Guidance for Dispersant Decision Making: Potential for Impacts on Aquatic Biota

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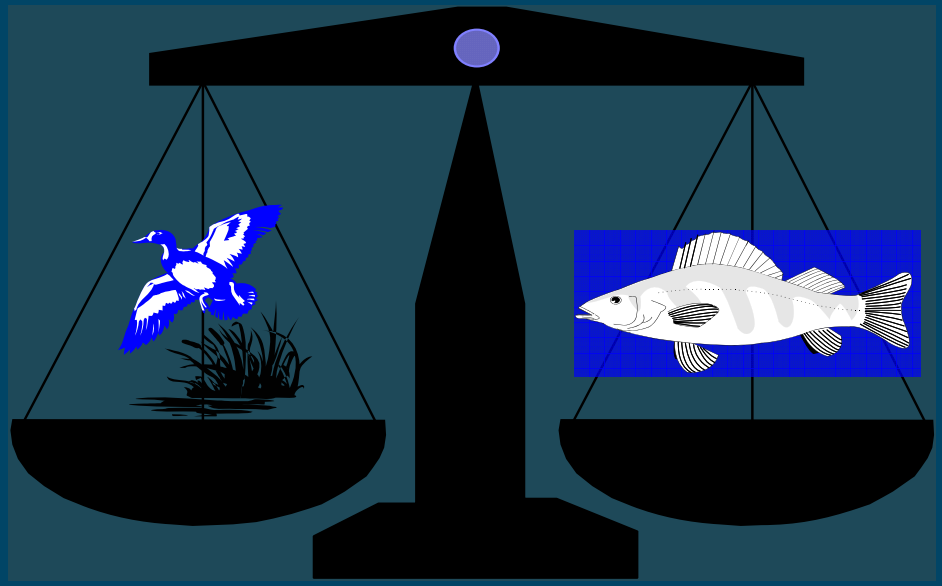
Problem Statement

- **Biologically/Ecologically-Driven Spill Response: Trade-off response decisions based on expected level of resource injury**

Use of chemical dispersants

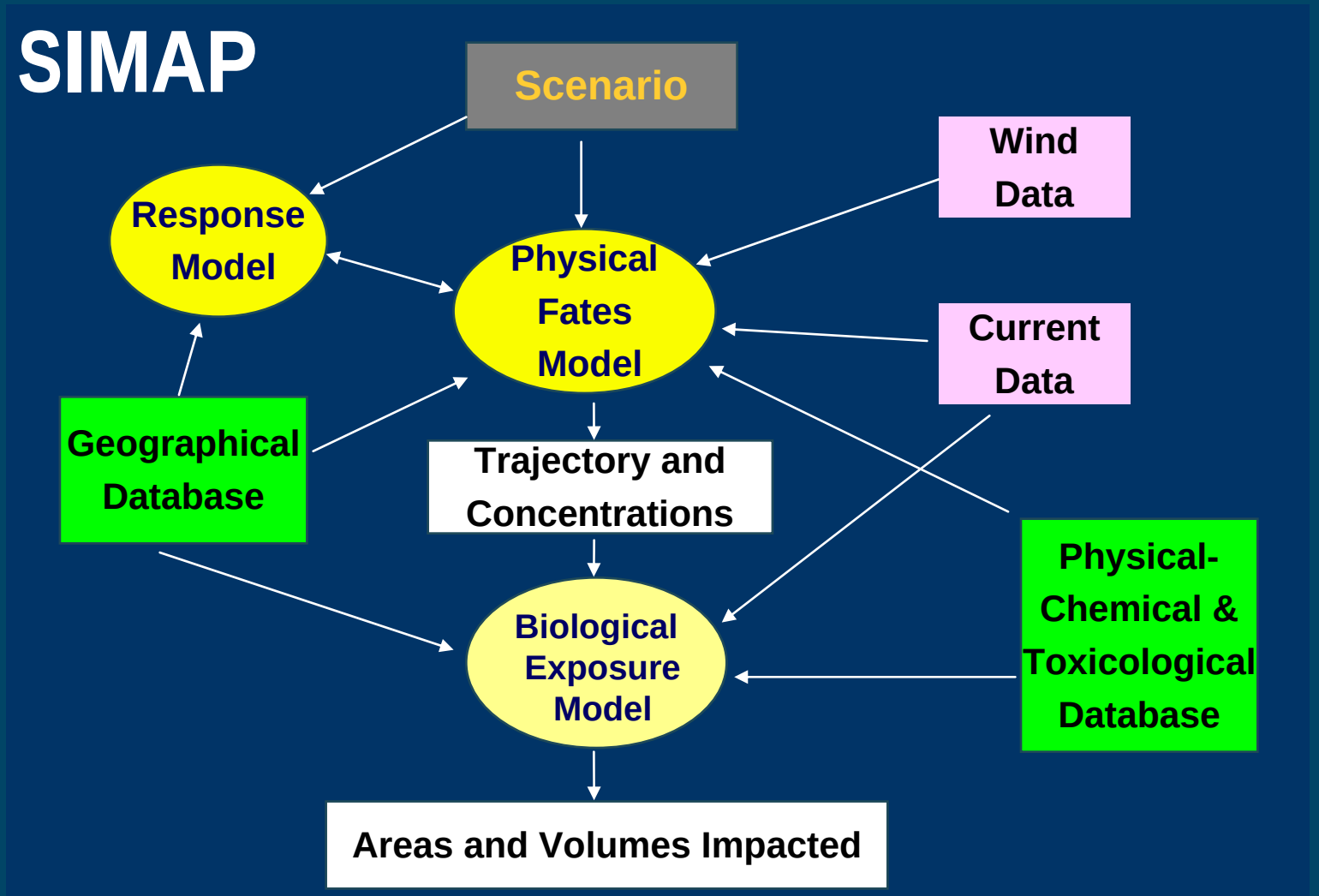
Quantify tradeoff



Investigative Approach

- Use oil fate and biological exposure modeling to quantify impacts
- Provide quantitative guidance for response decision makers
- Oil Spill Impact Guide (OSIG)
  - water volume adversely affected by dispersed oil and dissolved hydrocarbons
  - surface area impacted by floating oil
  - typical animal densities in shelf areas of US

SIMAP


Scenario
Wind Data
Response Model
Physical Fates Model
Current Data
Geographical Database
Trajectory and Concentrations
Physical-Chemical & Toxicological Database
Biological Exposure Model
Areas and Volumes Impacted

Toxic Components of Oil (Additive Effects)

