Aquatic Refugia: Relevance and Significance in Ecological Risk Assessment

Kayla Campasino, Jeffrey Giddings, David Campana

COMPLIANCE SERVICES INTERNATIONAL

Introduction

- Pesticides may enter aquatic environments via spray drift, runoff, erosion, etc.[1, 2, 3]
  - National Pesticide Loss database indicates runoff concentrations exceed toxicity thresholds for fish in numerous areas
  - Pyrethroids detected in 73% of sediment samples collected from water bodies adjacent to agricultural fields in CA Central Valley[4]
- Pyrethroids
  - Synthetic insecticides (bifenthrin, cypermethrin, permethrin, etc.)
  - Hydrophobic (log K_{ow} 6.40 – 7.48)[5]
  - Ecological risk assessment part of registration review process

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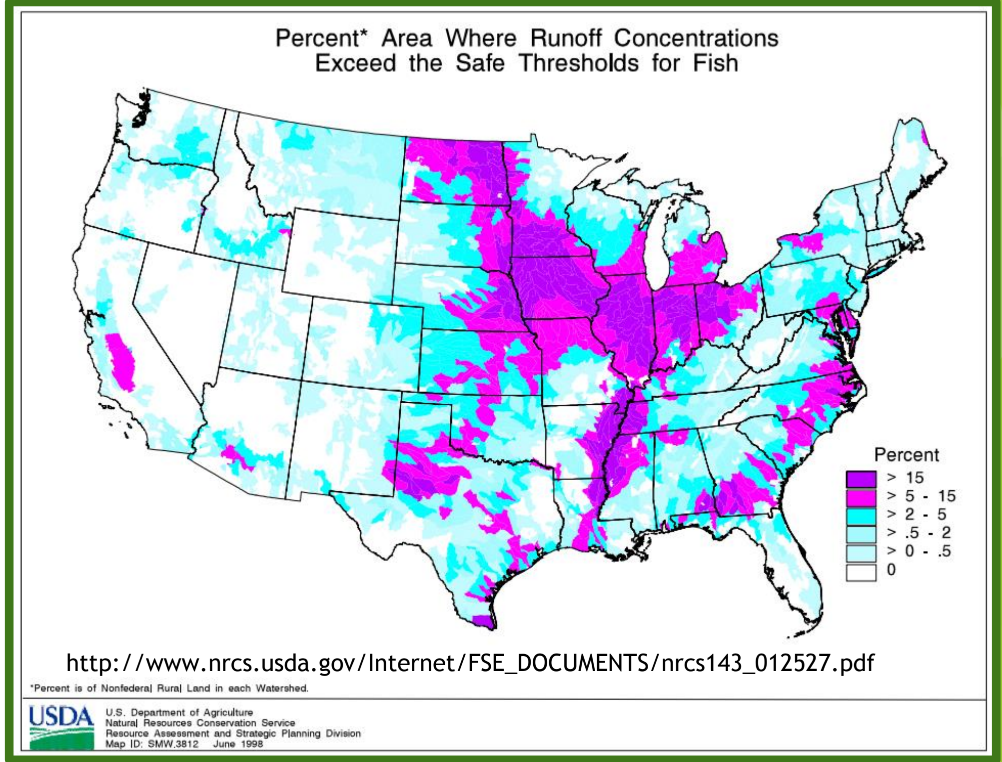

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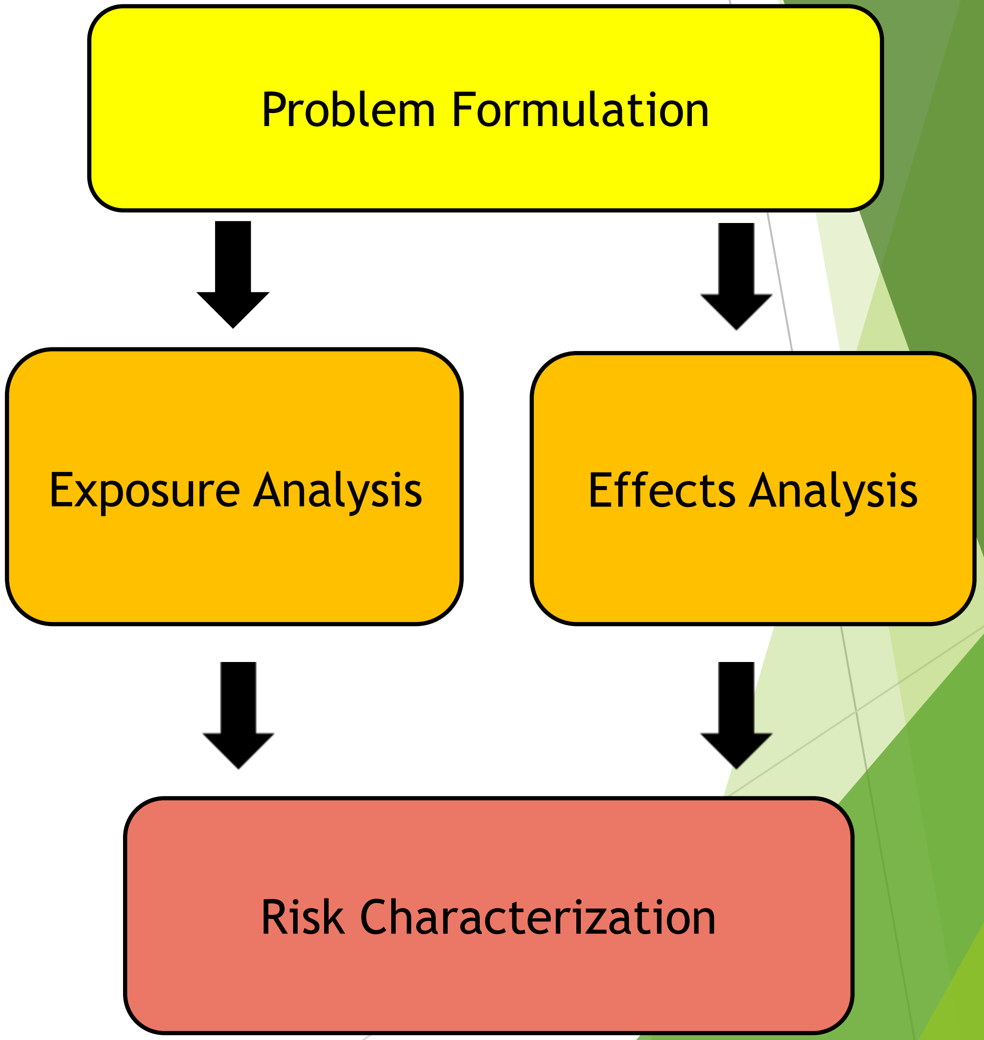
Ecological Risk Assessment (ERA)

