Integrated Assessments (and Monitoring) of Coastal Lagoons

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Anthropogenic Stressors

Stressors of coastal lagoons (and other ecosystems) in order of importance:

1. Climate Change
2. Habitat Alteration
3. Invasive Species
4. Eutrophication
5. Chemical Contaminants

Coastal lagoons are shaped by a large and changing set of environmental conditions **and** by **multiple stressors**; **they are *changing* ecosystems**

Tolerance (acclimation & adaptation) → more change

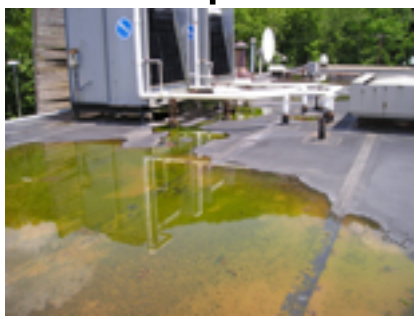
Simplification (e.g., "dangerous indices") for prioritization

Small — **Predicted magnitude and rate of climate change (rain, °C, extreme events, etc)** — **Large**

Long-term consequence of management decisions — **Large**

Small chemical spill

Less important



Oil pipeline rupture

Important

Invasive species

Important

US coastline at 2 (red) and 25 m (yellow) sea level rise

Very important

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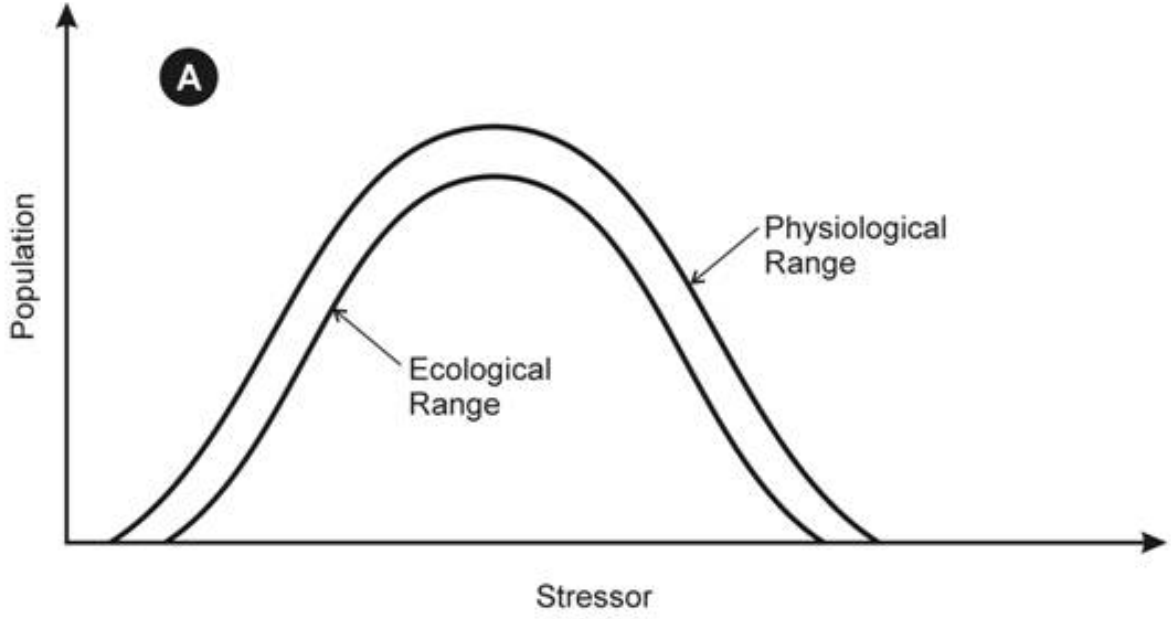
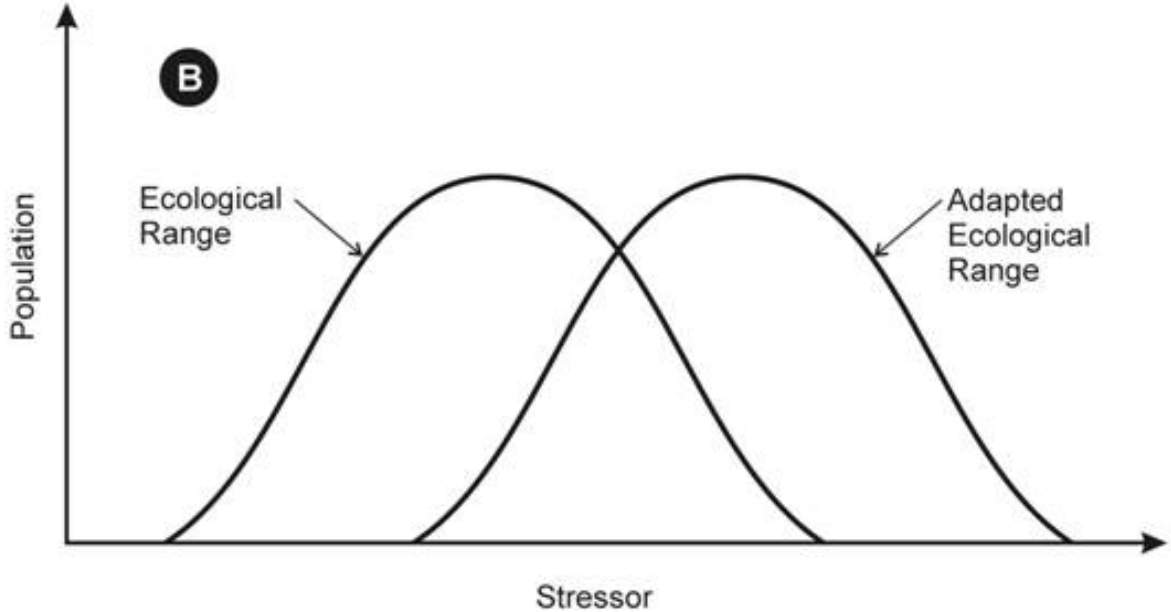
Acclimation (A) is physiological and an extension of an organism's ecological range



