Exploration of Methods for Characterizing Effects of Chemical Stressors to Aquatic Animals

United States Environmental Protection Agency

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Outline

- Introduction
- Species Sensitivity Distributions (SSDs)
- Extrapolation Factors (EFs)
- Potential applications of SSDs and EFs for OPP and OW
- Proposed Analysis
- Case Study

Introduction

- Assessment Endpoints
  - an explicit expression of the environmental value to be protected
  - OPP and OW = survival, growth and reproduction of aquatic animals
  - OPP = taxa (fish and invertebrates are separated)
  - OW = community (fish + invertebrates)

Introduction

- Measures of Effect
  - Results from acute and chronic toxicity tests
  - OPP = lowest endpoints for fish and invertebrates
    - EC50s, NOECs
  - OW = HC_5
    - EC50s, MATCs or EC20s

Introduction

- The objective of this project is to examine how available toxicity data can best be used to characterize adverse effects on aquatic animals

Sensitivity Distributions

- Definition
  - Cumulative distribution of responses of different biological taxa to the same stressor
  - Based on similar endpoints (*e.g.*, EC50s from acute toxicity tests)

Sensitivity Distributions

- Regulatory uses
  - OPP – SWAMP, ecological risk assessments
  - OW – 1985 guidelines
  - Europe
  - OECD
  - Australia, New Zealand
  - UC-Davis methodology

Sensitivity Distributions

- Distributions with large data sets
  - Toxicity test results are log-transformed
  - Normal, logistic, triangular, Burr, Gompertz
  - Cumulative distribution functions used to derive 5th percentile (aka HC_5) and other percentiles