- Estimating the likelihood that adverse effects will occur from exposure

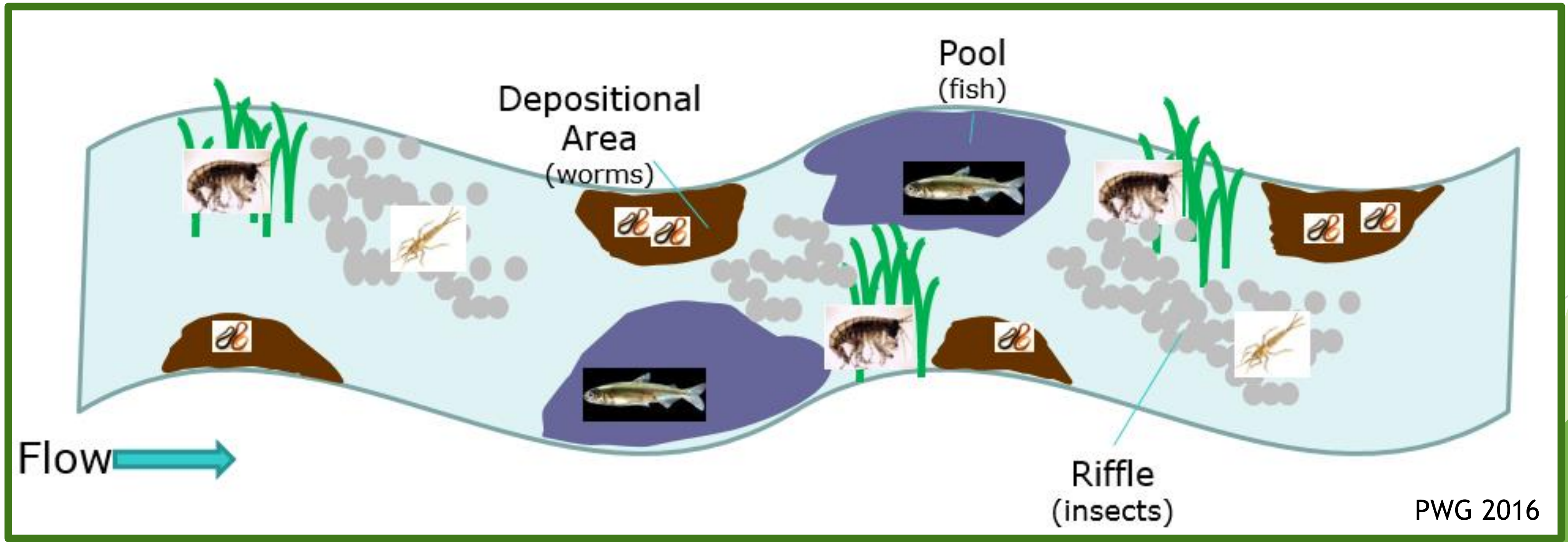
- EPA framework
  - Problem formulation: product use and assessment endpoints
  - Exposure analysis: modeling to estimate exposure concentrations
  - Effects analysis: derived from ecotoxicology studies
  - Risk characterization

- Current models assume a homogeneous distribution of the chemical within the water body



Refugia

- Places or times where the negative effects of disturbance are lower than in affected areas or times[6]
- Variables that influence refugia
  - Environmental heterogeneity: vegetated sections, sediment organic carbon gradients
  - Physicochemical properties: hydrophobicity → sorption to organic matter
  - Environmental fate: degradation, transport



Environmental heterogeneity creates spatial and temporal refugia

- Runoff simulation in a vegetated 650 m drainage ditch[7]
- Sorption of bifenthrin and lambda-cyhalothrin to aquatic macrophytes reduced downstream water concentrations
  - Aquatic vegetation acts as a sink
  - Rapid aqueous dissipation

Table 4. Estimated mass (g) of bifenthrin and lambda-cyhalothrin in the water, sediment, and plant compartments relative to each sampling time (*total active ingredient amended to ditch at time zero). E-02, E-03, and E-04 represent 10^{-2}, 10^{-3}, and 10^{-4}, respectively, for significant digit purposes

Bifenthrin (g)					Lambda-cyhalothrin (g)				
Time	Water	Plants	Sediment	Total	Time	Water	Plants	Sediment	Total
0 h	—	—	—	*11.4	0 h	—	—	—	*5.70
3 h	5.78	6.29	3.85E-02	12.1	3 h	3.10	6.13	6.24E-02	9.29
12 h	0.718	7.22	3.30E-02	7.97	12 h	0.353	3.76	1.12E-02	4.13
24 h	0.191	4.03	1.13E-02	4.24	24 h	0.106	1.59	3.68E-03	1.70
7 d	0.134	1.93	6.31E-02	2.13	7 d	4.05E-02	6.74E-02	1.79E-02	0.126
14 d	4.48E-02	3.00	5.25E-02	3.10	14 d	6.90E-03	2.09E-01	129E-02	0.229
30 d	4.37E-03	0.199	1.93E-03	0.206	30 d	1.05E-03	3.41E-02	4.24E-02	7.75E-02
44 d	8.82E-04	4.89E-02	8.31E-04	5.07E-02	44 d	6.22E-03	9.10E-02	5.04E-02	0.148