Tolerance

Genetic *adaptation* (B) comprises a new ecological range

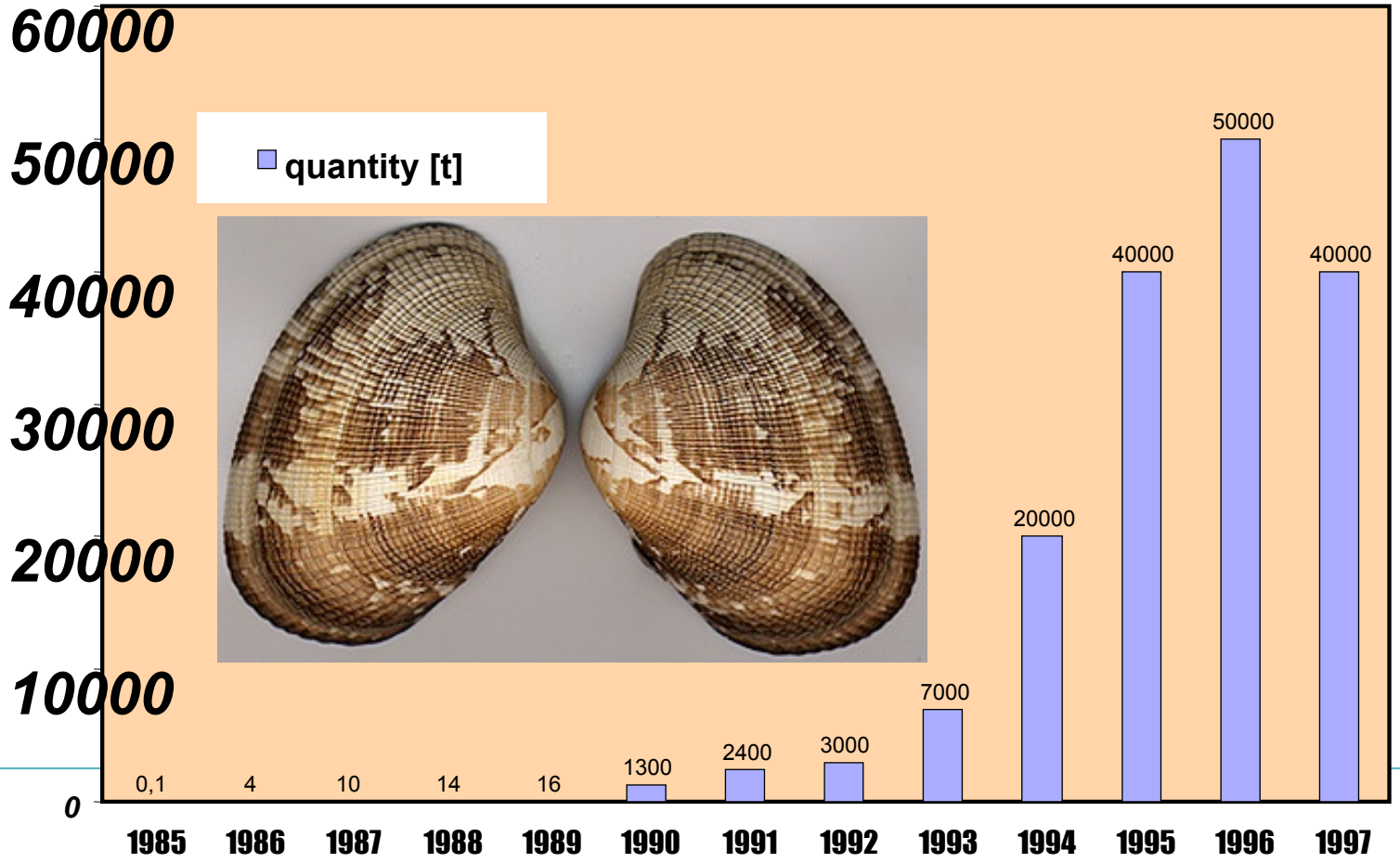


Habitat

Venice Lagoon: a tidal lagoon, linked to an enclosed shallow sea (Adriatic)

HARVEST OF SEDIMENT-DWELLING CLAMS

Catches of the benthic mussel *Tapes philippinarum* in the lagoon of Venice



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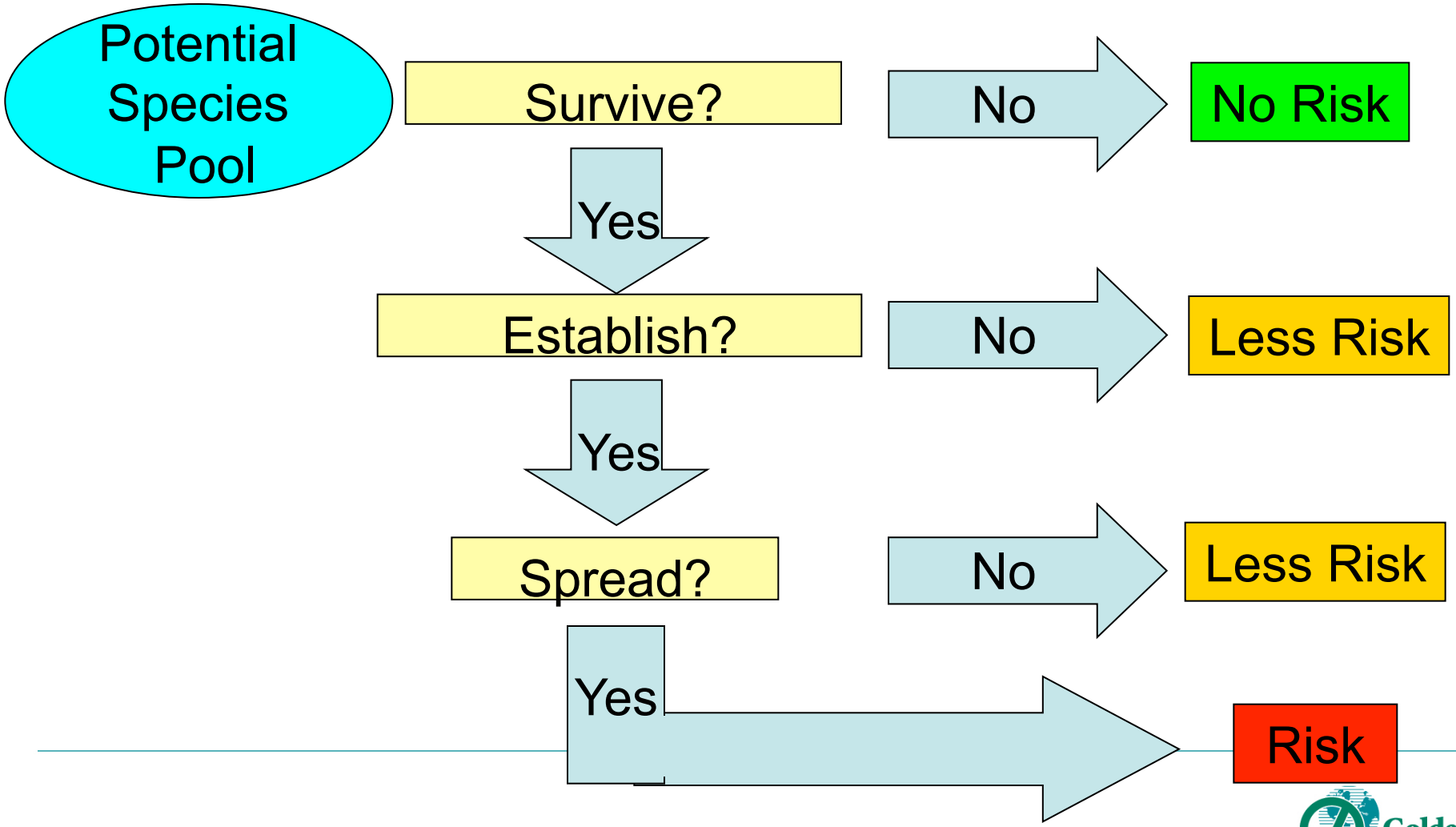
Invasive Species Assessment