Sensitivity Distributions

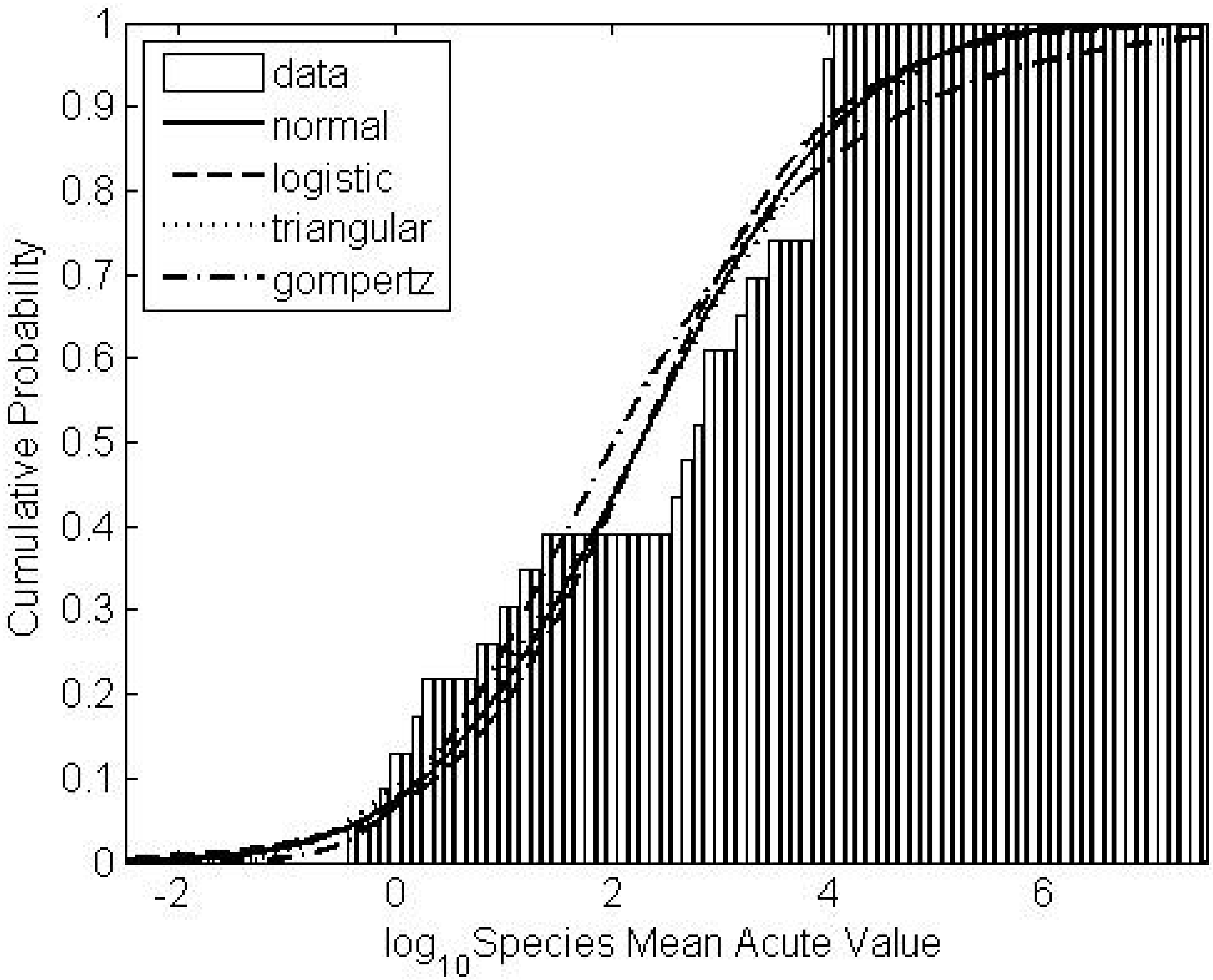

Figure 1. Fitted cumulative distribution functions of log-transformed SMAVs (ppb) for diazinon.

Sensitivity Distributions

- Distributions with small data sets
  - 2 Approaches are available to account for uncertainty in deriving HC_5
    - Approach 1:
      - Mean (x) and variance (s) are based on sample data (log-transformed data)
      - Use extrapolation constants (k)
        - Based on distribution shape and level of confidence
      - Equation:

$$HC_5 = 10^{\bar{x} - ks}$$

Sensitivity Distributions

- Distributions with small data sets
  - 2 Approaches are available to account for uncertainty in deriving HC_5 (cont.)
    - Approach 2:
      - Mean (α) is based on sample, variance (β) is known (de Zwart 2002)
        - variance based on MOA
        - Equation:

$$HC_5 = 10^{\alpha - 2.94\beta}$$

Sensitivity Distributions

- Distributions with small datasets
  - Methods available to derive chronic HC_5 values from acute toxicity data
    - De Zwart 2002
      - MOA is known, variance is known
    - Duboudin et al. 2004
      - Separate regressions for fish and invertebrates

Extrapolation Factors

- Definition
  - set values that are applied to available toxicity test results to account for various sources of uncertainty in extrapolating from individual species toxicity data to measures of effect
  - available toxicity data are identified for a chemical and the lowest toxicity test result is divided by the EF

Extrapolation Factors

- Great Lakes Water Quality Guidance Tier II values
  - EFs based on the number of MDRs
  - EFs intended to be below the FAV (5th percentile of triangular distribution)
  - Lowest GMAV is divided by EF
  - Several similar approaches in use by regulatory agencies
    - Michigan DEQ, Ohio EPA, USDOE, UC-Davis method

Extrapolation Factors

- Scientific Literature
  - Pennington 2003 derived EFs based on de Zwart (2002)
    - Variability is known and based on MOA
    - Can be used to approximate HC_5 values for normal, logistic and triangular distributions

Extrapolation Factors

- OPP Aquatic Benchmarks
  - Based on OPP's ERA process
  - Lowest toxicity test result is multiplied by LOC
  - 4 animal benchmarks (FW)
    - Acute fish
    - Acute invertebrate
    - Chronic fish
    - Chronic invertebrate

Potential Applications of SSDs and EFs

- SSDs in ERA
  - Characterization of monitoring data and EECs
  - Characterization of measures of effect
- EFs can be used to derive various percentiles of SSD to accomplish above
- Aquatic Life Screening Value (ALSV)
  - ≤ 5th percentile
  - Derive scientifically defensible water quality standards