Aliphatics = (e.g., alkanes) – more volatile than soluble

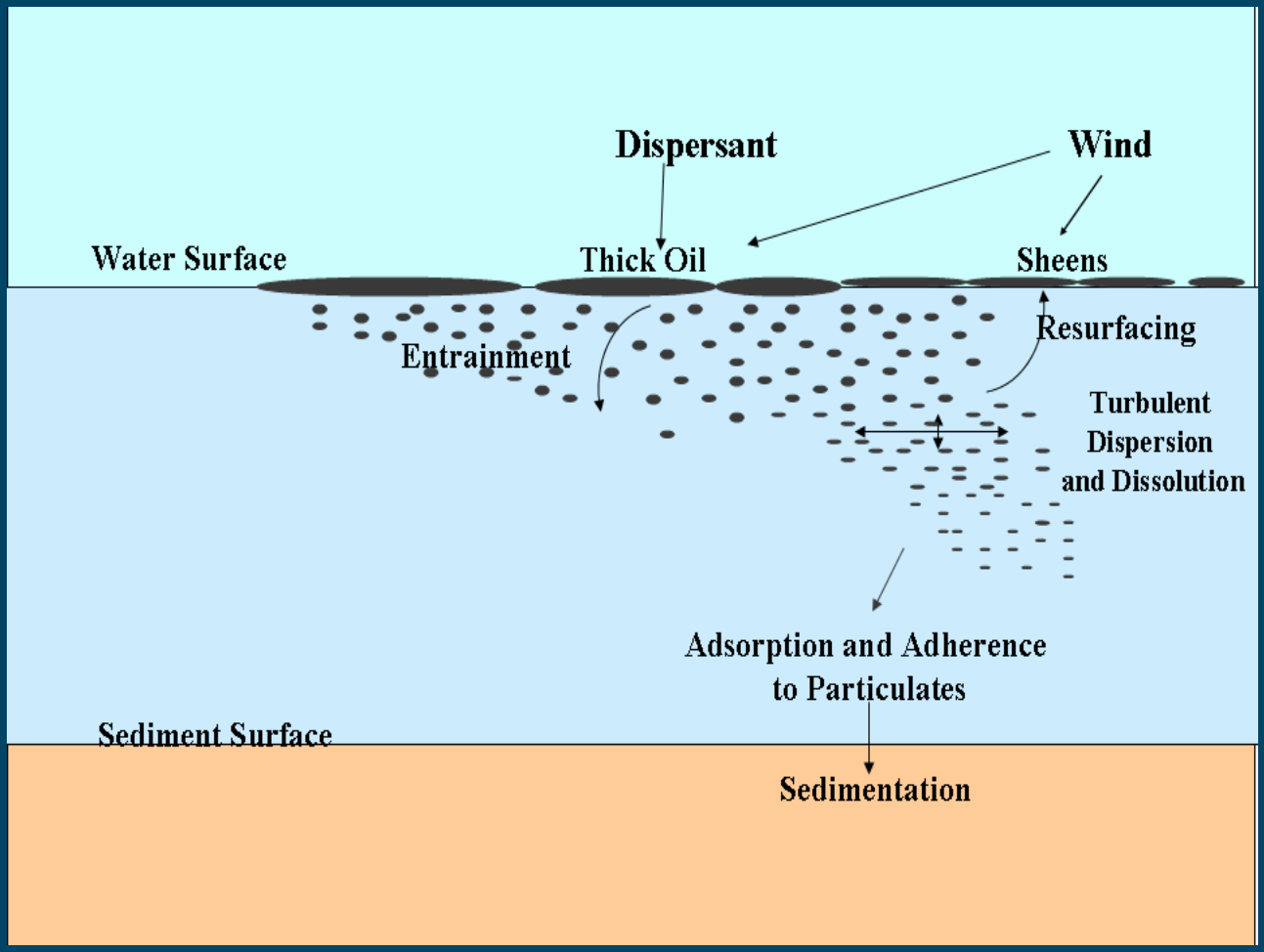
Monoaromatic Hydrocarbons (MAHs)

- Benzene, Toluene, Ethylbenzene and Xylenes = BTEX – highly soluble, highly volatile, moderately toxic
- Alkyl-substituted Benzenes – soluble, less volatile, more toxic

Polynuclear Aromatic Hydrocarbons (PAHs)

- Naphthalenes (2-ring PAHs)
  - soluble, less volatile, more toxic
  - with more alkyl chains, less soluble but more toxic
- 3 ring PAHs : Phenanthrenes, Fluorenes, Dibenzothiophenes
- 4-ring PAHs – parent compounds bioavailable
- larger PAHs insoluble

Important Oil Fate Processes



Biological Exposure Model

Organisms classified by behavior

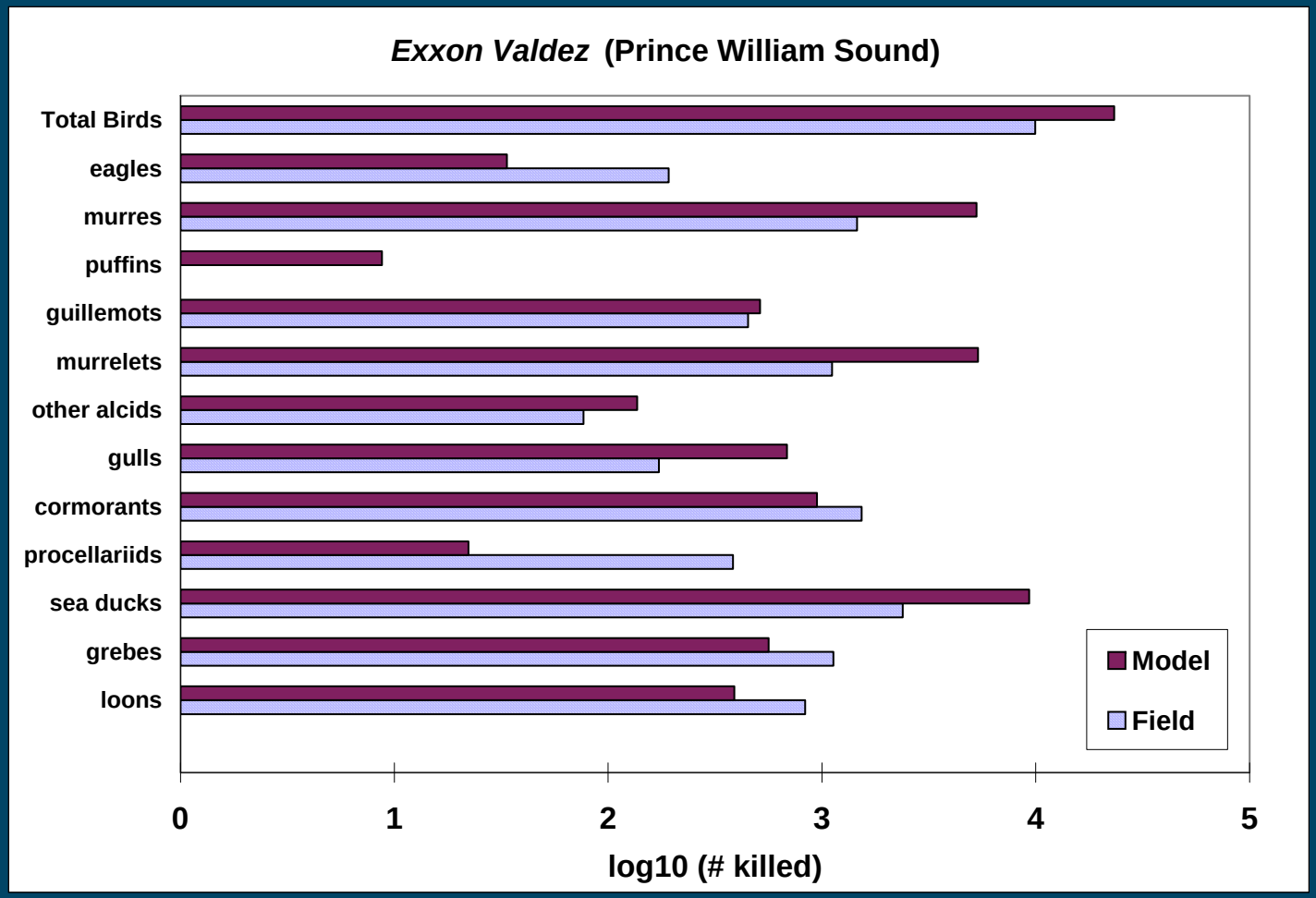
- Wildlife
  - % of time on water surface
  - Habitats used
  - Feathers & fur
- Fish and Invertebrates
  - Swimming
  - Drift with currents
  - Stationary