Environmental heterogeneity creates spatial refugia

- Pyrethroid runoff from nursery application into a sedimentation pond and 260 m drainage channel[8]
- Sorption of bifenthrin and permethrin to sediment resulted in increasing sediment concentrations with increasing distance from sedimentation pond
  - Offsite transport
  - Lower bioavailability in water column

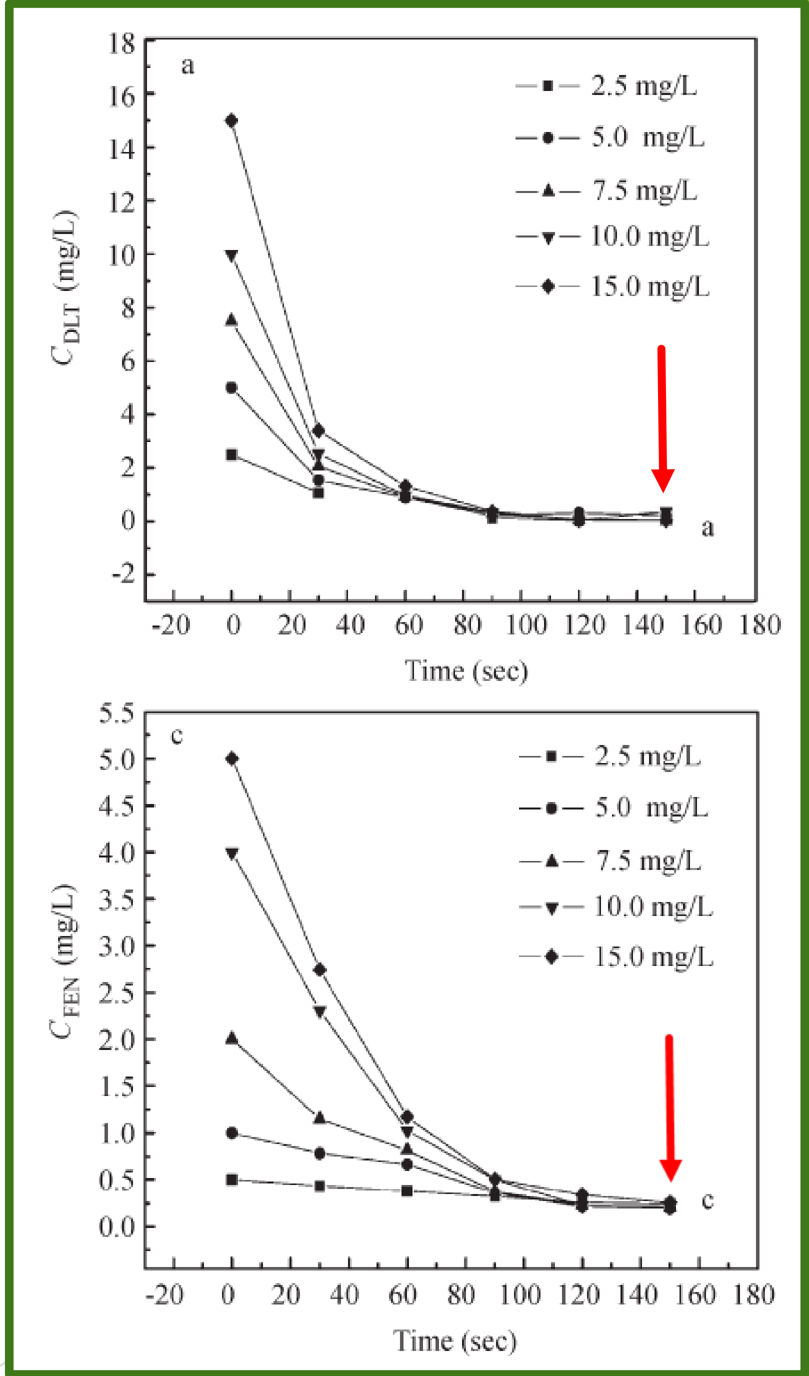
Table 2. Concentrations of bifenthrin and permethrin in sediments along a runoff path.

Distance from the sedimentation pond	Concentration: Bifenthrin	Concentration: *cis*-Permethrin	Concentration: *trans*-Permethrin	OC†	Clay
m	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	%	%
0	0.33 ± 0.01 (1.0)‡	0.77 ± 0.07 (1.0)	0.20 ± 0.03 (1.0)	0.65 (1.0)	5 (1.0)
104	2.27 ± 0.09 (6.9)	1.10 ± 0.03 (1.4)	0.28 ± 0.05 (1.4)	2.35 (3.6)	5 (1.0)
145	10.64 ± 2.82 (32.2)	4.45 ± 0.03 (5.8)	0.92 ± 0.22 (4.6)	6.37 (9.8)	23 (4.6)
166	10.06 ± 0.18 (30.5)	2.73 ± 0.12 (3.5)	0.82 ± 0.09 (4.1)	5.80 (8.9)	19 (3.8)
210	8.47 ± 1.10 (25.7)	6.10 ± 0.26 (7.9)	1.26 ± 0.20 (6.3)	4.58 (7.0)	19 (3.8)

† Organic carbon content.
‡ Numbers in parentheses are relative enrichment ratios.

