A Site-Specific Approach For Assessing Risks to Ecological Receptors From DDT at an Agricultural Site

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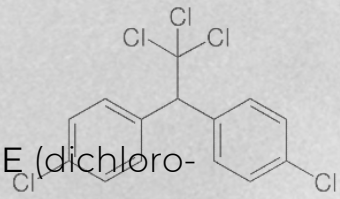
Overview

1. Site Introduction
2. DDT Introduction
3. The Site + DDT
4. Problem Formulation Summary & Protection Goals
5. Food Chain Models
6. TRVs (Issues and Derivation)
7. EDx-Based TRV Derivation Approach
8. Results and Conclusions

Site Introduction

- 300 ha agricultural research station with historical DDT contamination
- In operation for 100 years (still active)
- Near a stream and lake
- Climate: semi-arid shrubland desert
- Source of DDT
  - Direct application
  - Leaking and drum storage
  - Over spraying / spray drift
  - Widespread spraying throughout the region
- Current and future land use = agricultural research station
- Federal criteria applicable (provincial considered)
- Several investigations since the late '70s
- PQRA (Golder)
- DQRA completed under the assumption of a post remediation scenario
- Maximum DDT in soil = 7.7 mg/kg

DDT - *Dichloro-diphenyl-trichloroethane*



- **DDT + metabolites** = sum of DDT + DDD (dichloro-diphenyl-dichloroethane) + DDE (dichloro-diphenyl-dichloroethylene)
- As a simplification:
  - DDT degrades to DDE under aerobic conditions or to DDD under anerobic conditions
  - DDE is generally very stable to further degradation and has a higher potential for biomagnification based on site-specific bioaccumulation models for soil to earthworms.
- DDT was extensively used in Canada as an **insecticide for crop protection** from about the **1940s until 1985**,
- Canadian soil concentrations of DDT range: **ND to 132 mg/kg** (CCME 1999)
- The region of the Site is one of the most heavily DDT sprayed agricultural regions in Canada. (Kesic et al 2021)

The pesticide DDT, widely dispersed in the U.S. in the mid-20th century, was banned in 1972. Bettmann and Getty Images

Terrestrial Ecological Problem Formulation Summary

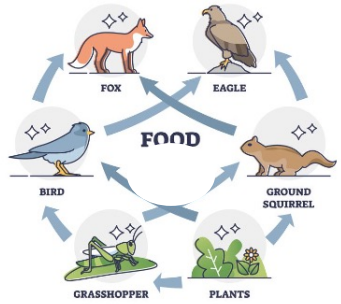
- **Receptors:**
  - Soil invertebrates (earthworms, grasshoppers), plants (grass, trees)
  - Wildlife – birds, mammals, herptiles (focus here is birds and mammals)
  - 20 species at risk (SAR) – plants, birds, & mammals
  - Evaluated feeding guilds for birds and mammals (invertivore, herbivore, omnivore, carnivore)
- **Exposure Pathways:**
  - Direct contact
  - Ingestion of dietary items
- **COPCs:** DDT
  - Soil DDT + Metabolites max = 7.7 mg/kg
  - Soil 95% UCLM DDT + Metabolites = 0.58 mg/kg
- **Soil Criteria:**
  - SIP = 12 mg/kg (CCME SC)
  - Birds and Mammals = 0.7 mg/kg (CCME SFI)

Protection Goals

- "Protect population of common species & individual species at risk (SAR)"
- Translated to EDx-based TRVs →
  - ED20 based on growth or reproduction represents a **low to moderate-low effect** and is **reasonable for common species**.
  - ED10 based on growth, reproduction, or behaviour is a **negligible level of effect** and is **reasonable for SAR**.