Movements of organisms are tracked to calculate exposure of individuals

Impact a function of dose

- Wildlife
  - Area swept
  - Slick thickness
- Fish and Invertebrates
  - Σ PAH Concentration (water, sediment pore water)
  - Exposure time
  - Temperature

Validation – Wildlife



Validation – Fish and Invertebrate Toxicity

- **Oil bioassays**

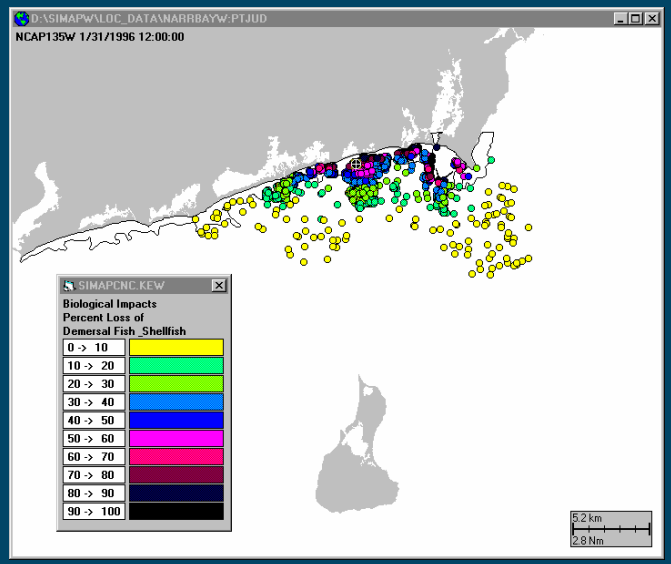
  (French McCay, 2002; Envir. Tox & Chem Vol. 10)

  - **24 data sets (2 to 91 species tested)**
  - **For all data sets: model not significantly different from observed**

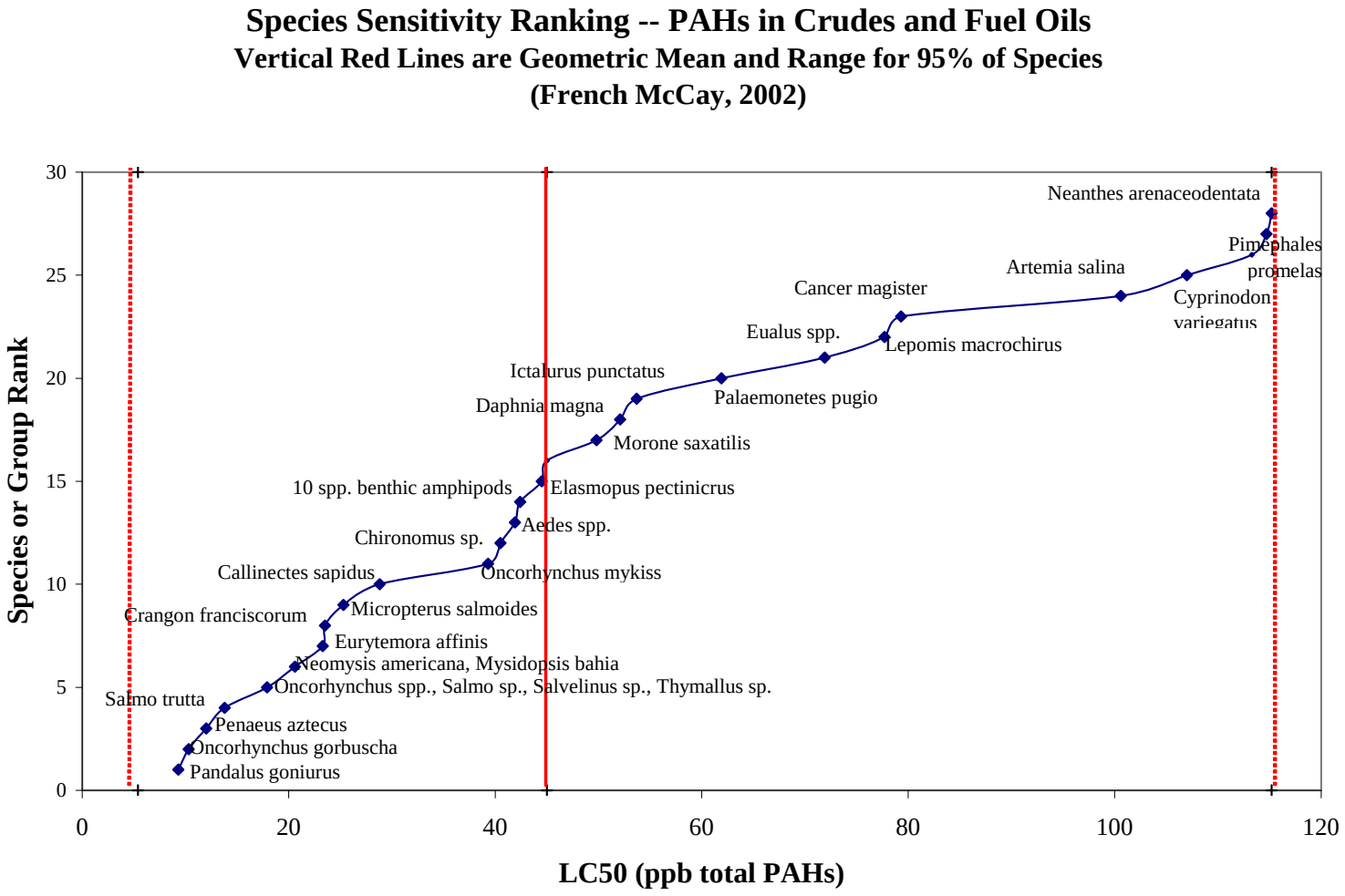
- ***North Cape* Oil Spill (RI, Jan 1996):**