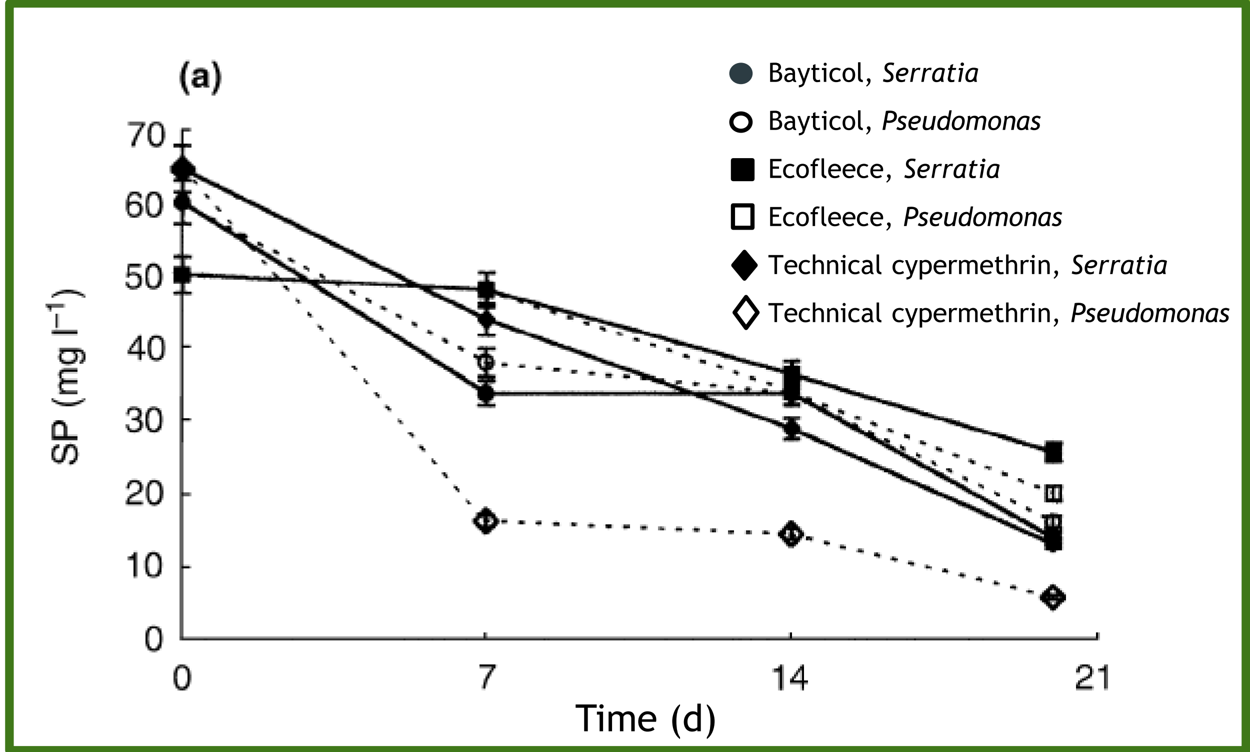
Environmental processes create spatial and temporal refugia

- Degradation of deltamethrin and fenvalerate exposed to UV light[9]
- > 95% degradation after 160 seconds
- Photoproducts (3-phenoxy benzaldehyde and 3-phenoxyenzoic acid) suggest photo-oxidation is the primary reaction
- Limited light penetration in water body → more rapid degradation at water surface



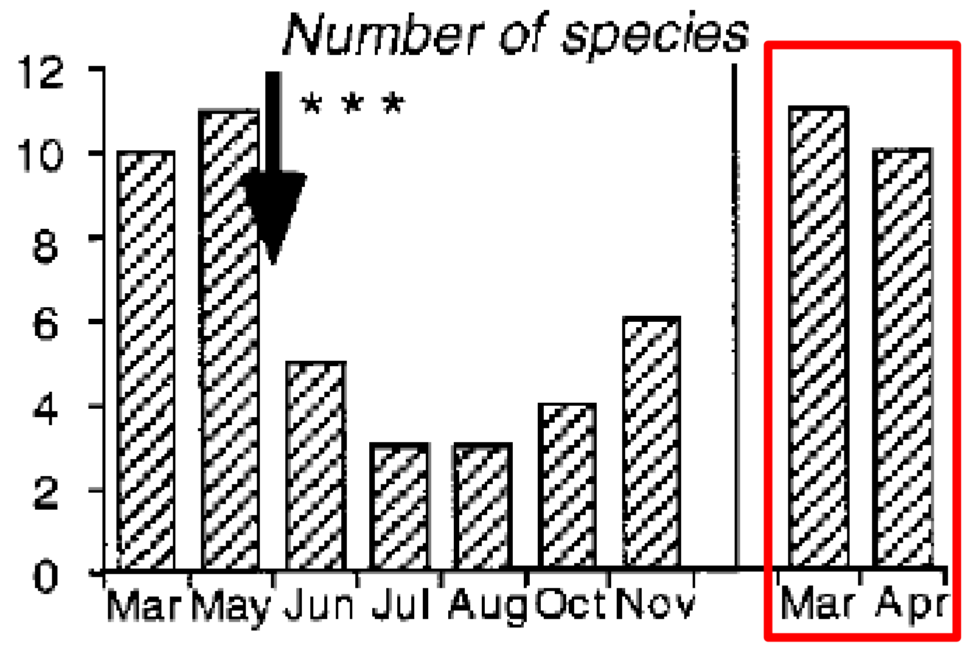
Environmental processes create spatial and temporal refugia

- Microrganisms (*Pseudomonas* and *Serratia* spp.) were cultured with cypermethrin or flumethrin[10]
- ≥ 50% of the pyrethroids were degraded after 20 days
- Average pyrethroid concentration in cultures after 20 days
  - With microorganisms: ~15mg/L
  - Without microorganisms: ~34 mg/L
- Pyrethroid degradation may be more rapid in sediments harboring abundant microbial communities compared to environments with less microbial biodiversity