Food Chain Models

Excel-Based Model



Ingested Dose from Soil

$$D_S = I_s \times C_s$$

D_S = Dose of contaminants from incidental ingestion of soil (mg/day)
I_S = Soil ingestion rate (kg dw/day)
C_S = Concentration of contaminant in soil (mg/kg dw)

Ingested Dose from Water

$$D_W = C_W \times WIR$$

D_W = Dose of contaminant from water (mg/day)
C_W = Concentration of contaminant in water (mg/L)
WIR = Water ingestion rate (L/day)

Ingested Dose from Food

$$D_F = \sum_1^j (C_{Fj} \times FIR \times p_{Fj})$$

D_F = Dose of contaminant from food (mg/day)
C_{Fj} = Contaminant concentration in prey item j in the diet (mg/kg ww)
FIR = Food ingestion rate (kg ww/day)
P_{Fj} = Represents the proportion of food item j in the diet (unitless)

Total Ingested Dose

$$D_I = \frac{(D_S + D_W + D_F)}{BW}$$

D_I = Total ingested dose (mg/kg bw/day)
D_F = Dose of contaminants from food determined from dietary concentrations (mg/day)
D_W = Dose of contaminants from drinking water (mg/day)
D_S = Dose of contaminants from incidental ingestion of soil (mg/day)
BW = Body weight of receptor in kg (ww)

Hazard Quotient

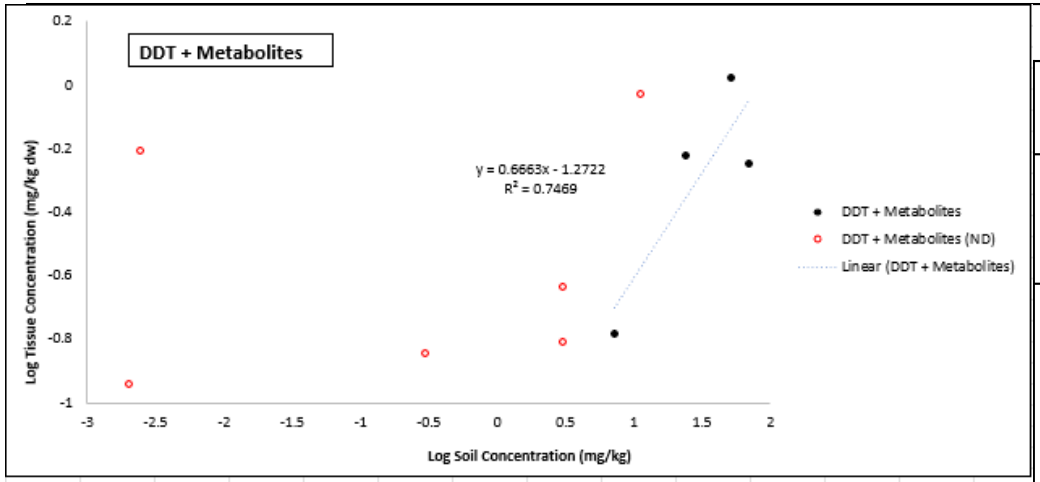
$$HQ = \frac{D_I \times HRF}{TRV}$$

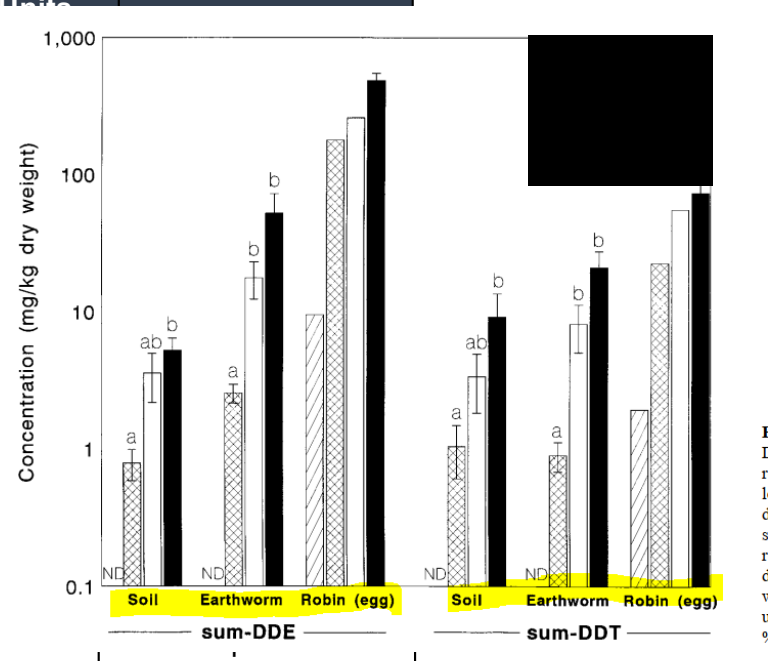
HQ = Hazard Quotient
D_I = Total ingested dose (mg/kg bw/day)
HRF = habitat range factor (unitless)
TRV = Toxicity reference value