  Lobsters

  - **Field estimate 9 million**
  - **Model estimate 8.3 million**
    - **(using best estimate of toxicity)**
  - **Strandings on beaches: 3 million**



LC50 for >96hrs Exposure Time



Biological Impacts: Equivalent Areas of 100% Loss

Wildlife (Birds primarily)

Area swept by oil >10 μm thick multiplied by probability of encounter with water surface:

[Area Swept] [Probability]

Water Column (Plankton)

Weighted sum of volumes affected at λ% loss:

Σ [Volume] [λ/100]

Divide by mixed layer depth to calculate area affected

Previously Modeled Scenarios

- Hypothetical spills in open water
- Restricted to surface mixed layer: 10m, 20m
- Light Arabian crude
- Oil volume:
  - maximum volume of oil treated by a single sortie of a C-130 (100,000 gal = 326.3 MT = 378 m^3, 20:1 oil:dispersant)
  - 80% efficiency
- Dispersant application scenarios:
  - No dispersant applied
  - Dispersant applied after weathered 8 or 16 hrs
- Wind speeds and associated turbulence conditions
  - 5 kts (2.5 m/s), 1 m^2/s
  - 15 kts (7.5 m/s), 10 m^2/s
- Background currents:
  - none
  - 0.25 kts (13 cm/s) downwind
  - 0.25 kts (13 cm/s) upwind

Summary of Impacts - Area (km^2)

Worst Case: 80% of 100,000 gal dispersed; no currents, 10m mixed depth

W = Wildlife
PA = Plankton: Average Toxicity
PS = Plankton: Sensitive Species

Wind Speed	*No Dispersant*	*With Dispersant*
5 kt (2.5 m/s)	**W: 197-209** **PA: 0** **PS: 0**	**W: 83-100** **PA: 0.6-1.8** **PS: 7-15**
15 kt (7.5 m/s)	**W: 391-425** **PA: 0** **PS: 0.03-0.20**	**W: 68-108** **PA: 0.06-0.09** **PS: 1.4-2.2**

On-Going Project

- Other scenarios
- Matrix of model runs:
  - spills in open water
  - range of smaller oil volumes more likely to be dispersed
  - vary dispersant efficiency
  - vary key input variables determining impact

Products

- Results of model matrix:
  - areas and volumes impacted
  - #s of animals for representative densities
- Presented in tabular and chart format for can look up order of magnitude of likely impact
- Methods of interpolation between results for intermediate spill volumes
  - Visually off chart or table
  - Calculator in Excel

Model Run Matrix – Fates

- 2 Oil types: light and medium/heavy crude oil
- 2 Weather conditions
  - light wind and low turbulent mixing
  - high wind and high turbulent mixing
- 3 Temperatures
  - low (5°C), medium (15°C), and high (25°C)
  - affects weathering, uptake into biota, and toxicity
- Dispersant application
  - none
  - with three different efficiencies
- 5 Volumes – to allow curve-fitting of results

Model Run Matrix – Biological

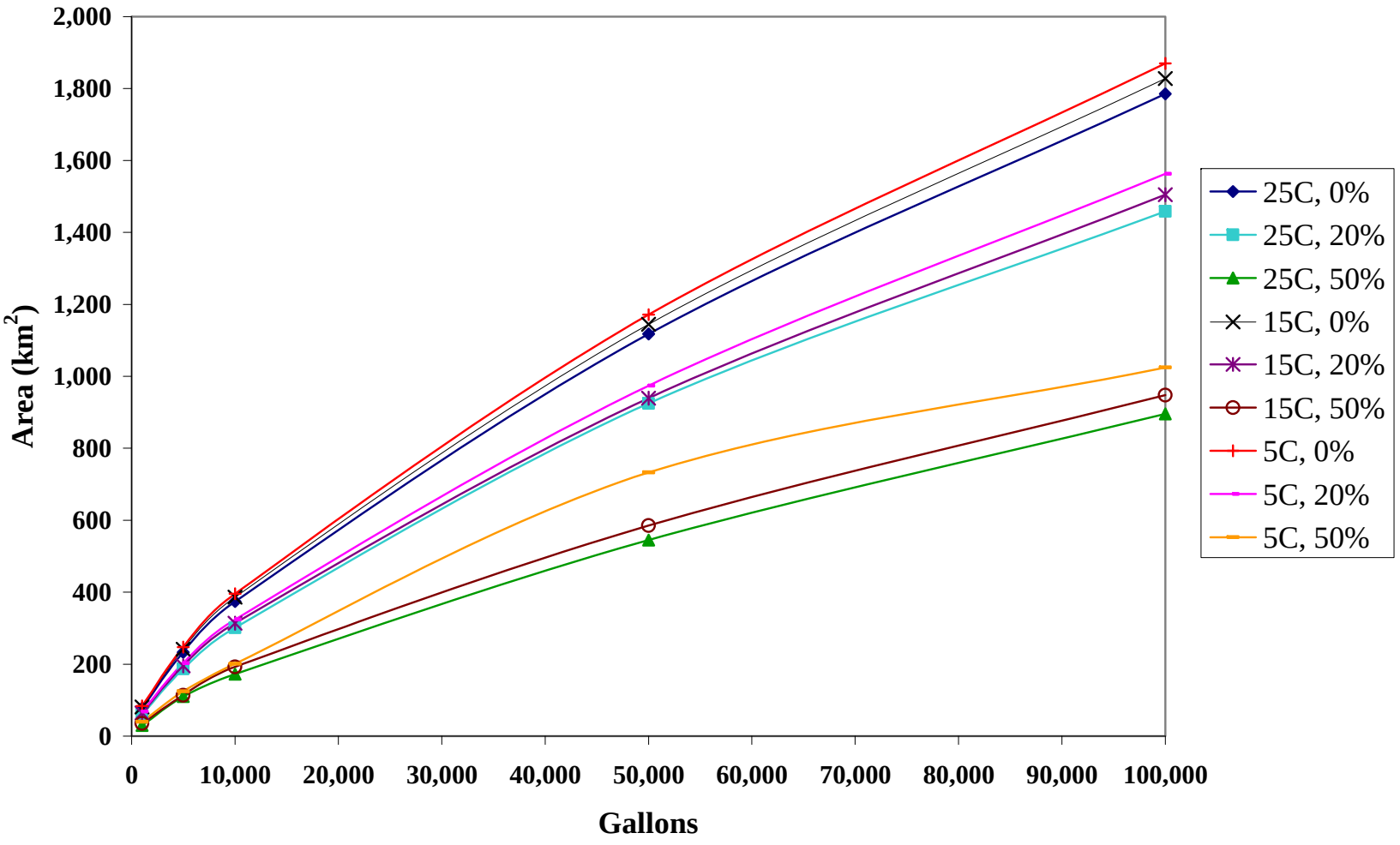
- **Aquatic Toxicity: 3 LC50s covering the range of ± two standard deviations (95%) of species response (French McCay, 2002)**
  - **mean [50 ppb dissolved PAH]**
  - **sensitive [5 ppb dissolved PAH]**
  - **insensitive [400 ppb dissolved PAH]**
- **Wildlife: Probability of oiling based on behavior and vulnerability**