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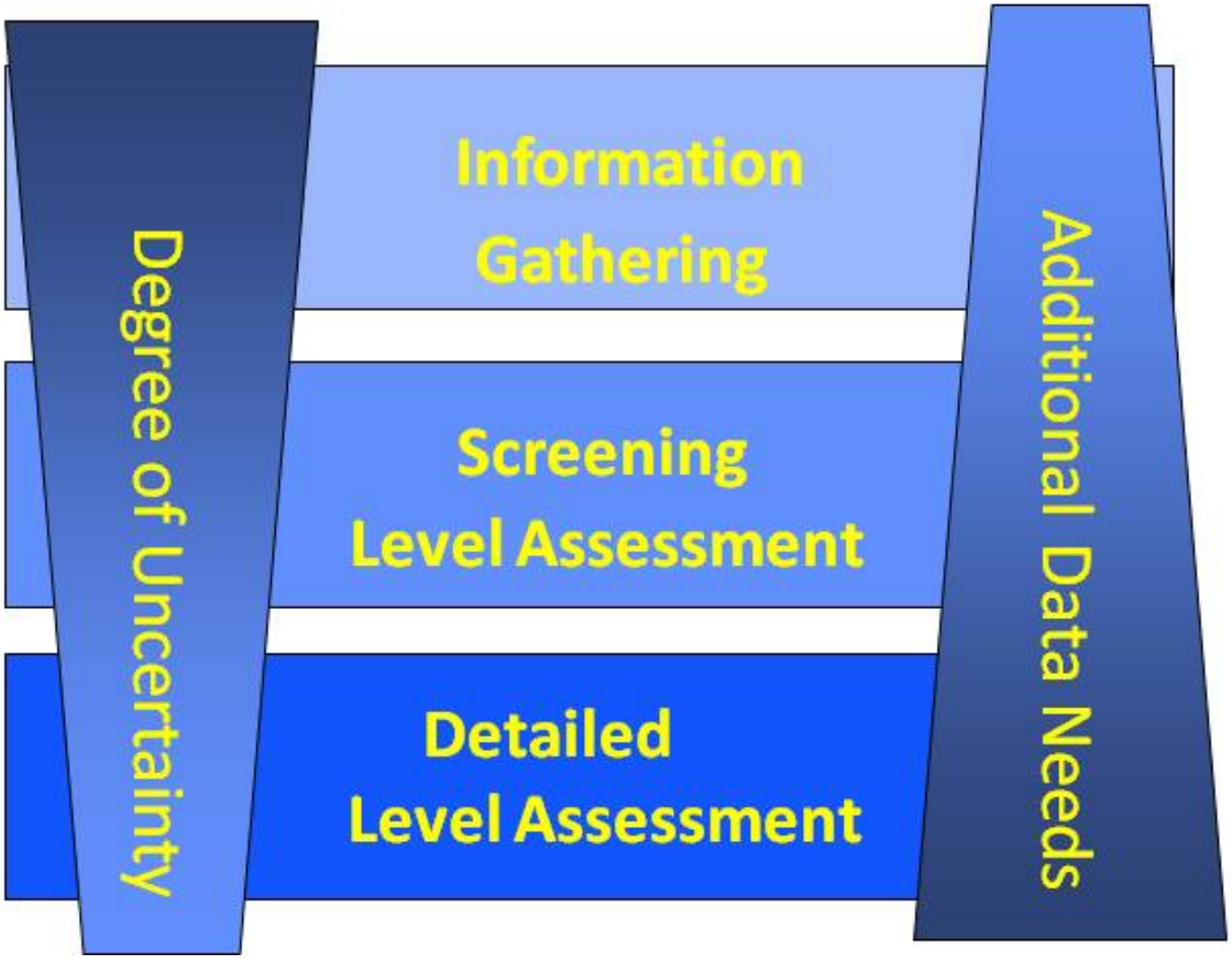
Coastal Lagoon Assessments

Present ('baseline', reactive) and future (proactive) steps:

1. Information Gathering (IG): what do we know?; and, what do we need to know?
2. Screening Level Assessment (SLA): answering the IG question based on available information "what do we need to know?"
3. Detailed Level Assessment (DLA): if necessary, based on SLA, additional assessment to reduce uncertainty for informed management decision-making: "what more do we need to know?"
4. Management and Restoration: based on SLA or DLA

But, with climate change, "you can never go home again"

Data Needs vs Uncertainty



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Uncertainty

Uncertainty has different forms:

- **Can be reduced:**
  - **Imperfect knowledge** – by obtaining necessary additional knowledge
  - **Human error** – by implementing appropriate quality assurance / quality control
  - **Simplification of the real world** – by increased realism (e.g., going beyond beyond models or laboratory studies)
- **Cannot be reduced:**
  - **Stochasticity (natural variability; "noise")** – boundaries (temporal and spatial) can be estimated / described – **increased stochasticity due to global climate change**

Embrace uncertainty and determine its major drivers

Generic Assessment Objectives

1. Determine ***acceptable*** natural [changing] background
   - Define reference conditions
   - Estimate / bound natural variability
2. Determine changes that may have occurred to the present resource characteristics – ***understand the past***
   - Temporal
   - Spatial
3. Determine, before the fact, any developing problems before they become critical – ***predict the [changing] future***
   - Temporal
   - Spatial

Consider the direction of change – **change can be positive, not just negative**, since a return to baseline is no longer possible

Coastal Lagoons

Complex ecosystems; ***stochasticity can mask gradual stressor-induced changes***

Key biotic and abiotic components (bases for Lines of Evidence – LOE):

- Water and sediment quality
- Community structure / <u>function</u>:
  - Plankton
  - Benthos
  - Aquatic flora
  - Fish
  - Water birds
- Human usage – direct and indirect (**<u>ecosystem services</u>**)

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Ecosystem Services

CLASSES OF ECOSYSTEM SERVICES:

Provisioning (food, water, energy)

Regulating (flood control, erosion prevention)

Cultural (recreation, spiritual value, sense of place)

Supporting (nutrient cycling, oxygen)

- *"the products of **ecological functions or processes** that directly or indirectly contribute to human well-being, or have the potential to do so in future"*
- *"the **benefits of nature** to households, communities, and economies"*
- *Ecological processes and resources expressed in terms of the goods and services they provide:*
  - *Link scientific understanding of the environment to socio-economic factors*
- ***Assessment endpoints** = what we protect, e.g., viability of a fisheries and of the food chain they depend upon*
  - ***measurement endpoints** = what we actually measure*