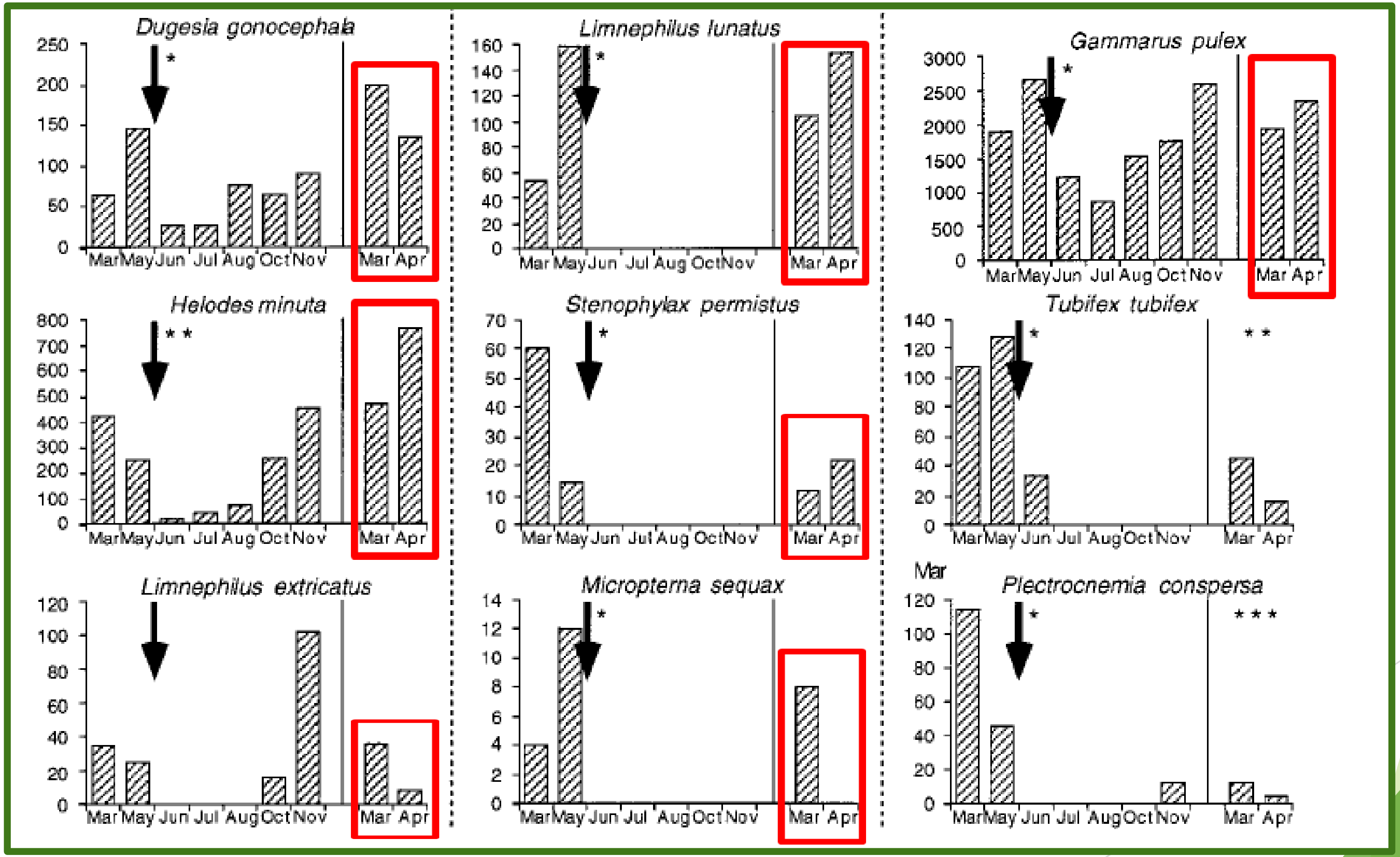


Habitat refugia contribute to ecosystem recovery after pesticide contamination

- Rainfall-induced parathion-ethyl and fenvalerate runoff into a headwater stream on agricultural land[11]
- Eight out of 11 macroinvertebrate species eliminated after three high contamination runoff events
- 9 out of 11 populations recovered within 11 months despite no observed in stream emergence
- No observed in stream emergence; uncontaminated stream located 500 m from study site
- Population recovery likely due to recolonization from less affected sites