Acute ALSV

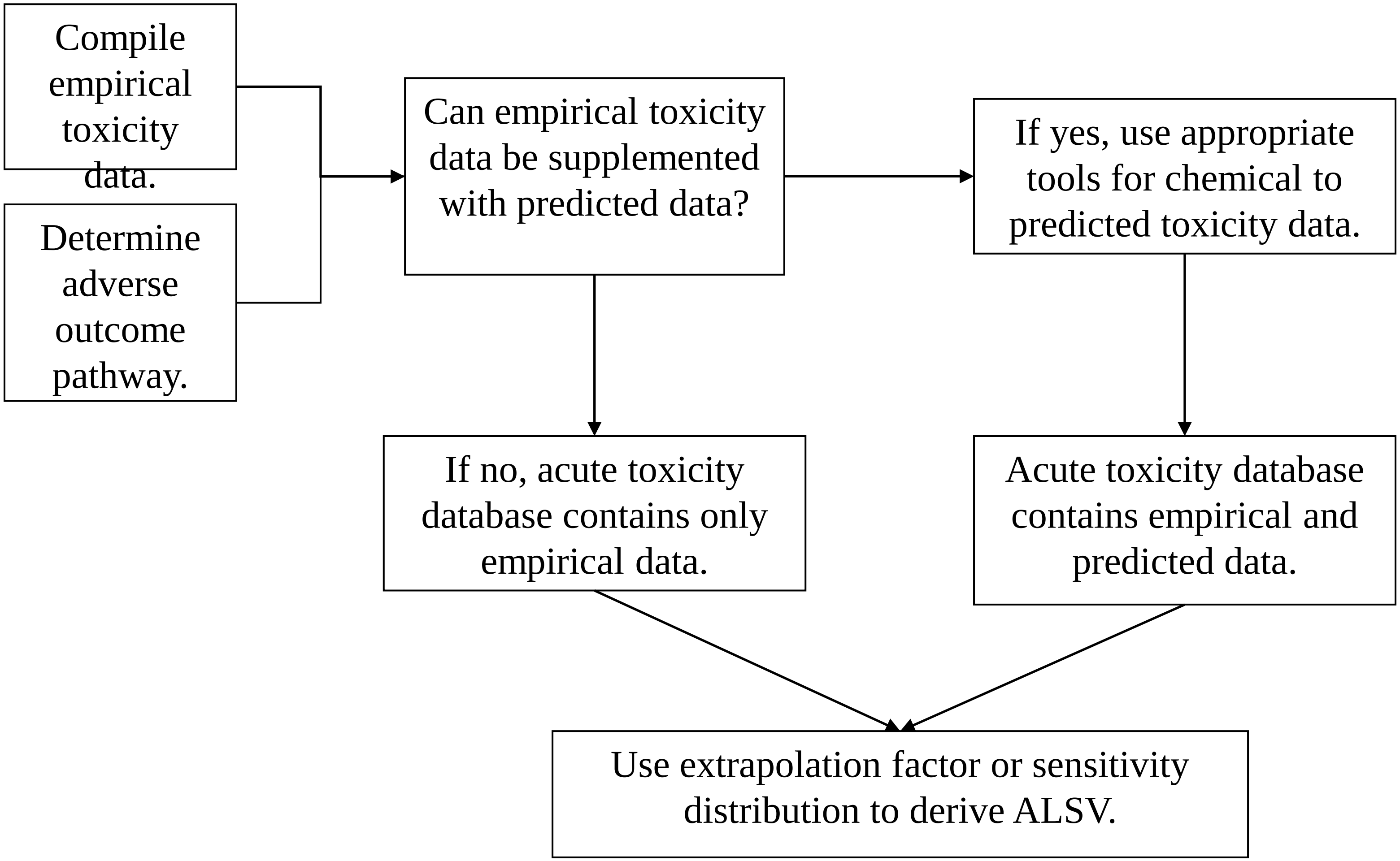

Figure 2. Conceptual framework for deriving acute ALSV.