Site Specific EPCs Used in the FCM

Medium	Area or Source	Parameter	Concentration	Units	Basis
Statistics-Based EPCs					
Soil	Site-Wide[1]	Total DDT	0.15	mg/kg	95% UCLM
		Total DDE	0.43	mg/kg	95% UCLM
		DDT + metabolites	0.58	mg/kg	95% UCLM
Surface Water	Waterbody X	DDT + metabolites	<0.005	µg/L	Minimum DL
Grasshoppers	Site-specific samples	DDT + metabolites	0.024	mg/kg ww	Maximum
Fruit	Site-specific samples	DDT + metabolites	<0.01	mg/kg ww	Maximum

Modelled EPCs Used in the FCM

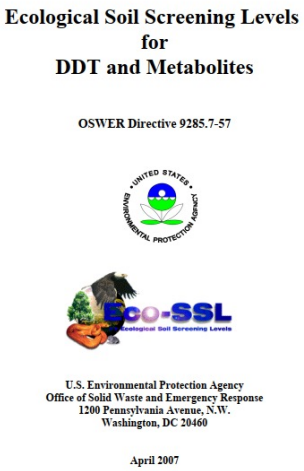
Medium	Area or Source	Parameter	Concentration	Units
				m
				m
				m
Earthworms to Robin Eggs	Harris et al. (2000)	DDT + metabolites	104	m

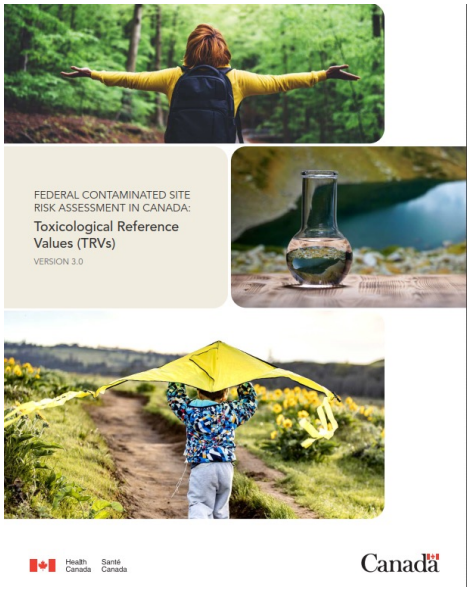


paper

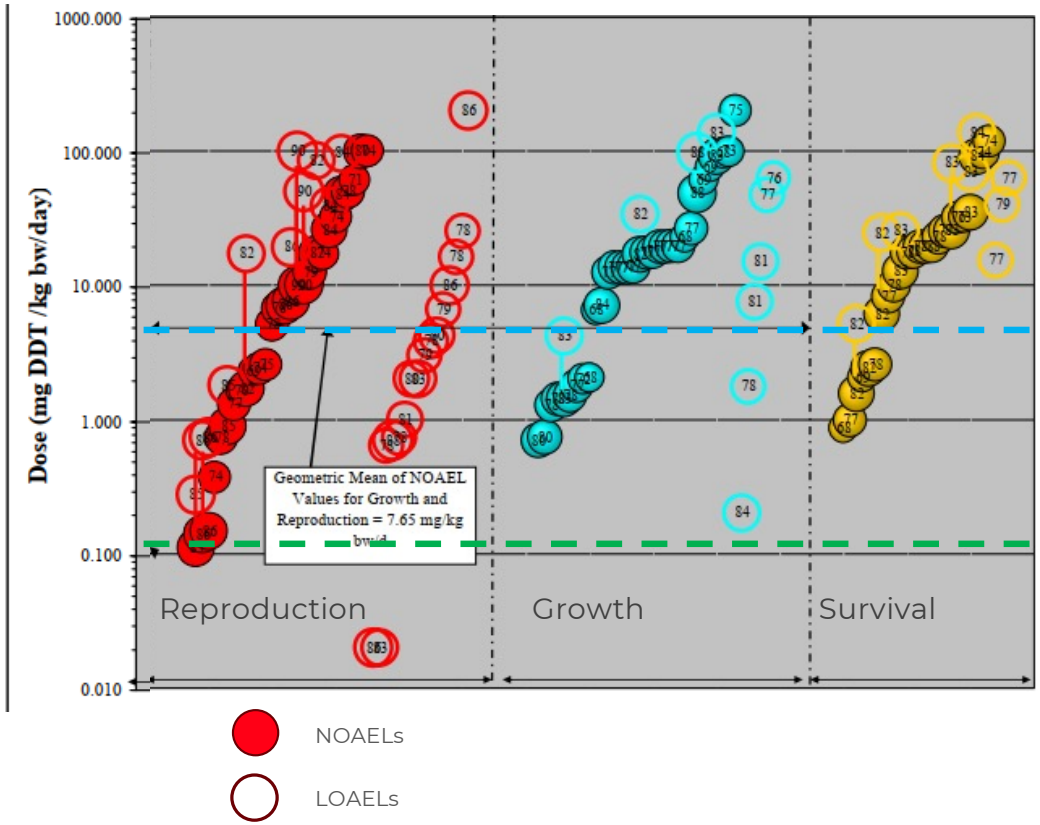
Toxicity Reference Values (TRVs)