Model Results

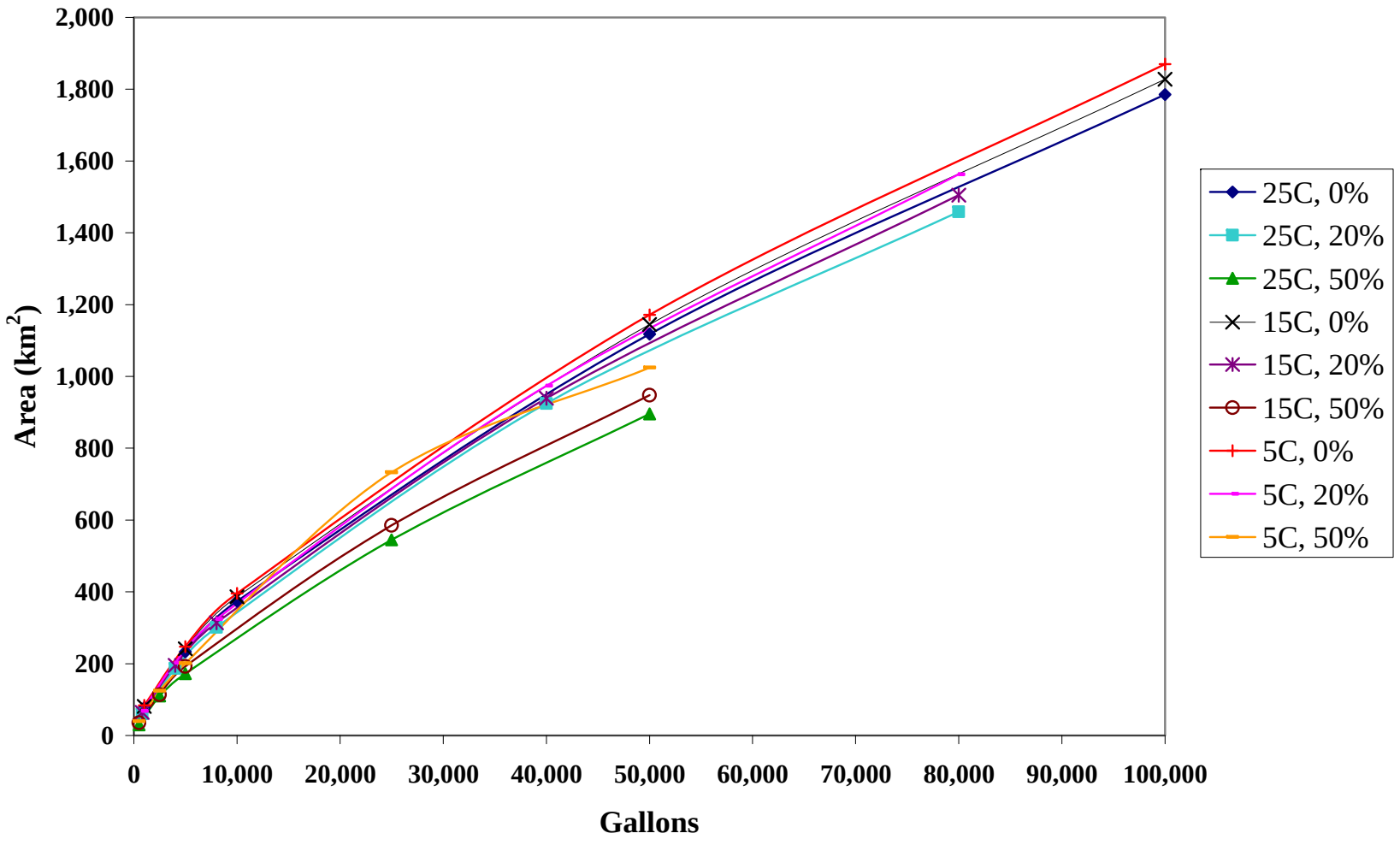
- Water column impact
  - Volume where acute toxic effects would occur
    - equivalent volume for 100% mortality
    - multiply by mixed layer depth → area impact
  - Volume exceeding 1 μg/L total dissolved aromatics (sublethal and chronic effects)
- Area of water surface oiled
  - > Lethal dose to wildlife

    Probability of oiling varies by behavior group
  - >0.01 g/m^2 ~approximate sheen thickness (socioeconomic impact)