Chronic ALSV

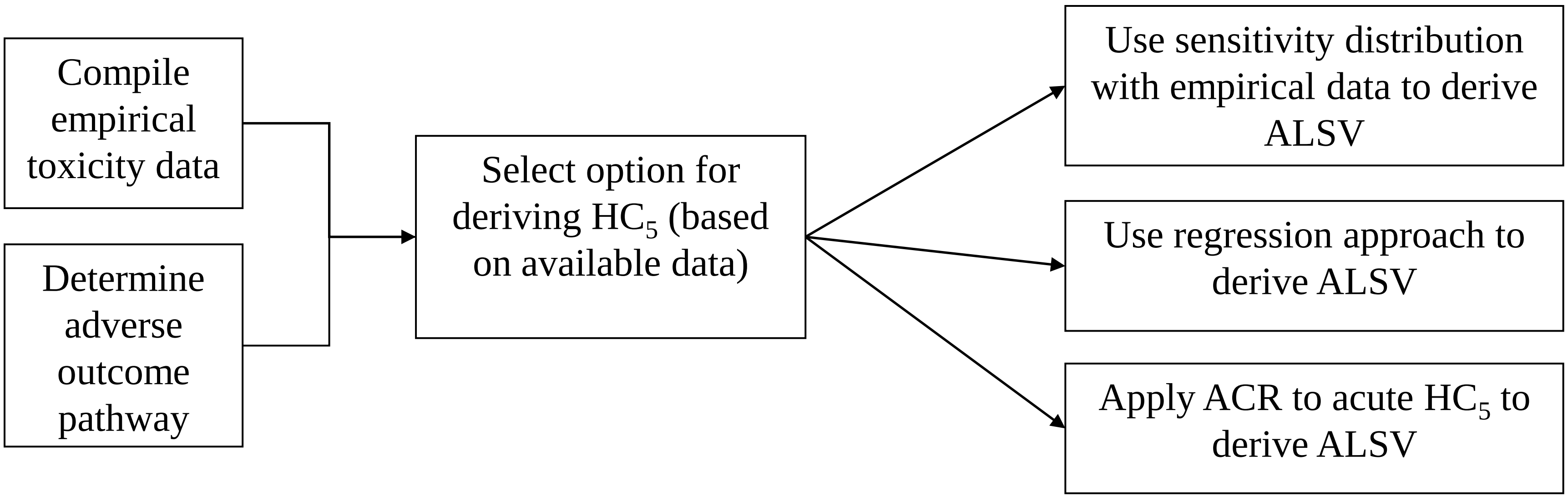

Figure 3. Conceptual framework for deriving chronic ALSV.

Proposed Analyses

- 3 Phases:
  - Analyses with “data-rich” chemicals
  - Analysis with “data-limited” chemicals
    - Empirical data only
  - Analysis with “data-limited” chemicals
    - Empirical and predicted data

Proposed Analyses

- Phase 1: Analyses with “data-rich” chemicals
  - Use large data sets
    - Acute: from Web-ICE empirical database
    - Chronic: AquaChronTox database
  - Compare fit of several distributions
  - Derive reference percentile values (HC_p) for each chemical
    - including HC_5
    - Other percentiles will be considered

Proposed Analyses

- Phase 2: Analysis with “data-limited” chemicals
  - EPA will explore the accuracy of HCp estimates from limited subsets of the same data
    - Consider MOA
    - Use EF and SSD approaches to derive HC_5 values and other percentiles
    - Compare to “known” HC_5 values from full distributions
  - EPA will derive EFs

Proposed Analyses

- Phase 3: Analysis with “data-limited” chemicals and predicted toxicity data
  - Evaluate various approaches described in tools paper
    - Acute and chronic methods
  - Compare estimated HC_5 values to “known” HC_5 values from phase 1

