. Princeton University Press, Princeton, NJ, 511 pp.

Ridgely RS, Gwynne JA (1989) A Guide to the Birds of Panama: With Costa Rica, Nicaragua, and Honduras. Princeton University Press, Princeton, NJ, 534 pp.

Ridgway R, Friedmann H (1946) The Birds of North and Middle America. US Nat Mus Bull 50.

Roland DA, Sr, Sloan DR, Harms RH (1972) Calcium metabolism in the laying hen. I. Calcium retention in the digestive tract of the laying hen. Poult Sci 51:598-601.

Root T (1988) Atlas of Wintering North American Birds: An Analysis of Christmas Bird Count Data. University of Chicago Press Chicago, IL, 336 pp.

Rosenberg KV, Rosenberg GH (1982) Autumn migration. Southwest region (Arizona and northern Sonora). Am Birds 36:204-205.

Rosenberg KV, Ohmart RD, Hunter WC, Anderson BW (1991) Birds of the Lower Colorado River Valley. University of Arizona Press, Tuscon, AZ, 416 pp.

Rotenberry JT (1980) Dietary relationships among shrubsteppe passerine birds: Competition or opportunism in a variable environment. Ecol Monog 50:93-110.

Rotenberry JT, Wiens JA (1980) Habitat structure, patchiness, and avian communities in North American steppe vegetation – a multivariate analysis. Ecol 6:1228-1250.

SAP (2001) Probabilistic Models and Methodologies: Advancing the Ecological Risk Assessment Process in the EPA Office of Pesticide Programs. FIFRA Scientific Advisory Panel Meeting, March 13-16, 2001. United States Environmental Protection Agency, FIFRA Scientific Advisory Panel, Arlington, VA. No. 2001-06

Sallabanks R, James FC (2002) American robin (*Turdus migratorius*). In: Poole A (ed), The Birds of North America Online. Cornell Laboratory of Ornithology, Ithaca, NY pp 462.

Schneider K, Wilkens S (2008) Chlorpyrifos (Dursban 480 EC): Residues of Chlorpyrifos in Arthropods after Spray Application of Dursban 480 EC in Brassica Fields – Magnitude and Time Course of Residue Decline. Dow AgroSciences (Unpublished Report), Abingdon, OX, UK.

Sears MK, Chapman RA (1979) Persistence and movement of four insecticides applied to turfgrass. J Econ Entomol 72:272-274.

Semenchuk GP (1992) The Atlas of Breeding Birds of Alberta. Federation of Alberta Naturalists, Edmonton, AB, 391 pp.

Smith AR (1996) Atlas of Saskatchewan Birds. Saskatchewan Natural History Society Special Publication, Regina, SK, 456 pp.

Smith HH, Rastall RN (1911) Grit. In: Leslie AS (ed), The Grouse in Health and Disease. Smith Elder, London, UK pp 94-99.

Smith RE, MacIntyre TM (1959) The influence of soluble and insoluble grit upon the digestibility of feed by the domestic fowl. Can J Anim Sci 39:164-169.

Smith WW (1997) Avian Monitoring in Furadan® 4F Treated Cotton Fields 1995 – Texas, Oklahoma, California, Mississippi; 1996 – Arkansas, California, Louisiana, Mississippi, Oklahoma, Tennessee, Texas. FMC Corporation (Unpublished Report), Philadelphia, PA.

Solomon KR, Matthies M, Vighi M (2013) Assessment of PBTs in the EU: A critical assessment of the proposed evaluation scheme with reference to plant protection products. Environ Sci EU 25:DOI.

Stafford JM (2010) Evaluation of Northern Bobwhite (*Colinus virginianus*) Food Consumption Relative to the Concentration of Chlorpyrifos in the Diet. Dow AgroSciences (Unpublished Report), Indianapolis, IN.

Stafford TR, Best LB, Fischer DL (1996) Effects of different formulations of granular pesticides on birds. Environ Toxicol Chem 15:1606-1611.

Stafford TR, Best LB (1997) Effects of granular pesticide formulations and soil moisture on avian exposure. Environ Toxicol Chem 16:1687-1693.

Stafford TR, Best LB (1999) The Relationship Between Gizzard Grit Counts and Daily Grit Consumption Rate. Department of Animal Ecology, Iowa State University (Unpublished Report), Ames, IO.

Stromberg KL (1979) Pheasant food habits in spring and consumption of seed treatment pesticides. J Wildl Manage 43:185-189.