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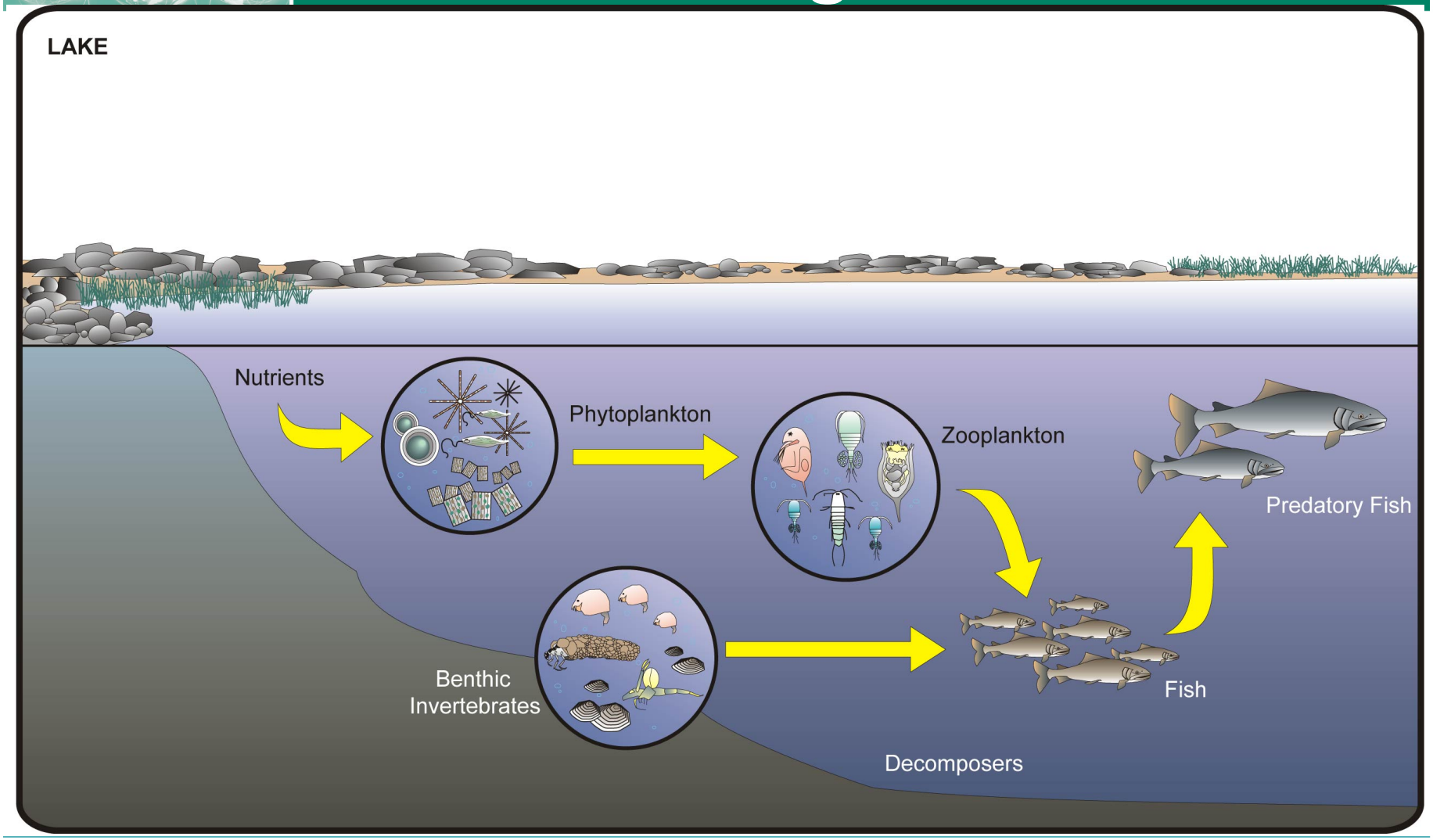
Schematic Lagoon Food Web



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Lines of Evidence (LOE)

- **Observation:**
  - Resident organisms
- **Experimentation:**
  - Laboratory or *in situ*
- **Chemical analyses:**
  - Water
  - Sediment
  - Tissue
- **Biomagnification:**
  - rare, restricted to a few organic chemicals (e.g., methyl Hg; 2,3,7,8,TCDD; PCBs)

Consider LOE individually and in combination to answer the "So what? question

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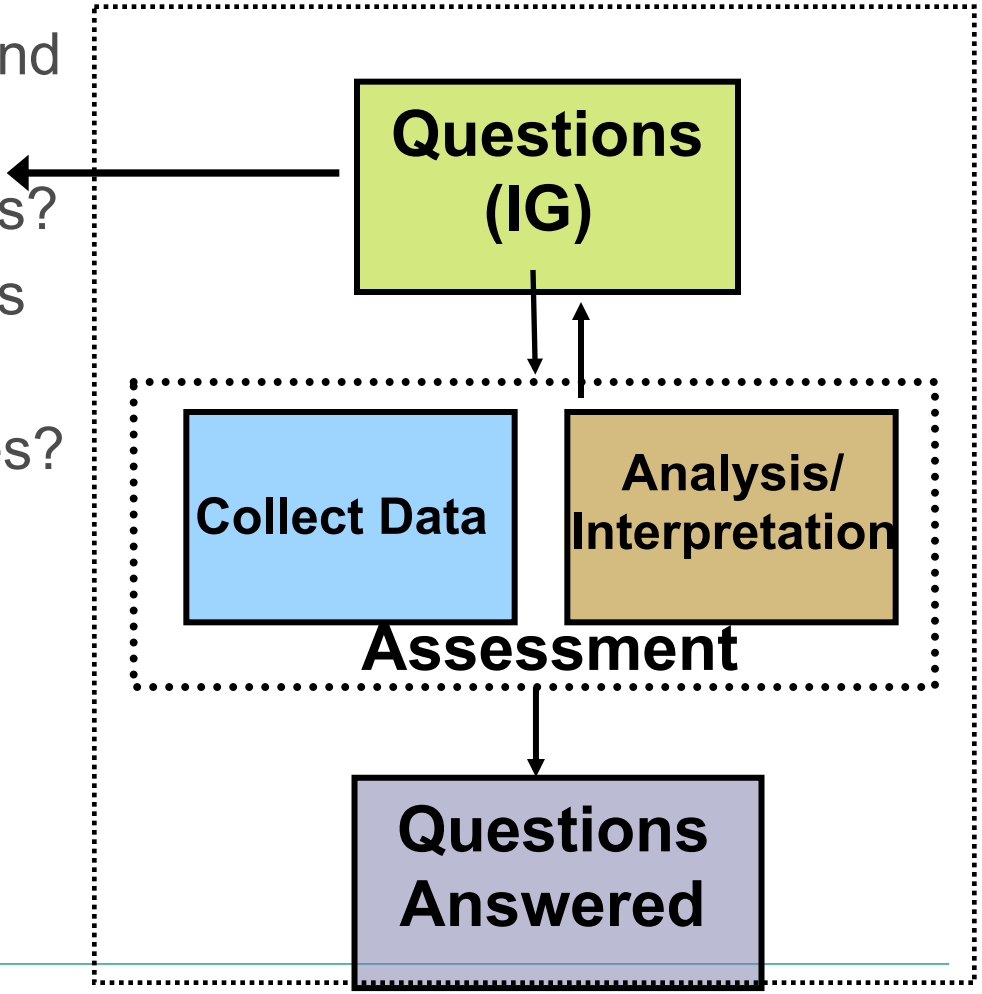
Good Questions = Good Study Design

- What do we know / need to know?
- Which stressors are important and which are not?
- What are the exposure pathways?
- What are the biological receptors including humans?
- What are the ecosystem services?