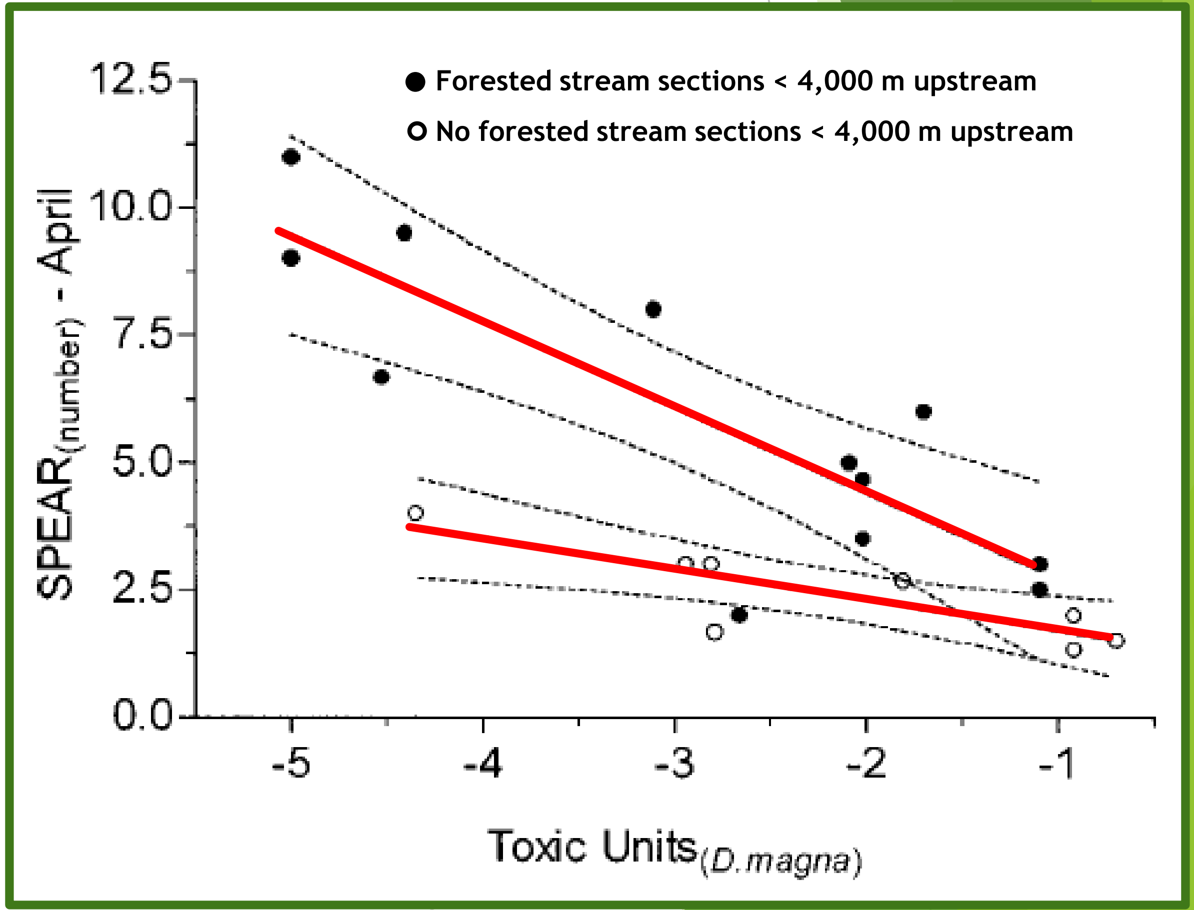


Habitat refugia contribute to ecosystem recovery after pesticide contamination



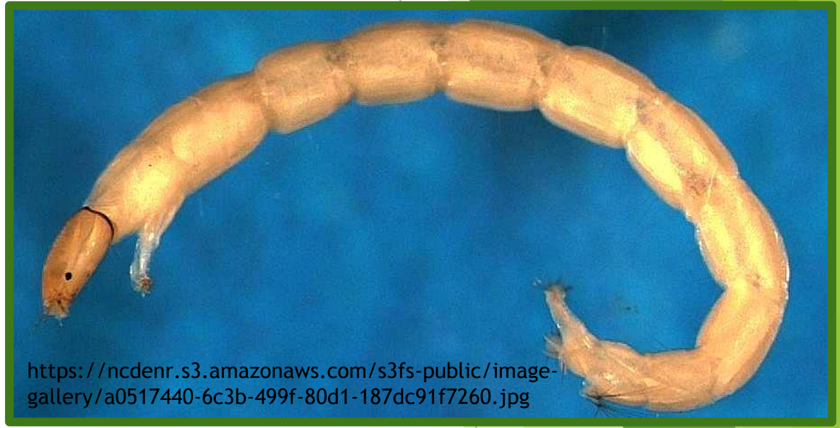
Habitat refugia contribute to ecosystem recovery after pesticide contamination

- Macroinvertebrate abundance measured in streams subjected to agricultural runoff[12]
- SPEAR = Species At Risk
  - Sensitivity to pesticides
  - Life history traits influencing recovery
- Ten months after the peak pesticide concentrations, SPEAR were more abundant in affected stream sites when forested sections were less than 4,000 m from study sites and greater than 200 m in length
- Upstream forested sections allowed in-stream recolonization



Effect of refugia on aquatic recovery after exposure to pesticides may vary with species

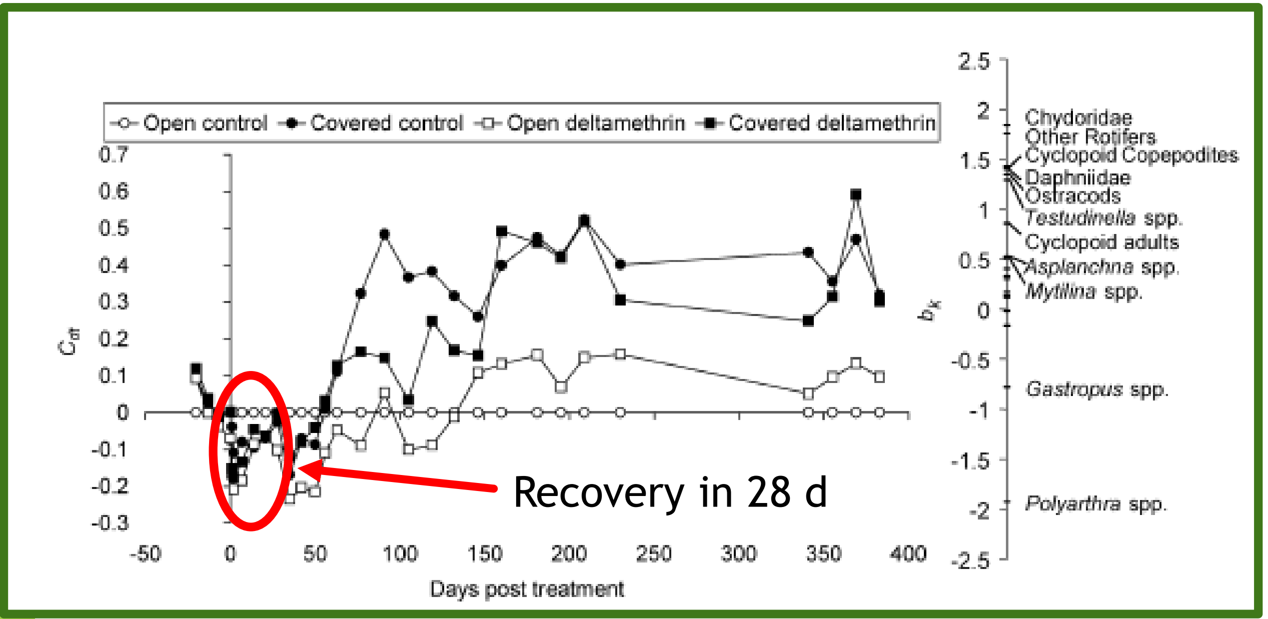
- Invertebrate recovery in covered vs. open pond mesocosms after deltamethrin treatment[13, 14]
- Caquet et al. (2007)
  - Open mesocosms → faster benthic macroinvertebrate recovery
  - Aerial recolonization probably had a significant influence on recovery
- Hanson et al. (2007)
  - Closed mesocosms → faster zooplankton recovery
  - Recovery likely due to sediment egg bank and predation release
- Internal vs. external recovery mechanisms in different species groups