SLAC, 5kt Wind: Area Where Wildlife Killed vs. Spilled Oil Volume



SLAC, 5kt Wind: Area Where Wildlife Killed vs. Oil Volume Not Dispersed



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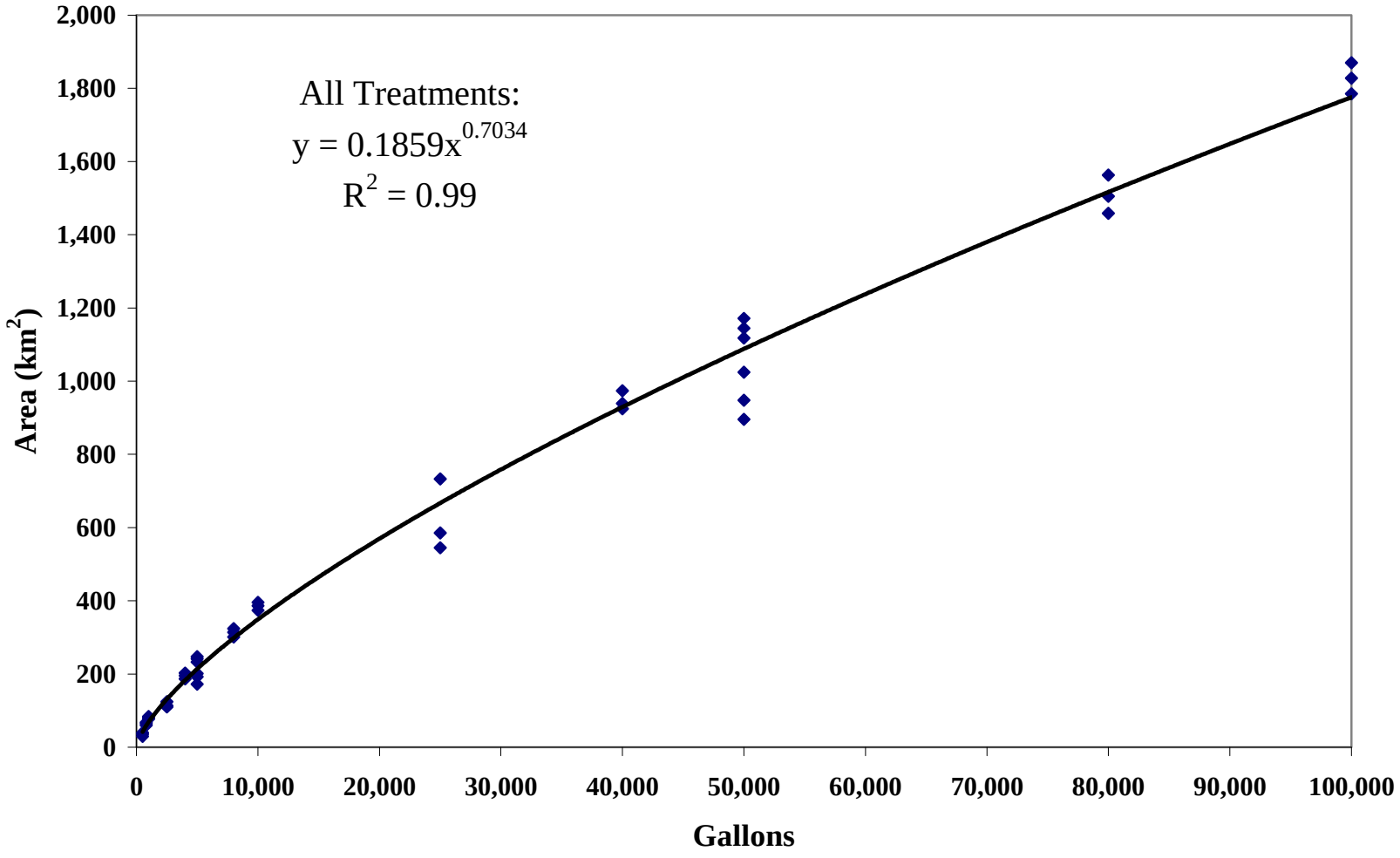
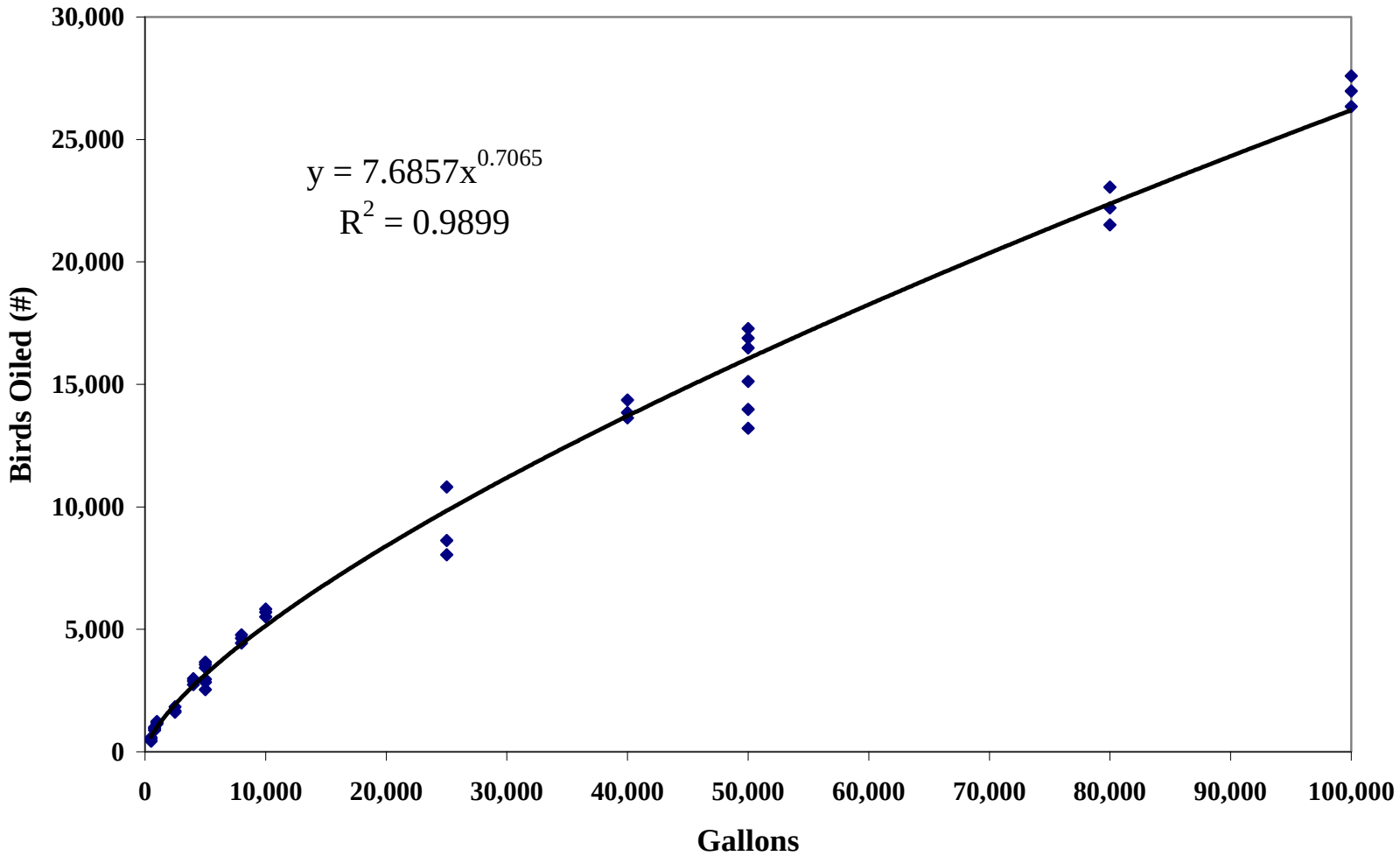



SLAC, 5kt Wind on DelMarVa Shelf:
Birds Oiled vs. Oil Volume Not Dispersed
y = 7.6857x^0.7065
R^2 = 0.9899
Birds Oiled (#)
30,000
25,000
20,000
15,000
10,000
5,000
0
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
Gallons