Develop a Conceptual Model

- Is assessment necessary (e.g., does a relatively small affected area have any significance for species with low site fidelity)?
- What are effects/impacts?



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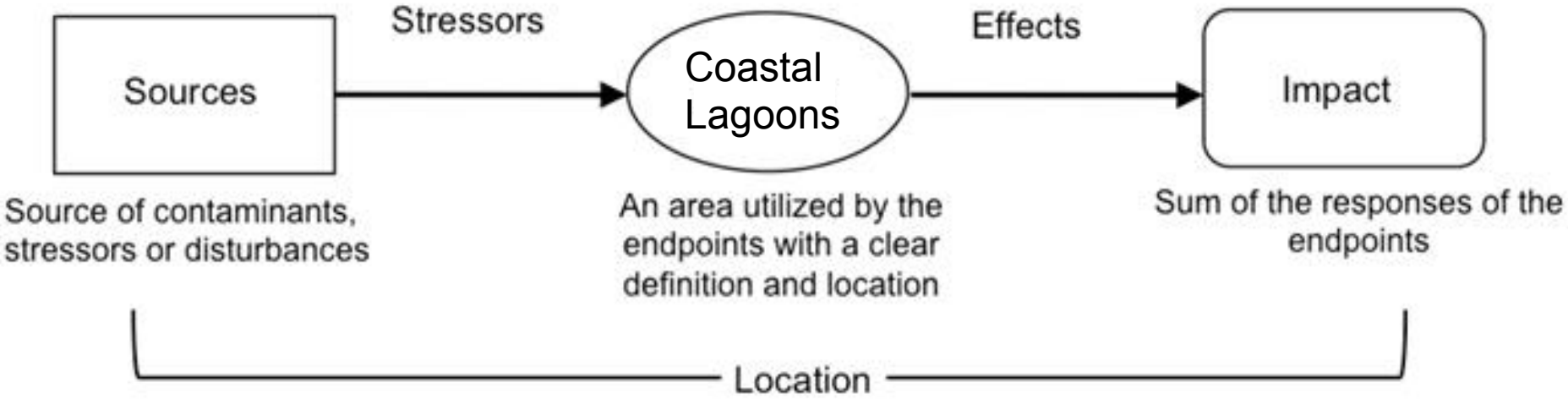
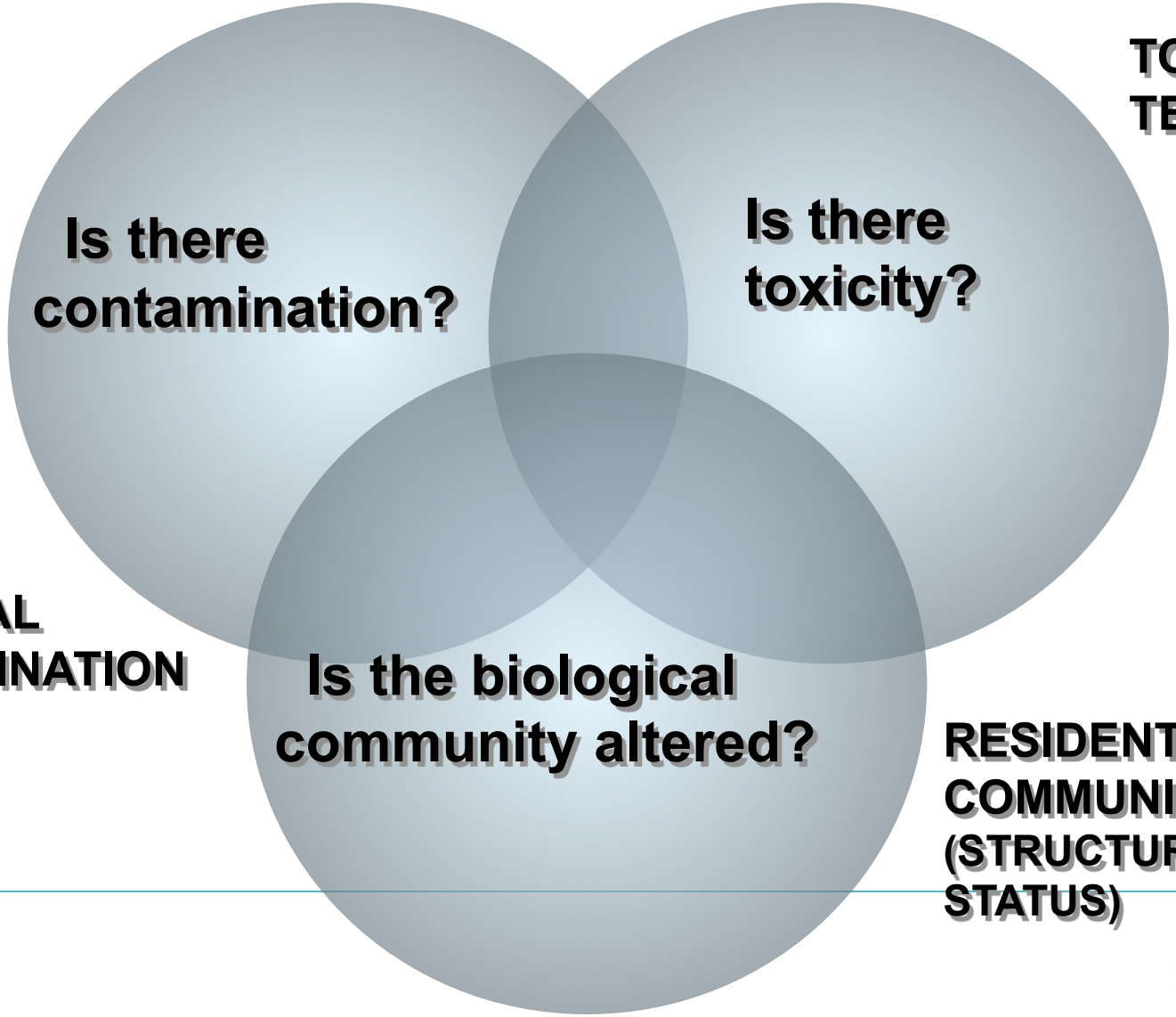
Basis for Conceptual Diagram/Assessment

Based on Landis and Wiegers 1997, 2005.