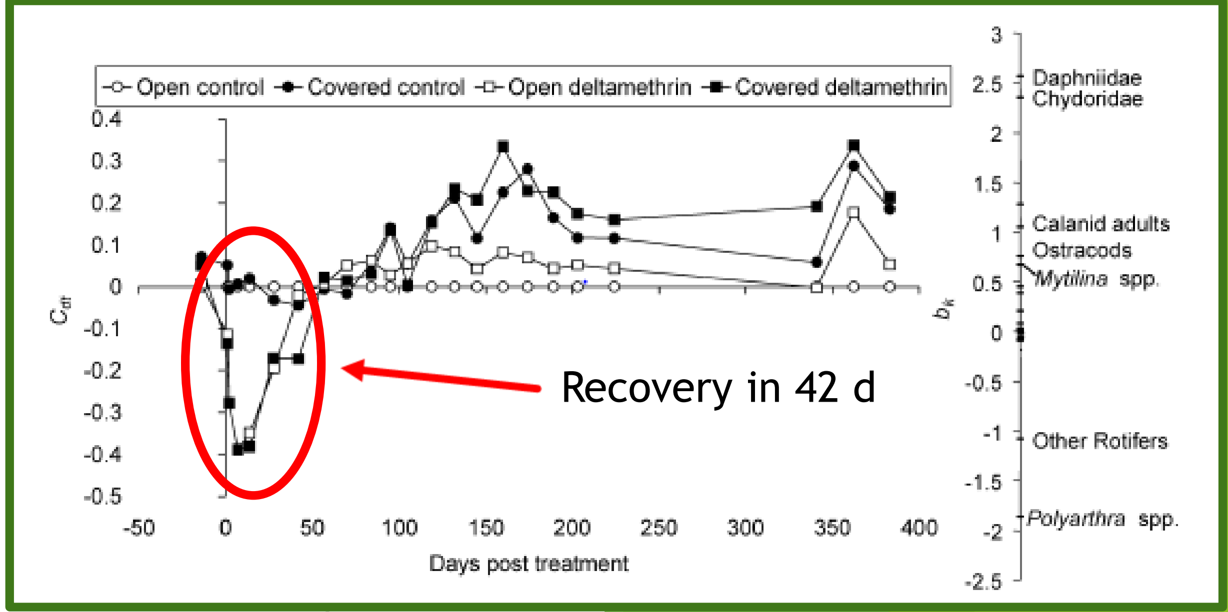
Effect of refugia on aquatic recovery after exposure to pesticides may vary with species

- Benthic vs. water column zooplankton recovery in covered vs. open pond mesocosms after deltamethrin treatment[14]
- Recovery of benthic organisms was slower than recovery of organisms found in the water column
- Different species groups utilize refugia differently with a water body