Case Study: Diazinon

- Organophosphate Insecticide
- MOA in animals: AChE inhibition
- Criteria and benchmarks are available

OPP Benchmarks	Value (ppb)	OW Criteria	Value (ppb)
Acute FW Fish	45	Acute FW (CMC)	0.17 (FAV = 0.3397)
Acute FW inverts	0.105		
Chronic FW fish	<0.55	Chronic FW (CCC)	0.17
Chronic FW inverts	0.17		

Case Study- Acute

- Criterion derived from acute toxicity test results for FW fish and invertebrates
  - 23 species
  - 19 genera
  - Invertebrates represent the top 9 most sensitive species
    - cladocerans are top 4
  - SMAVs range 0.3773 – 11,640 ppb

Case Study - Acute

HC$_5$ values (ppb)

-Normal = 0.50

-Logistic = 0.54

-Triangular = 0.39

-Gompertz = 0.71

(FAV = 0.34)

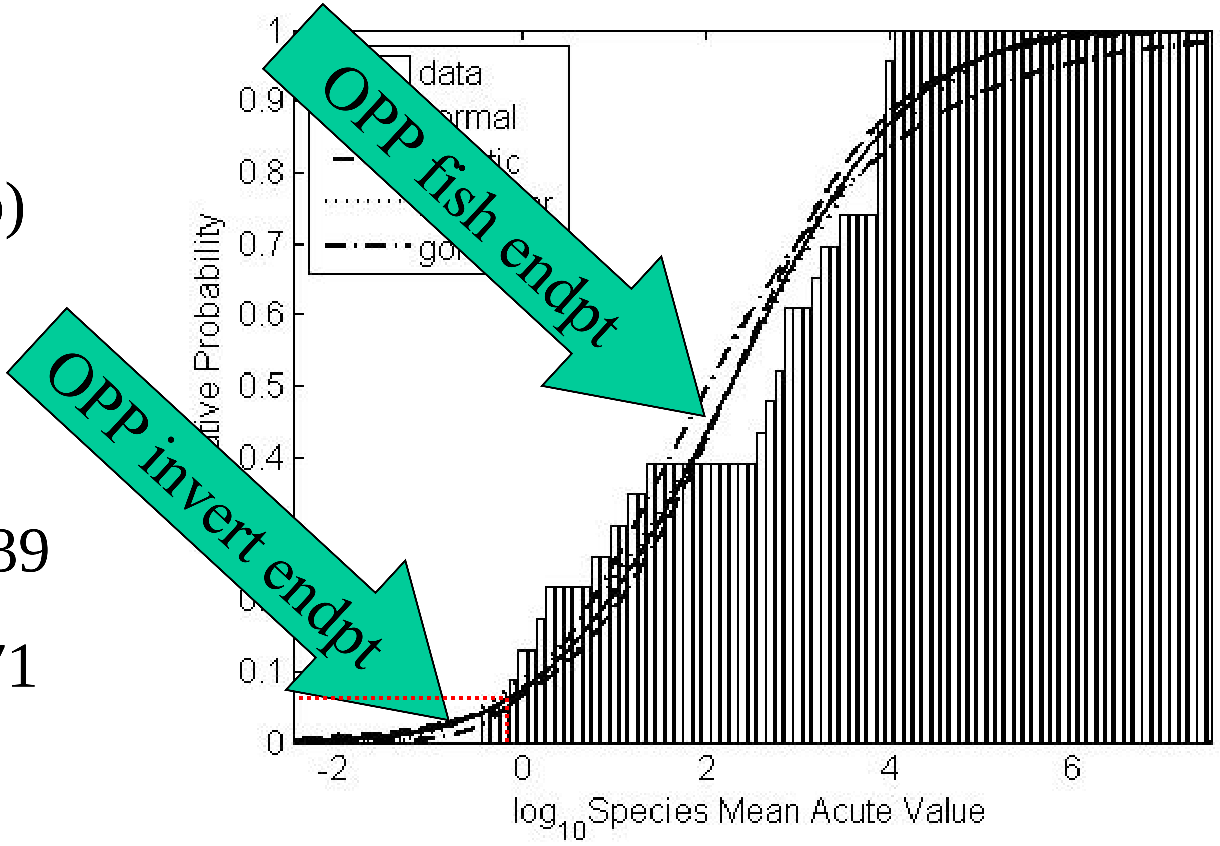

Figure 1. Fitted cumulative distribution functions of log-transformed SMAVs (ppb) for diazinon (from criteria).