- TRV = dose / concentration that is not expected to cause an unacceptable level of effect
- Typically use published TRVs for mammals and birds (Health Canada, US EPA,...)
- TRVs are typically derived from oral exposure
- Used in conjunction with exposure estimates





The Issues with NOAEL & LOAEL Based TRVs



EcoSSL – Presents a Geomean of NOAELs = 7.65 mg/kg bw/day

EcoSSL Screening TRV Highest bounded NOAEL lower than the lowest bounded LOAEL = 0.147 mg/kg bw/day

Why Derive Edx-Based TRVs Here?

To help make informed decisions

- Initial screening risk assessment = HQ>1
- EDx = Effect dose at x where x = a reduction in the endpoint (10%, 20%)
- The range of plausible TRVs was sufficiently wide = source of uncertainty would impact the ability to make **informed Site management decisions**

Receptor Group	EcoSSL Recommended TRV (mg/kg bw day)	EcoSSL Geomean of NOAELs (mg/kg bw day)	Magnitude Difference
Birds	0.227	4.66	21-times lower
Mammals	0.147	7.65	52-times lower

- More detailed evaluation of the toxicological data to understand the dose-response relationship and the likely magnitude of effects associated with the TRV was appropriate.

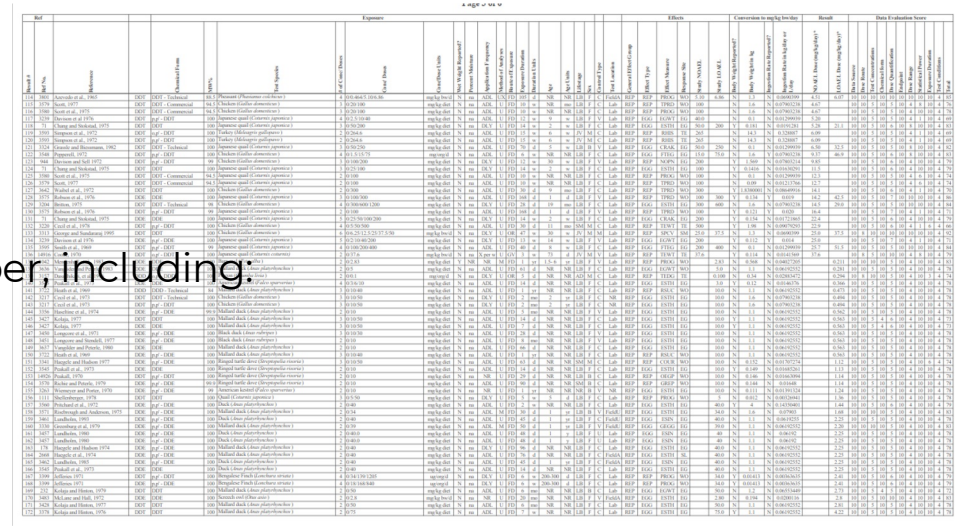
TRV Derivation Approach

- **Toxicity Data Source:** US EPA Eco-SSL compendium (US EPA 2007)
- Focus on the studies that indicated effects - both bounded and unbounded LOAELs.
  - A study with only a NOAEL is not useful because it has no effects.
- We reviewed the original paper to confirm that Eco-SSL's summary of the NOAEL and LOAELs was correct.
- Raw data were extracted to determine the level of effects (i.e., change relative to negative control) for each test concentration.
- Consolidated dose-response relationships were explored graphically to evaluate the relative strength of the different regression relationships
  - survival, growth, and reproduction