Taber W, Johston DW (1968) *Passerina cyanea* (Linnaeus), indigo bunting. In: Austin OL (ed), Life Histories of North American Cardinals, Grosbeaks, Buntings, Towhees, Finches, Sparrows, and Allies. Vol. 237, US National Natural History Museum Bulletin, Washington, DC pp 80-111.

Tagami S (1974) On the variation of retention and form of grit in gizzard of growing chicks. Science Reports, Faculty of Agriculture, Ibaraki University 22:7-13.

Temple S (2002) Dickcissel (*Spiza americana*). In: Poole A (ed), The Birds of North America Online. Cornell Laboratory of Ornithology, Ithaca, NY.

Thompson HM, Walker CH, Hardy AR (1988) Avian esterases as indicators of exposure to insecticides – The factor of diurnal variation. Bull Environ Contam Toxicol 41:4-11.

Tollner EW, Cryer SA (1997) X-ray line-scanning for insecticide granule distribution detection following T-band placement. Rec Res Dev Entomol 1:49-57.

Trost RE (1981) Dynamics of grit selection and retention in captive mallards. J Wildl Manage 45:64-73.

USDA (1994) Soil Survey Geographic (SSURGO) Database. U.S. Department of Agriculture, Natural Resources Conservation Service. Accessed 2012 December. http://soils.usda.gov/survey/geography/ssurgo/

USDA (2012) National Agricultural Statistics Service. U.S. Department of Agriculture. Accessed 2012 April, August and September. http://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Chemical_Use/index.asp

USEPA (1993) Wildlife Exposure Factors Handbook, Vol. 1. United States Environmental Protection Agency. Office of Research and Development, , Washington, DC. No. EPA/600/R-93/187a

USEPA (2004) Overview of the Ecological Risk Assessment Process in the Office of Pesticide Programs: Endangered and Threatened Species Effects Determinations. United States Environmental Protection Agency. Office of Prevention, Pesticides, and Toxic Substances, Office of Pesticide Programs, Washington, DC.

USEPA (2005) Reregistration Eligibility Science Chapter for Carbofuran. Environmental Fate and Effects Chapter. Environmental Risk Assessment and Human Drinking Water Exposure Assessment. United States Environmental Protection Program, Office of Pesticide Programs, Washington, DC.

USEPA (2008) Terrestrial Investigation Model Version 2.1. United States Environmental Protection Agency, Office of Pesticide Programs, Washington, DC.

USEPA (2012) Guidance for Using Incident Data in Evaluating Listed and Non-listed Species Under Registration Review. United States Environmental Protection Agency (EPA), Washington, DC. Accessed 2013 June 27. http://www.epa.gov/pesticides/science/efed/policy_guidance/team_authors/endangered_species_reregistration_workgroup/esa_incident_guidance.htm#eiis

USEPA (2013) Ecological Incident Information System (EIIS) Summary Reports (General Information and Species Information) for Chlorpyrifos. Acquired through FOIA request submitted June 4th, 2013 and provided by EPA on June 20th, 2013. United States Environmental Protection Agency, Washington, DC.

Verbeek NA, Caffrey C (2002) American crow (*Corvus brachyrhynchos*). In: Poole A (ed), The Birds of North America Online. Cornell Laboratory of Ornithology, Ithaca, NY pp 647.

Vodela JK, Dalvi RR (1995) Comparative toxicological studies of chlorpyrifos in rats and chickens. Vet Hum Toxicol 37:1-3.

Vose D (1996) Risk Analysis: A Quantitative Guide to Monte Carlo Simulation Modeling. John Wiley & Sons, New York, NY, 328 pp.

Walter ED, Aitken JR (1961) The value of soluble and insoluble grit in all mash and mash grain rations for caged layers. Poult Sci 40:904-909.

Wetmore A (1916) Birds of Puerto Rico. US Department of Agriculture Bulletin, No. 326. US Department of Agriculture, Washington, DC.

Wheelwright NT (1986) The diet of American robins: An analysis of U.S. Biological Survey records. Auk 103:710-725.

Wildlife International (1978) Eleven-day Toxicant 2 x LC50 Option with Untreated Food – Mallard Duck. Dow Chemical Company (Unpublished Report), Midland, MI.

Wilkens S, Frese I, Schneider K (2008) Chlorpyrifos (Dursban 480 EC): Residues of Chlorpyrifos in Invertebrates after Spray Application of Dursban 75 WP in Citrus Orchards – Magnitude and Time Course of Residue Decline. Dow AgroSciences (Unpublished Report), Abingdon, OX, UK.

Williams M, Giddings J, Purdy J, Solomon KR, Giesy JP (2013) Exposures of aquatic organisms resulting from the use of chlorpyrifos in North America. Rev Environ Contam Toxicol 231 ????.