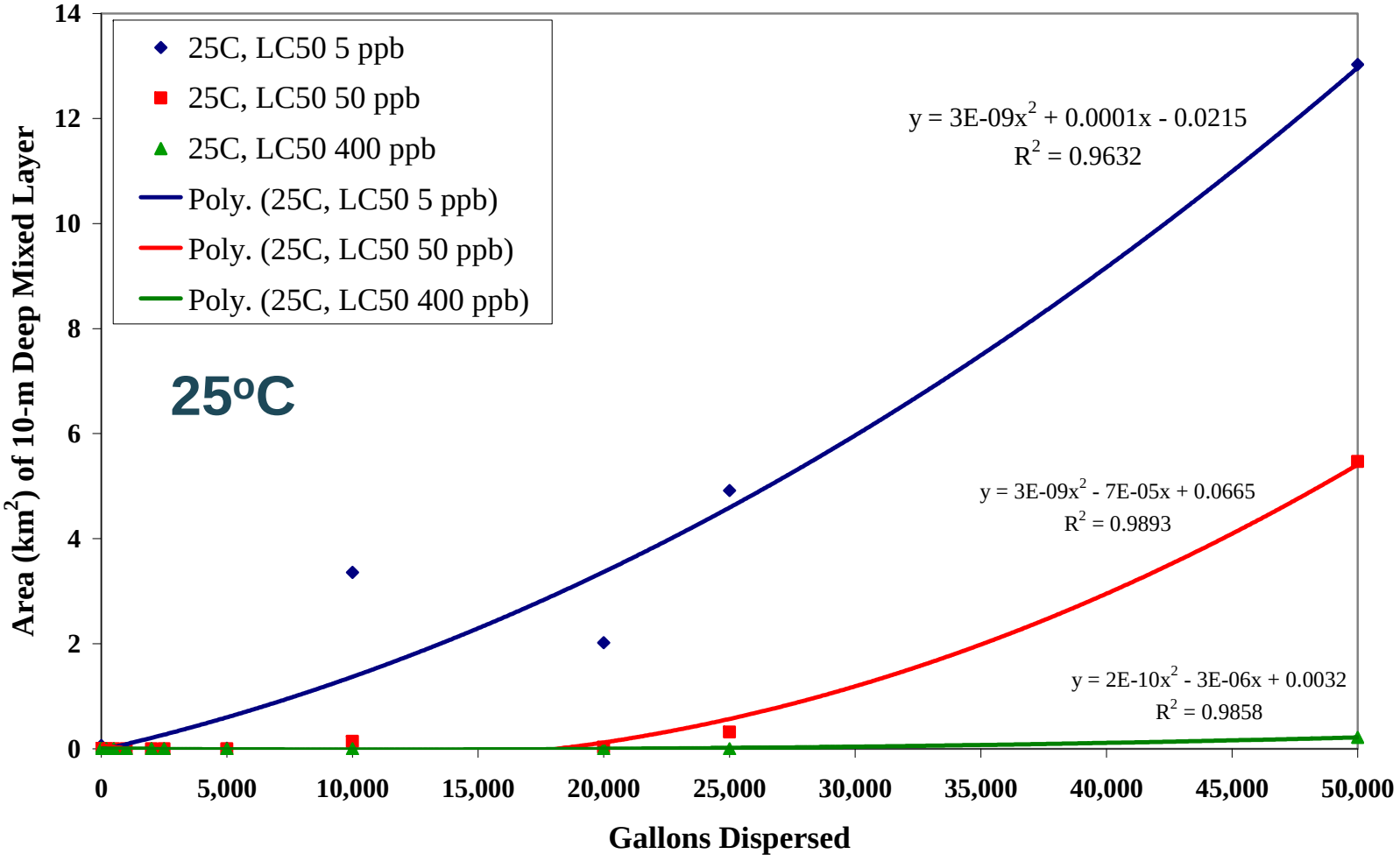
Wildlife Impact: Light Winds

$$\#\ \text{Oiled} = [0.257\ V_s^{0.6759}]\ [\#/km^2]\ [\text{Prob}]$$

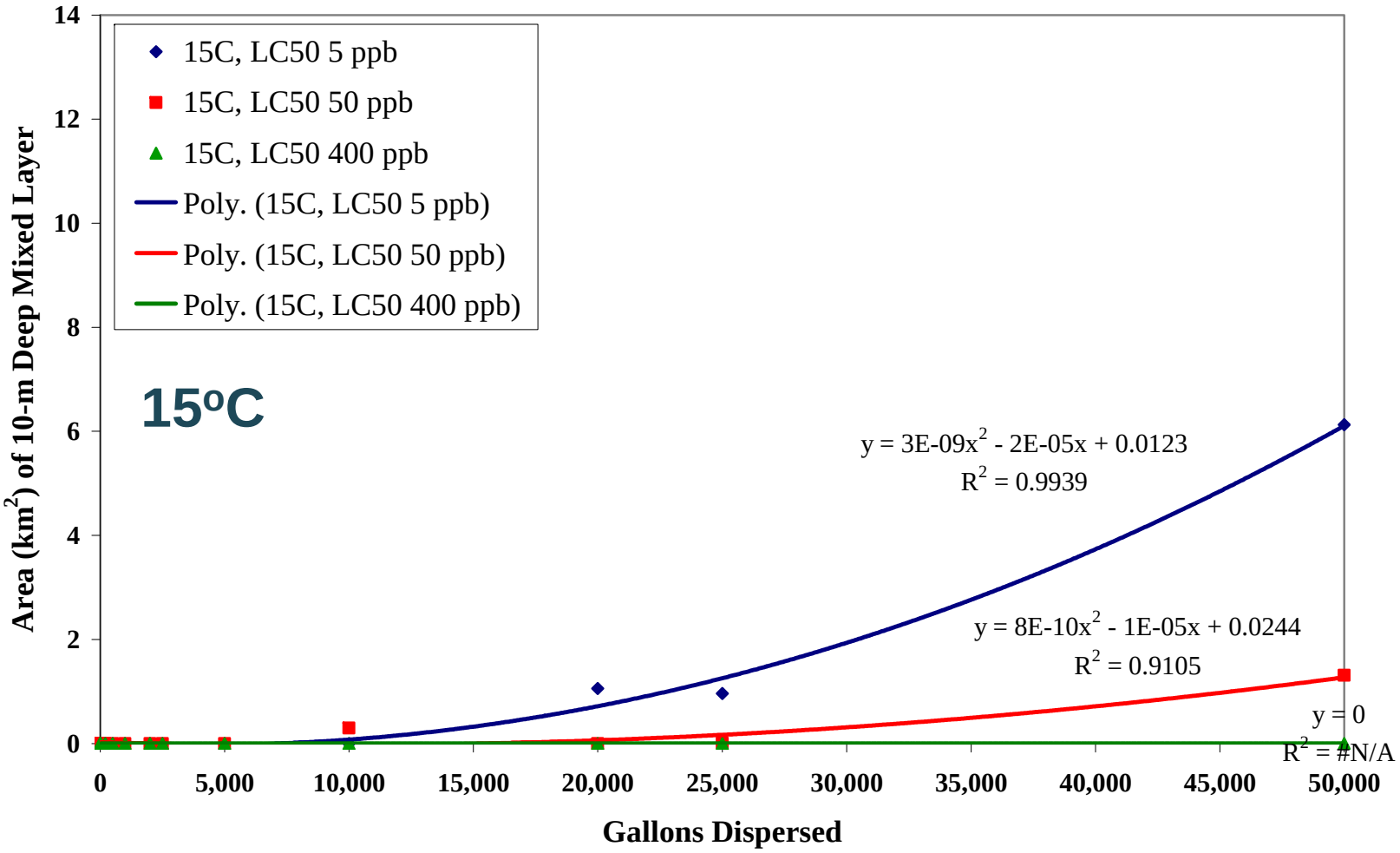
V_s = Volume of oil not dispersed

Prob = Probability of being present on water surface

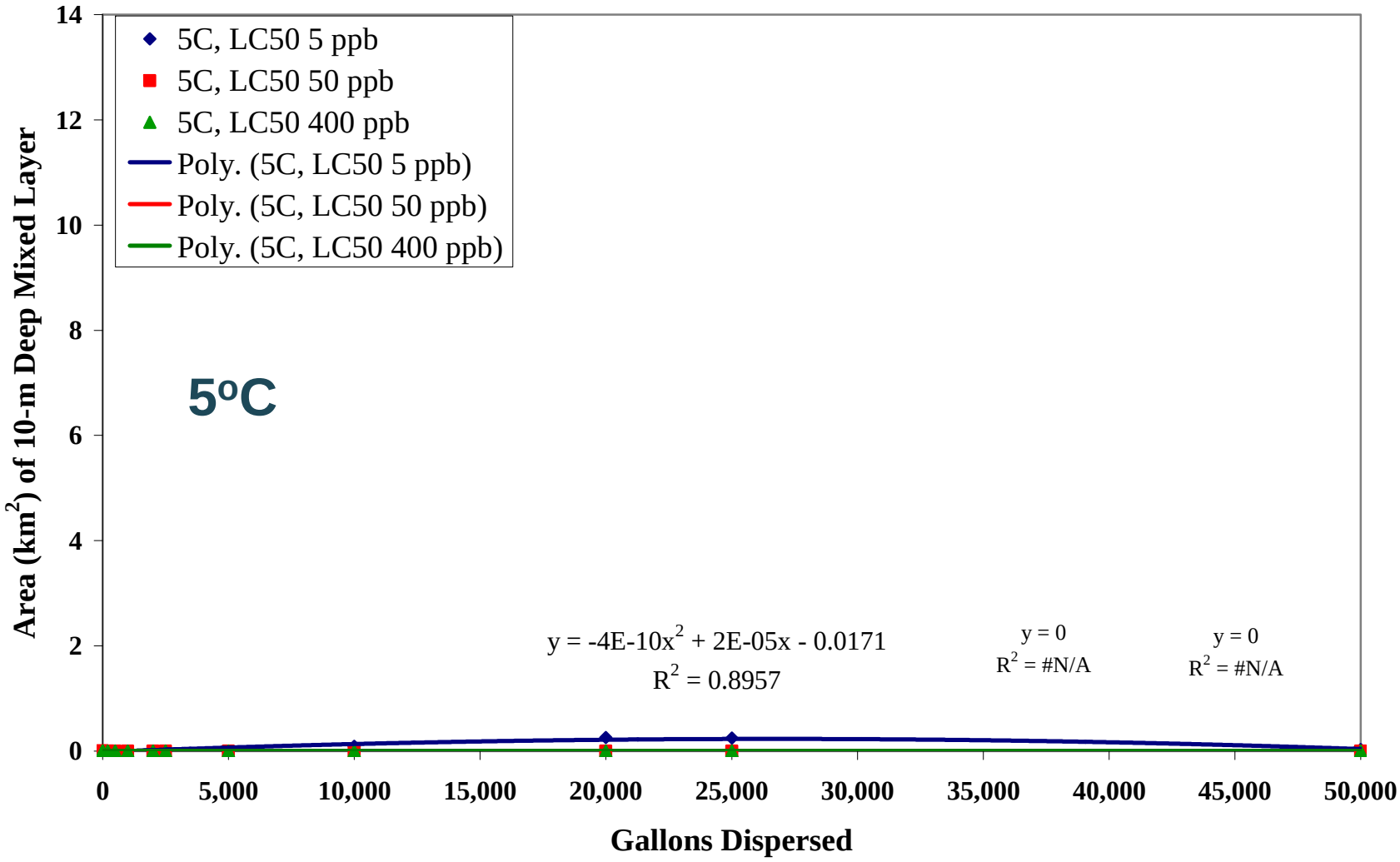
SLAC, 5kt Wind: Area Where Plankton Killed vs. Oil Volume Dispersed



SLAC, 5kt Wind: Area Where Plankton Killed vs. Oil Volume Dispersed



SLAC, 5kt Wind: Area Where Plankton Killed vs. Oil Volume Dispersed



Water Column (Plankton) Impact: Light Winds

$$\# \text{ Killed} = [\ f(V_d)\ ]\ [\#/m^3]\ [z_{mix}]$$

V_d = Volume of oil dispersed

Z_{mix} = surface mixed layer depth

Products

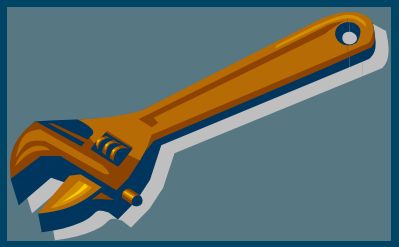
- **Report** – describing the technical approach, assumptions and results of the modeling and guidance development
- **Field guide** (PDF format)
  - Summarize the results
  - Look-up tables with charts, for each oil type and environmental condition
- **Spreadsheet-calculator** for looking up and interpolating results

Use of Guidance Calculator

- User inputs
  - Environmental conditions
  - Oil type
  - Volume spilled
  - Volume/fraction dispersed and efficiency
- Calculator
  - Will interpolate from results of model matrix to in-between conditions
  - Based on regressions of results

Workshop

- Conduct a focused half-day workshop
- At or adjunct to a spill-response related meeting or conference
- Present the results of the study
- Discuss dispersant decision-making using the tool



Conclusions

- Guidance provides order of magnitude results
  - as an input to response decision-making
  - for scoping potential impacts and NRDA
  - for planning water column sampling
- Use of volumes and areas impacts
  - Allows analysis when animal densities unknown or uncertain
  - Multiply by estimated animal densities – scales proportionately