- A recommended regression relationship was identified and used to establish an appropriate EDX-based TRV for the different measurement endpoint.
  - ED20 based on survival, growth, reproduction, or behavior represents a low to moderate-low effect and is reasonable for common species.
  - ED10 based on growth, reproduction, or behavior is a negligible level of effect and is reasonable for SAR.

Papers and Endpoints Reviewed

Receptor Group	Total Number of Endpoints (and Papers) with LOAELs According to Eco-SSL	WSP's Endpoints (Papers) Reviewed
Birds	117 (68)	75 (42)
Mammals	50 (35)	29 (18)

Toxicity Data Reviewed



- Raw data were extracted from each paper, including:
  - Confirmation of test organism
  - Exposure duration
  - Form of DDT (or metabolite)
  - Test concentrations
  - Calculation of dose
  - Calculation of percent effect for each test concentration relative to the negative control.
  - **We identified multiple instances where the information in the original paper did not match Eco-SSLs summary**

Toxicity Data Reviewed

WSP's Summary Tables

Round	Eco-SSL Reference No.	Endpoint	Endpoint Description	Species	Duration	Duration Grouping	Form	Concentration (ppm)	Dose (mg/kg bw/day)	% Effect
2	14919	GRO	Body weight	Ring-necked pheasant (Phasianus colchicus)	74 d	1 - 3 mo	DDT	90	5.33	4%
2	14919	GRO	Body weight	Ring-necked pheasant (Phasianus colchicus)	74 d	1 - 3 mo	DDT	355	21.0	8%
2	14919	SUR	Mortality	Ring-necked pheasant (Phasianus colchicus)	74 d	1 - 3 mo	DDT	90	5.33	0%
2	14919	SUR	Mortality	Ring-necked pheasant (Phasianus colchicus)	74 d	1 - 3 mo	DDT	355	21.0	100%
2	14919	SUR	Mortality	Ring-necked pheasant (Phasianus colchicus)	57 d	1 - 3 mo	DDT	50	2.96	0%
2	14919	SUR	Mortality	Ring-necked pheasant (Phasianus colchicus)	90 d	1 - 3 mo	DDT	200	11.9	10%
2	14919	SUR	Mortality	Ring-necked pheasant (Phasianus colchicus)	90 d	1 - 3 mo	DDT	400	23.7	0%
2	14919	SUR	Mortality	Ring-necked pheasant (Phasianus colchicus)	57 d	1 - 3 mo	DDT	600	35.6	20%