Case Study - Acute

- Scenario: data are only available for 3 animal species
  - Typical species tested to fulfill FIFRA data requirements
    - *Daphnia magna* EC50 = 1.05 ppb
    - Rainbow trout LC50 = 426 ppb
    - Bluegill Sunfish LC50 = 470 ppb

Case Study - Acute

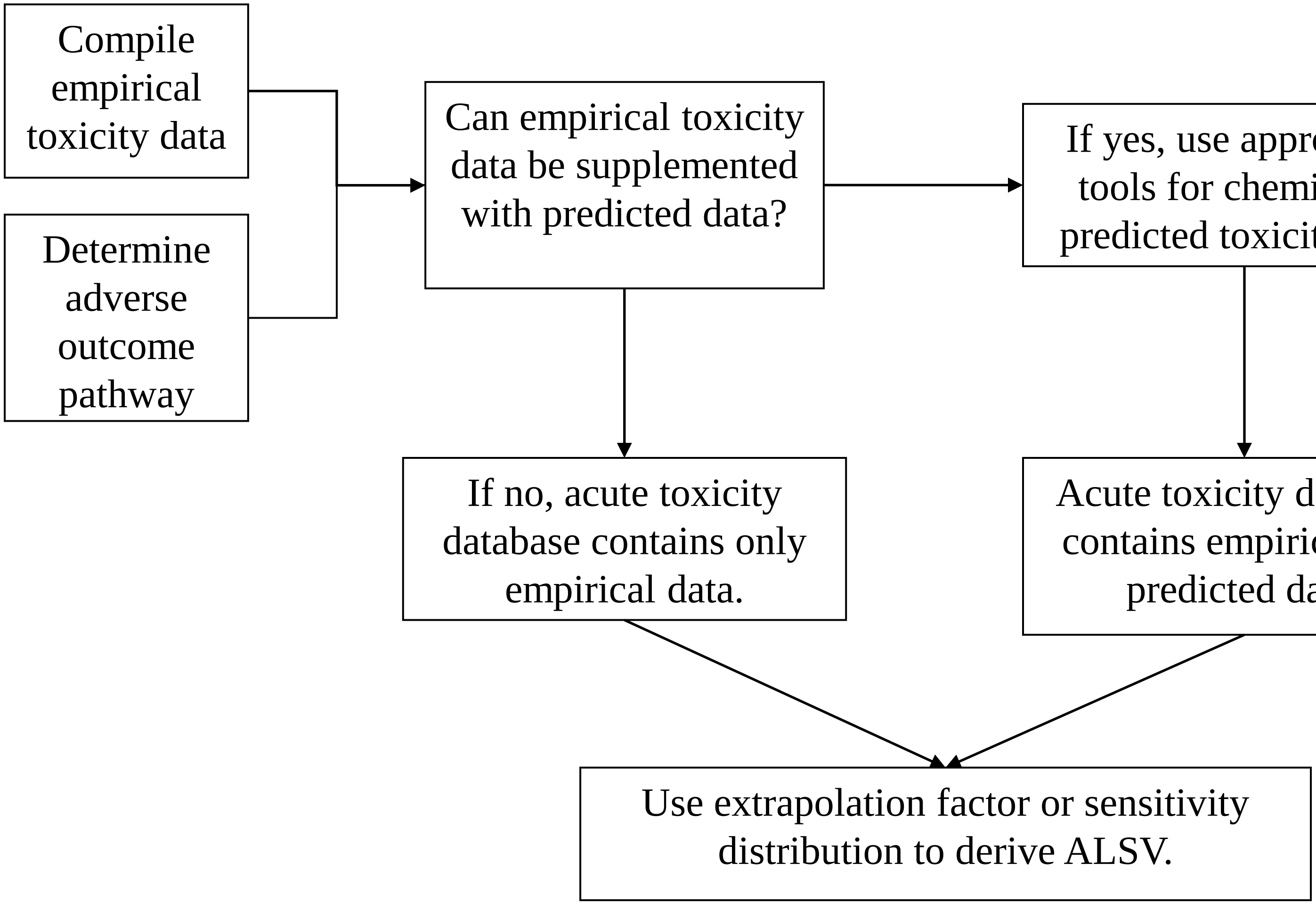

Figure 2. Conceptual framework for deriving acute ALSV.

Case Study - Acute

- Example tool: Web-ICE
  - Can estimate EC50 values for several species
  - Need to consider
    - extrapolation outside of models
    - df$\geq$3
    - MSE <0.22
    - close taxonomic relatedness

Case Study - Acute

- Web-ICE estimates + logistic SSD
  - HC_5 = 29.8 ppb
  - Limitations:
    - All species are fish
    - based on the MOA of diazinon, invertebrates are expected to be more sensitive
    - The HC_5 may not be conservative (supported by fit data where HC_5 values were 2 orders of magnitude lower)

Species	Surrogate	EC50 (ppb)
Atlantic salmon	B	225
Brook trout	B	233
Apache trout	R	350
Yellow perch	B	367
Brown trout	R	393
Lake trout	R	396
Largemouth bass	B	400
Cutthroat trout	R	458
Spotfin chub	R	542
Green throat darter	R	557
Chinook salmon	R	588
Coho salmon	R	625
Cape fear shiner	R	723
Green sunfish	R	749
Razorback sucker	R	917

B= bluegill; R = rainbow trout

Case Study - Acute

- If no tools are available for this chemical, SSDs or EFs can be applied directly to empirical data