Regional Risk Assessment

Chemical Contamination Assessment



TOXICITY TESTING

CHEMICAL CONTAMINATION

RESIDENT COMMUNITIES (STRUCTURE AND STATUS)

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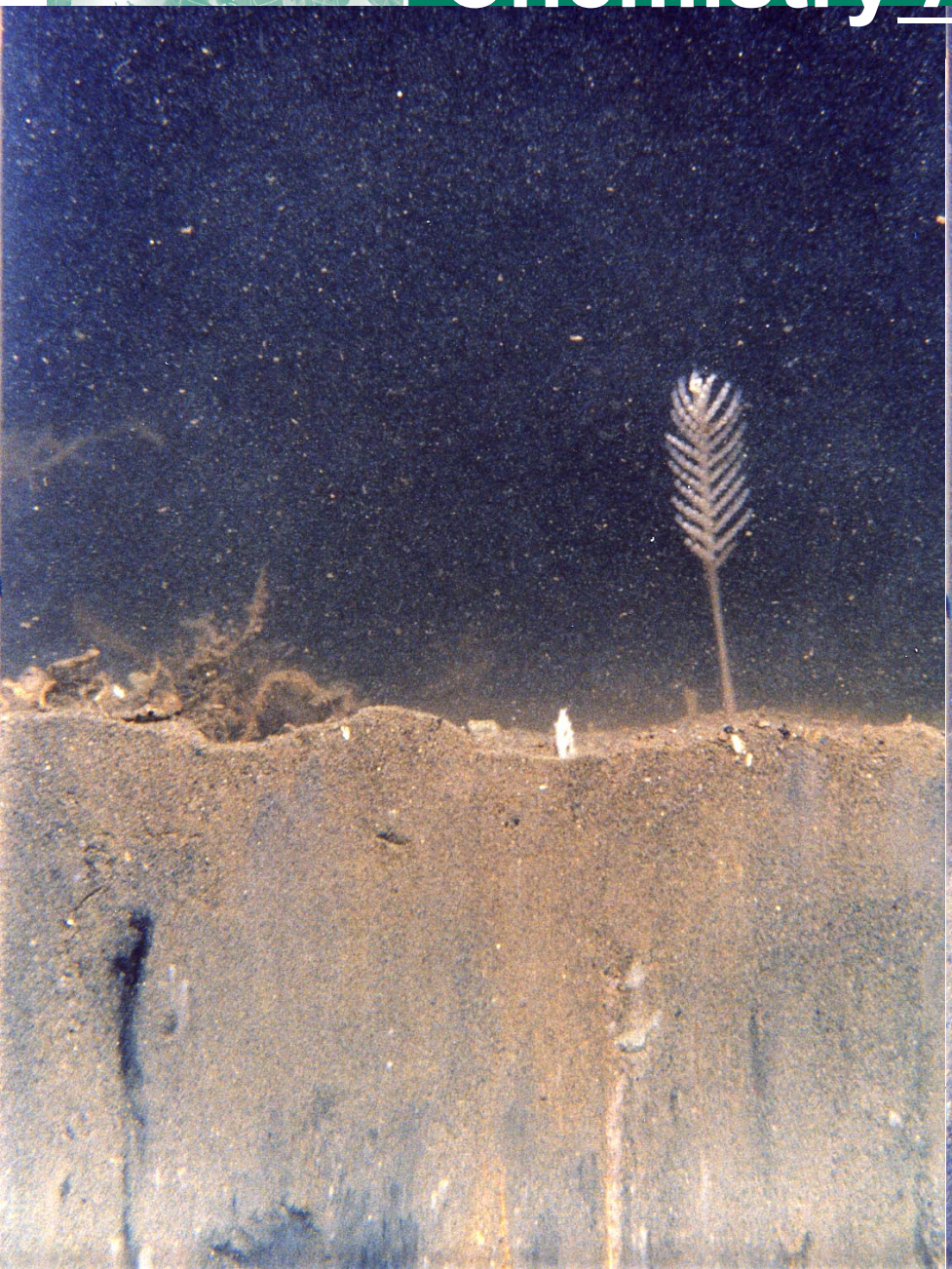
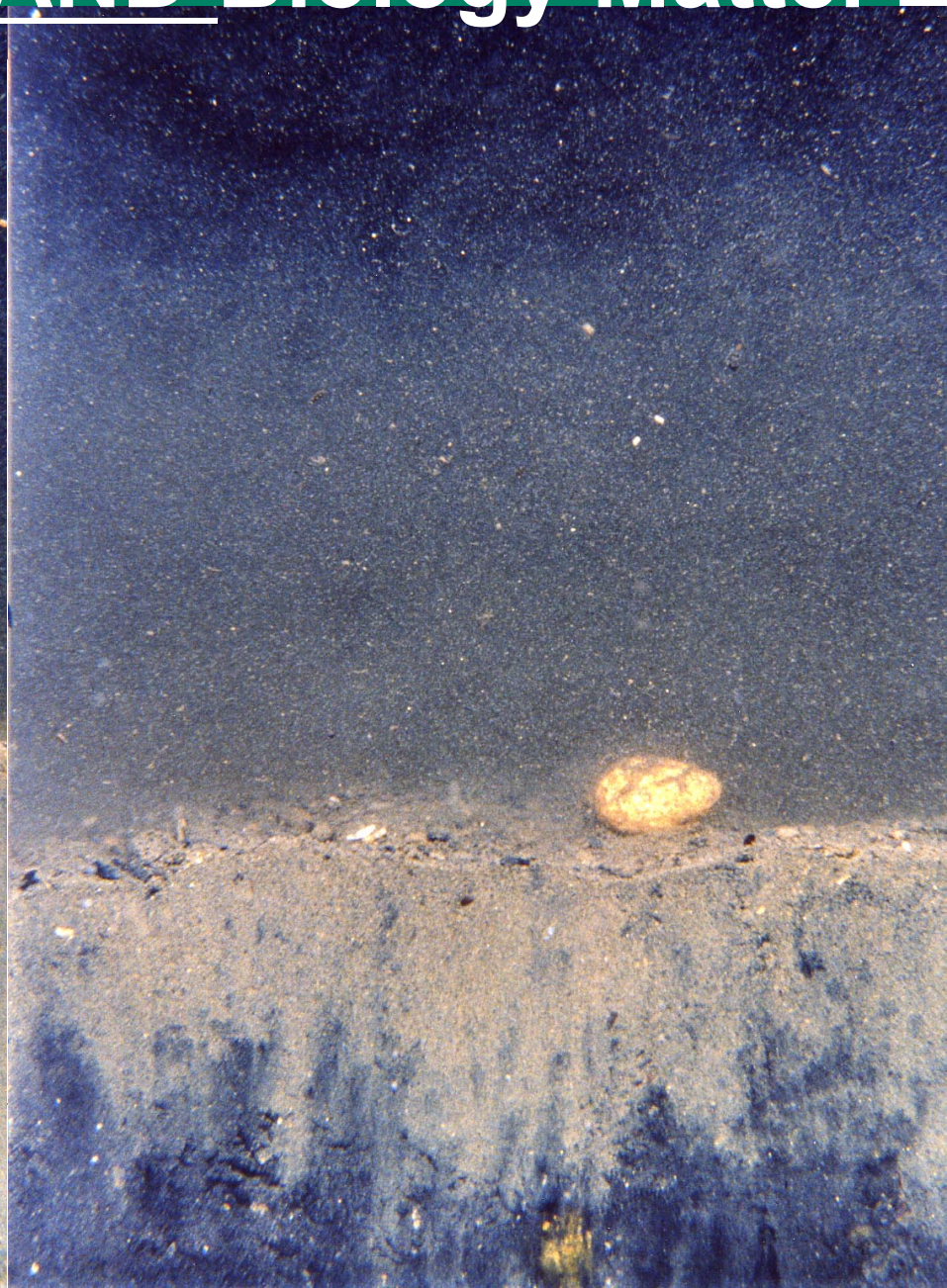
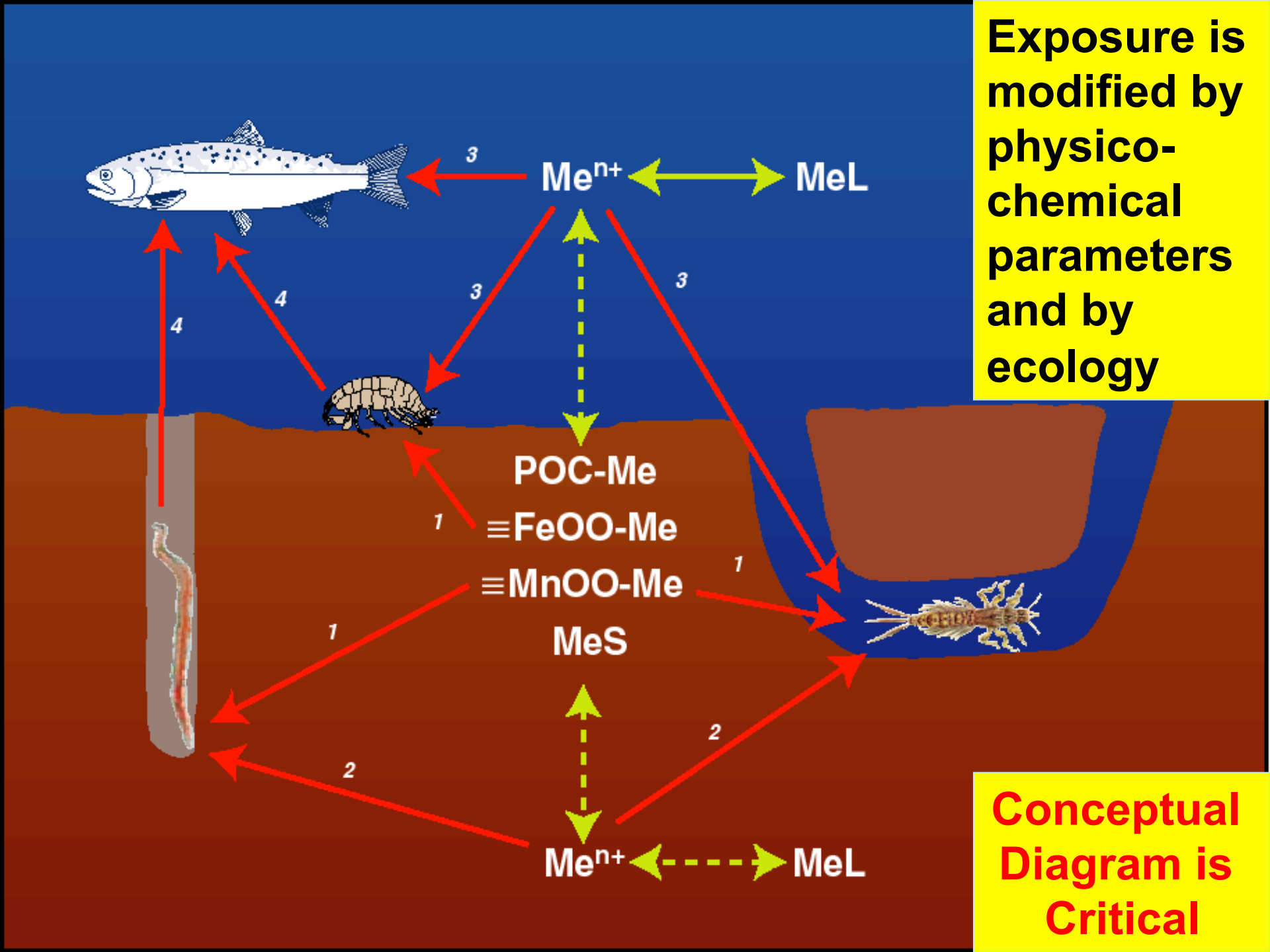
Chemistry AND Biology Matter