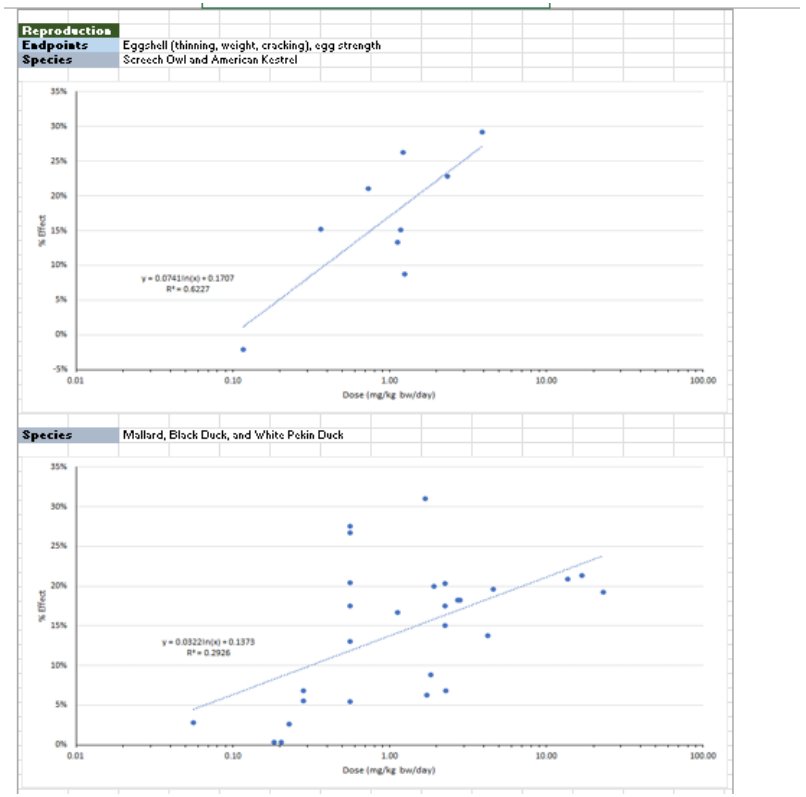
- Do gut checks for % Effects

- Mortality: reported as percentages (lower = better)

- Body Weight: reported as mean weight change (higher is better)

Data Exploration and Regression Relationships

- Compiled data was presented graphically as percent effect (relative to the negative control) to calculated dose on a logarithmic scale.
- This allowed for visual inspection for potential outliers or instances where the data extraction leads to a non-intuitive result inconsistent with the underlying relationship.
- We refined the data exploration to find the optimum regression in a systematic process that allowed us to retain the largest possible n, while achieving significance and highest R^2



Data Exploration Process - *Stepwise Process*

RELATIONSHIP

1. Review the regression for the "**all endpoint-specific data**" (survival, growth, reproduction)
   • If the relationship has a **strong** (R^2 = 0.5) or **acceptable** (R^2 = 0.2) = retain the regression

RELATIONSHIP

2. If acceptable R^2 not met:
   • subdivide the major endpoints & repeat the regression analysis in step 1.

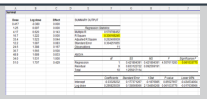
RELATIONSHIP

3. If acceptable R^2 not met at step 2, further subdivide endpoints (specific related endpoints) & repeat

RELATIONSHIP

4. If acceptable R^2 not met at step 3, further subdivide specific related endpoints by species, & repeat

5. Evaluate all retained regression relationships for their statistical significance - P-value of < 0.1



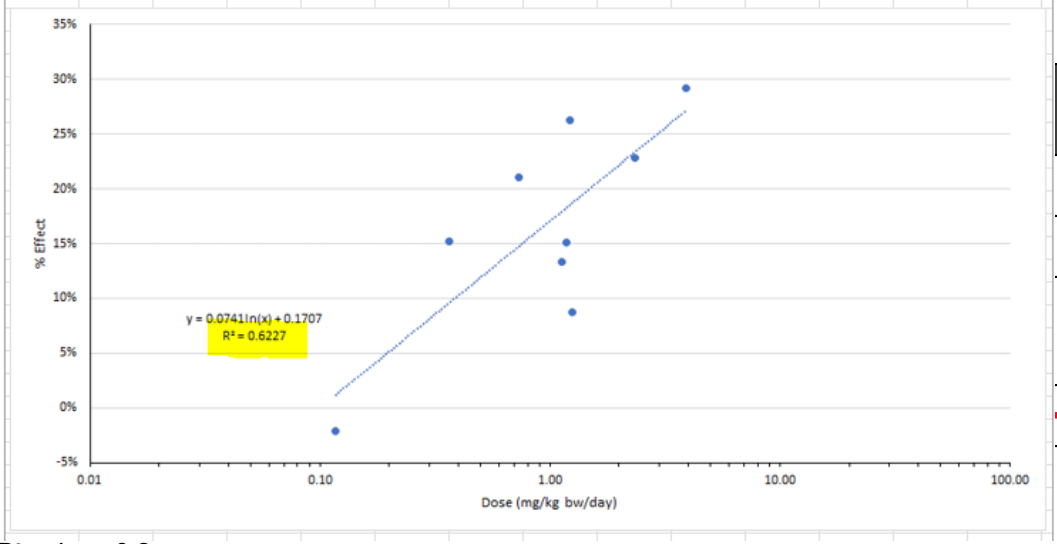
6. For statistically significant relationships: Accept regression & evaluate conservatism of regression in deriving a TRV by calculating the ED10 and ED20 values; conduct checks as required on survival endpoints (i.e., for SAR).