- Diazinon toxicity data subset used for this case study
  - *Daphnia magna* EC50 = 1.05 ppb
  - Rainbow trout LC50 = 426 ppb
  - Bluegill Sunfish LC50 = 470 ppb

Case Study - Acute

- SSDs for subset of diazinon toxicity data
  - Mean and variance is estimated from sample
  - Equation: $HC_5 = 10^{\bar{x} - ks}$
    - Mean (x) = 1.77 (log transformed)
    - Standard deviation (s) = 1.52

Distribution (method source)	**Extrapolation constant (k)**	**Median HC_5**	**HC_5 - full data set**
Log-normal (Aldenberg and Jaworska 2000)	1.94	0.0674	0.50
Log-triangular (Pennington 2003)	1.9	0.0775	0.39
Log-logistic (Aldenberg and Slob 1993)	2.05	0.0459	0.54

Case Study - Acute

- SSDs for subset of diazinon toxicity data
  - Equation: $HC_5 = 10^{\alpha - 2.94\beta}$ (de Zwart 2002)
    - Mean is estimated from sample
      - Mean (α) = 1.77 (log-transformed)
    - Variance is known
      - For AChE inhibition (by OPs), β = 0.50
    - HC_5 = 2.01 ppb

Case Study - Acute

- Extrapolation factors for subset of diazinon toxicity data
  - Lowest toxicity value is divided by extrapolation factor
    - Extrapolation factor for n = 3
    - Lowest toxicity value = 1.05 ppb

Description (method source)	Extrapolation factor	Estimated HC_5 (µg/L)	HC_5 - full data set
Great lakes guidance	8	0.131	0.39
Log-normal (Pennington 2003)	10	0.105	0.50
Log-logistic (Pennington 2003)	12	0.0875	0.54
Log-triangular (Pennington 2003)	9.4	0.112	0.39