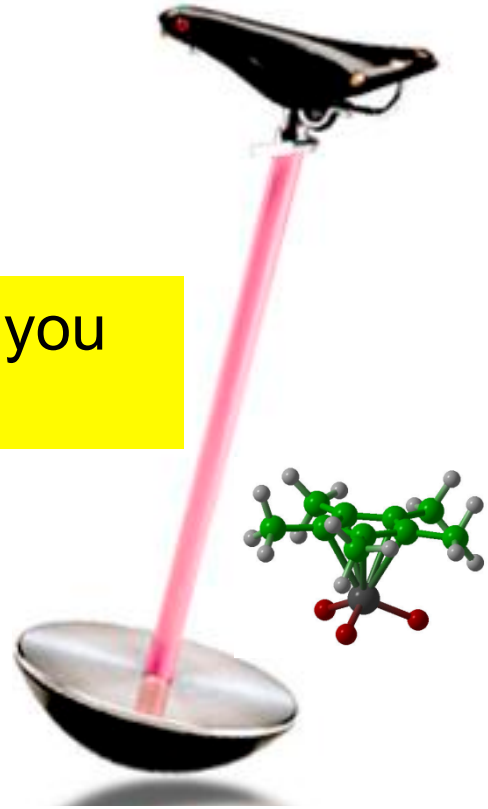



Exposure is modified by physico-chemical parameters and by ecology
Me^{n+}
MeL
POC-Me
≡FeOO-Me
≡MnOO-Me
MeS
Me^{n+}
MeL
1
2
3
4
Conceptual Diagram is Critical

Don’t Rely Only on Chemistry

- One line of evidence yields a highly uncertain assessment

Which would you rather sit on?



Limitations of Chemical Analyses

- We can't measure everything!
- Chemical analyses provide no information on ***bioavailability*** of contaminants or on factors that modify bioavailability
- Chemical analyses provide no information on ***effects***, let alone ***impacts***

An effect = a change to a valued ecosystem component (VEC)

An impact = an effect to a VEC that adversely affects the utility or viability of that VEC

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HISTORIC METALS BIOAVAILABILITY TOOLS

Tool	Date	Description	Comments
Total recoverable metals	Pre-1985	Dissolved + easily dissolved solid metals; hard mineral acid digestion	Highly conservative for metals that may become environ-mentally active
Acid soluble metals	1985	Less aggressive digestion procedure	Not much improvement
Dissolved metals	1993	<0.45 micron, pH 6.5-9.0, TOC/TSS < 5 mg/L	Improved approximation, but not ideal
Biotic Ligand Model	2003	Model based on water chemistry	Continuing research focus

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Multi-stressor Effects Are Complex

Parameter	Metric	Nutrient Exposure	Toxic Contaminant Exposure
Density	No./m²	↑	↓
Richness	Number of taxa	↑ or ↓	↓
Community Composition	Relative proportion of major groups	Change in most dominant groups	
Diversity	Relative proportion of different taxa	↑ or ↓	↓

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Correlation Is Not Causation

- Empirically observed co-variation is a necessary <u>but not sufficient</u> condition for causality
- The numerical strength of correlation/ regression (R^2) is often misconstrued as a direct indicator of environmental relevance
  - Doesn't address stochasticity (natural variability)
  - Doesn't address form of relationship
  - Doesn't address Type II errors!