Results – Regression Relationships

- Birds and mamma
- **Birds:** 4 relationsh

Major Endpoints		Accepted?
Survival	ED_X	Yes
Growth	ED_X	Yes
Reproduction	ED_X	Yes
~~Behaviour~~	~~ED_X~~	~~No~~

Reproduction	
Endpoints	Eggshell (thinning, weight, cracking), egg strength
Species	Screech Owl and American Kestrel



and R^2

Notes:

ED_X = effective dose repre

Acceptable Relationship = R^2 value >0.2

Strong Relationship = R^2 value >0.5

Bold = P-value <0.1

Results – Regression Relationships

- **Mammals:** 3 relationships were retained → survival (x2) & reproduction

Major Endpoints	Regression Equation	Notes on Specific Endpoints	R^2	Significance (P-value)	Accepted ?
Survival	$ED_X = e^{((\% \text{ Effect} + 0.0333) / 0.1285)}$	All survival; limited studies, inconsistent dose response	0.34	**0.06**	Yes
	$ED_X = e^{((\% \text{ Effect} + 1.1342) / 0.5184)}$	Single study with dose response	0.83	**0.09**	Yes
Growth	n/a	No relationship identified	-	-	No
Reproduction	$ED_X = e^{((\% \text{ Effect} - 0.1083) / 0.0734)}$	Pup weight, pup count, fertility	0.26	**0.02**	Yes
Behaviour	n/a	Negative relationship, no dose response	-	-	No

Notes:

ED_X = effective dose representing an X% effect level

Acceptable Relationship = R^2 value >0.2

Strong Relationship = R^2 value >0.5

Bold = P-value <0.1

Results – Recommended TRVs - Common Species

Receptor Group and Major Endpoint	Specific Endpoints	ED_{20}-based TRVs
Birds		
Survival	All survival	3.22
Growth		52.9
Reproduction	Eggshell thinning, weight, cracking for birds of prey	1.48
Mammals		
Survival	All survival; limited studies, inconsistent dose response	6.14
Survival		18.6
Reproduction		3.49

EcoSSL = 0.227 mg/kg bw/d (7X)

Eco SSL = 0.147 mg/kg bw/d (23X)

Results – Recommended TRVs - SAR

Receptor Group and Major Endpoint	Specific Endpoints	ED_{10}-based TRVs
Birds		
Survival	All survival	1.27
Growth		5.85
Reproduction		0.39
Mammals		
Survival	All survival; limited studies, inconsistent dose response	2.8
Survival	Single study with dose response	15.3
Reproduction	Pup	0.89

0.227 mg/kg bw/d (1.7X)

0.147 mg/kg bw/d (6X)

Risk Conclusions

- No risks evident for soil invertebrates & plants
- HQ < 1 for insectivorous and herbivorous wildlife receptors (mice, robins, bats)
- Risks were identified for three carnivorous receptors (ermine, owl and kestrel), including SAR

Using the Derived TRVs to Estimate Risk in the FCM

Surrogate Receptor	Screening Level RA Hazard Quotient	DQRA Hazard Quotient
American robin	**2.7** (SAR)	0.78
Barn Swallow (SAR)	-	0.021
Ruffed grouse	0.051	0.00064
Dark eyed junco	**2.3**	0.010
American kestrel	**25** (SAR)	**3.7**
Western screech owl (SAR)	-	**1.9**
Masked shrew	**48** (SAR)	0.36
Little brown myotis (SAR)	-	0.016
Montane vole	0.069	0.0014
Nuttall's cottontail (SAR)	-	0.0088
Deer mouse	**1.6** (SAR)	0.016
Western harvest mouse (SAR)	-	0.0051
Ermine	**37**	**2.8**
American badger (SAR)	-	0.45

Questions?