Case Study - Chronic

- ACRs (from criteria)
  - range 1.112-1.586 for aquatic invertebrates (2 species)
  - Range 23.84 to >903.8 for fish
  - None of these ACRs correspond to the data subset used above (*i.e.*, D. magna, bluegill, rainbow trout)
    - Scenario: no chronic data are available for the example chemical

Deriving the Chronic ALSV

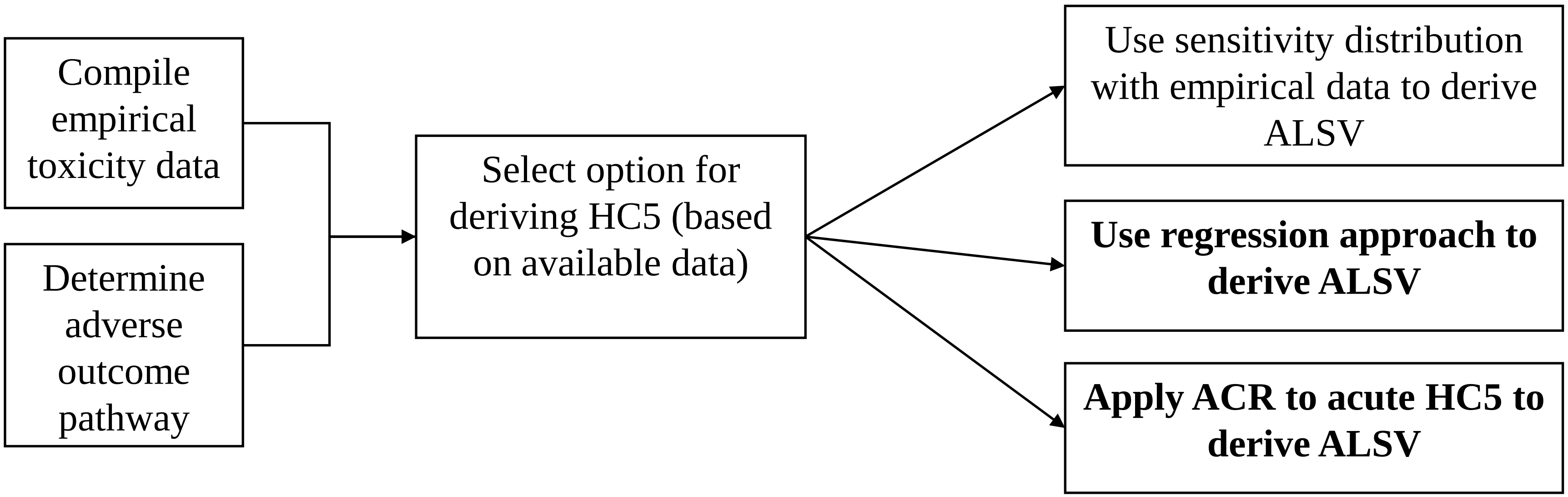

Figure 3. Conceptual framework for deriving chronic ALSV.

Case Study - Chronic

- Can use MOA-specific ACRs (Raimondo et al 2007)
  - For OPs, median and 90th percentile ACRs are 6.2 and 77.8, respectively
  - If acute ALSV were based on the great lakes EFs (0.131 ppb), and the median ACR is used
    - the chronic ALSV would be 0.0211 ppb

Case Study - Chronic

- Can use SSD based on acute toxicity data (de Zwart 2002)
  - Regression equation:

$$\alpha_{chronic} = 1.053 * \alpha_{acute} - 1.430$$

  - Mean of acute data (α_{acute}) = 1.77
  - Use AChE inhibition variance (0.50)
  - HC_5 equation: $$HC_5 = 10^{\alpha - 2.94\beta}$$
  - Chronic HC_5 = 0.0930 ppb

Summary

- EPA is currently considering 2 approaches for characterizing available toxicity data for aquatic animals
- These approaches can be used by OPP and OW for ecological risk assessment and criteria development

Summary

- EPA will evaluate available methods and tools to derive a process that OPP and OW can use to characterize the effects of chemicals with varying amounts of empirical data

Comments/Questions