Water column

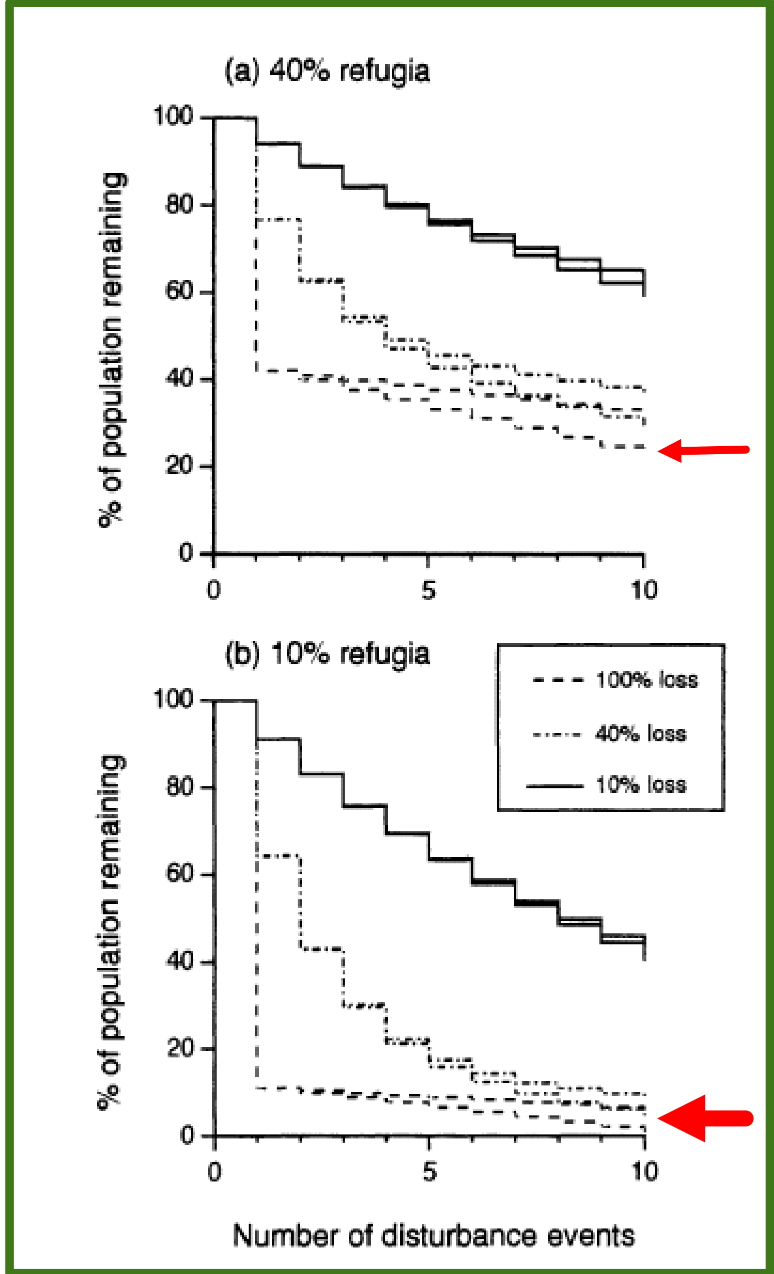


Sediment surface



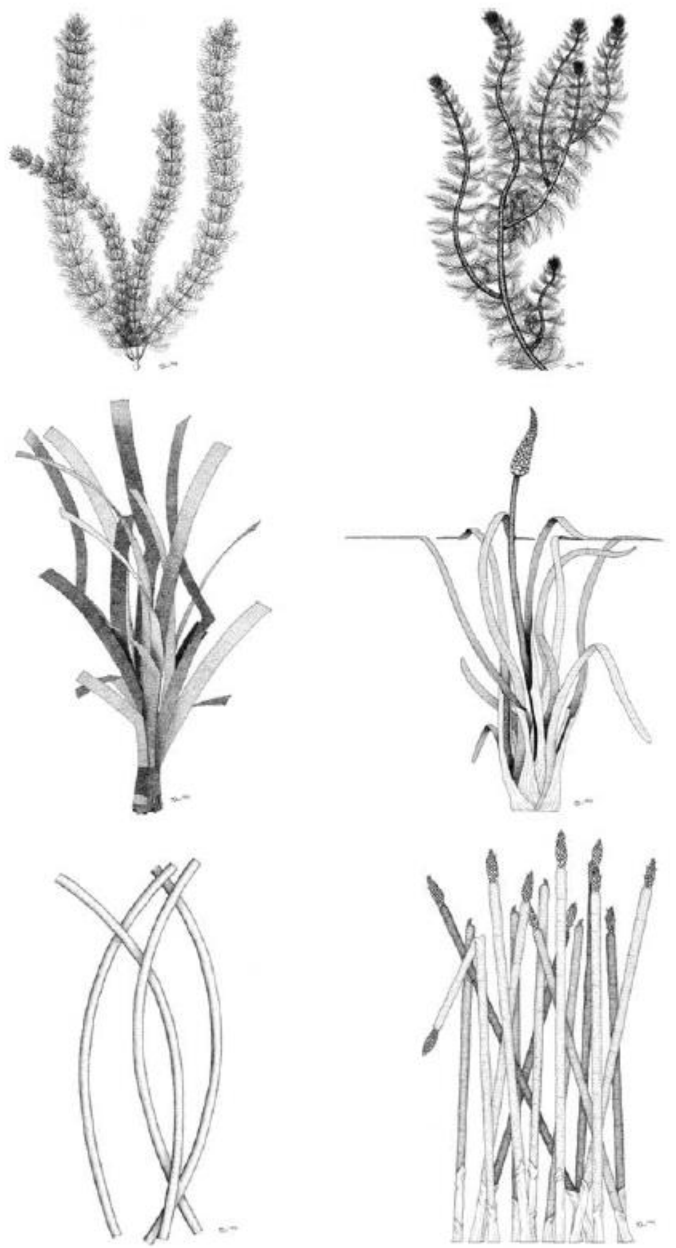
Refugia in ERA

- Mathematical models supported by empirical evidence[6]
  - Simulated population changes after disturbance events
  - Refugium size, proportion of individuals lost, time between disturbances
- Simulated short term movements of individuals into and out of refugia
  - Population persistence with 10% vs. 40% refugia
  - Total area of refugia had a greater impact on population persistence than proportional loss or disturbance frequency



Refugia in ERA

- Quantifying refugia[15]
  - Relationship of macrophyte structure and macroinvertebrate abundance and species richness
  - Surface convolution and refuge space correlated to macroinvertebrate distribution
- Population modeling[16]
  - Comparison of ecological models applicable to risk assessment
  - Suitable aquatic ecosystem models
    - AQUATOX
    - IFEM
    - CASM



Warfe et al. (2008)

Conclusions

- Models assume homogeneous distribution
- Sorption to sediment, vegetation, and other organic matter reduces aqueous concentrations
- Pyrethroid concentrations are highly dynamic within a water body across small temporal and spatial scales
- Invertebrate populations exhibit faster recovery when refugia are present; may be variable depending on internal vs. external refugia
- Refugia may have a smaller effect on species without dispersal capabilities
- Development of methods to incorporate quantifying refugia and population modeling into ERA should lead to more realistic estimates of exposure and effects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