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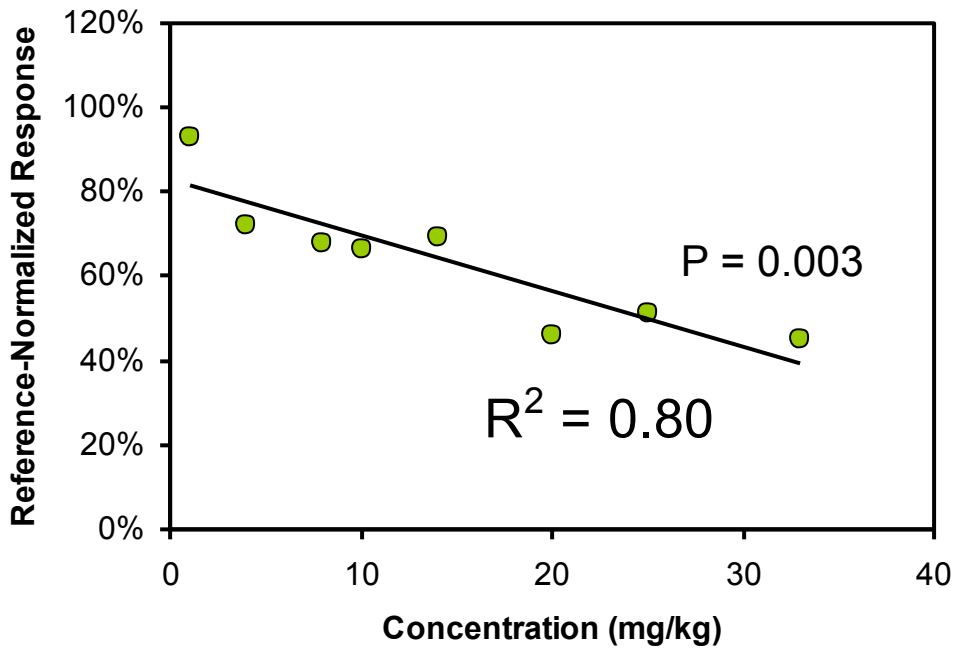
Hypothetical Example

- Following 3 examples all depict the relationship between a response and exposure (same data used in all 3)
- Effect size is factor of 2 across full exposure range

A factor of 2 drop in species richness would likely be regarded as ecologically significant

When R^2 strong, need to ask whether the relationship is spurious (Type I error?)



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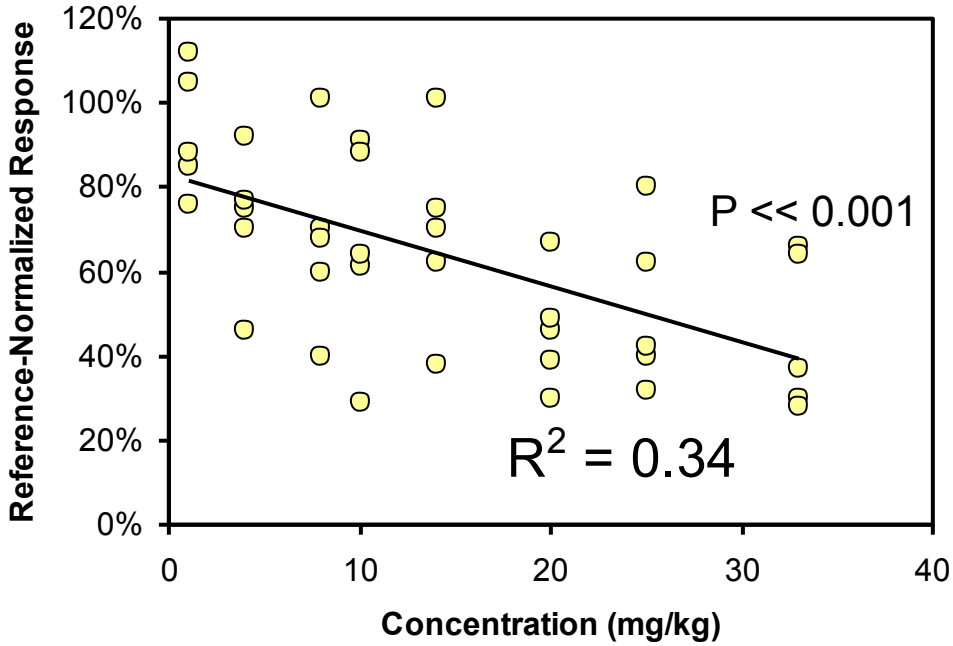
Hypothetical Example (cont'd)

- Natural stochasticity has been added, typical of natural environments – mean of replicates is identical to previous slide
- Coefficient of determination drops significantly

Variability is a fact of life – it should be embraced, not feared



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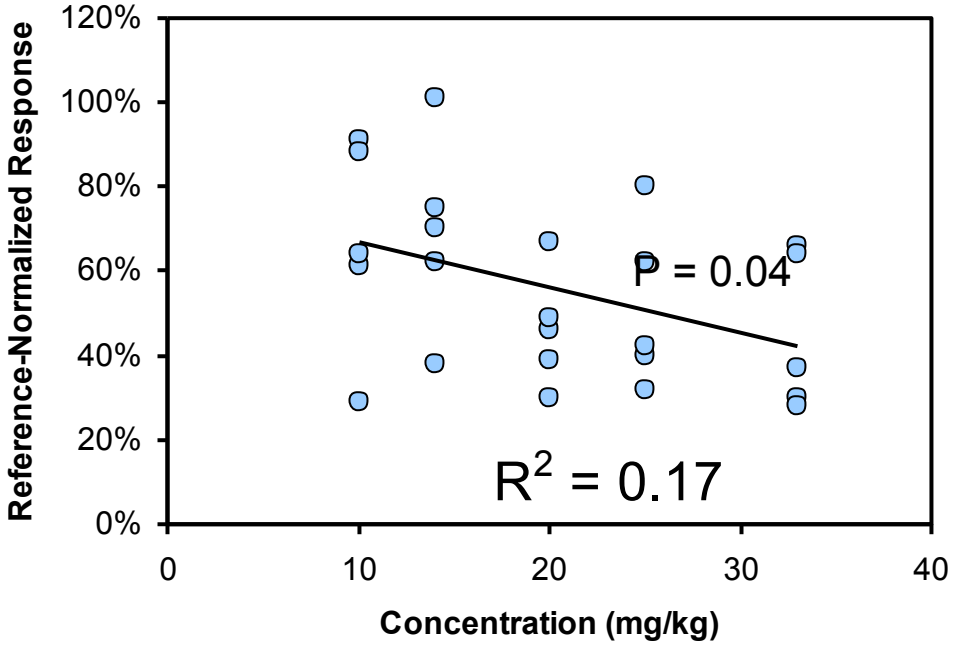
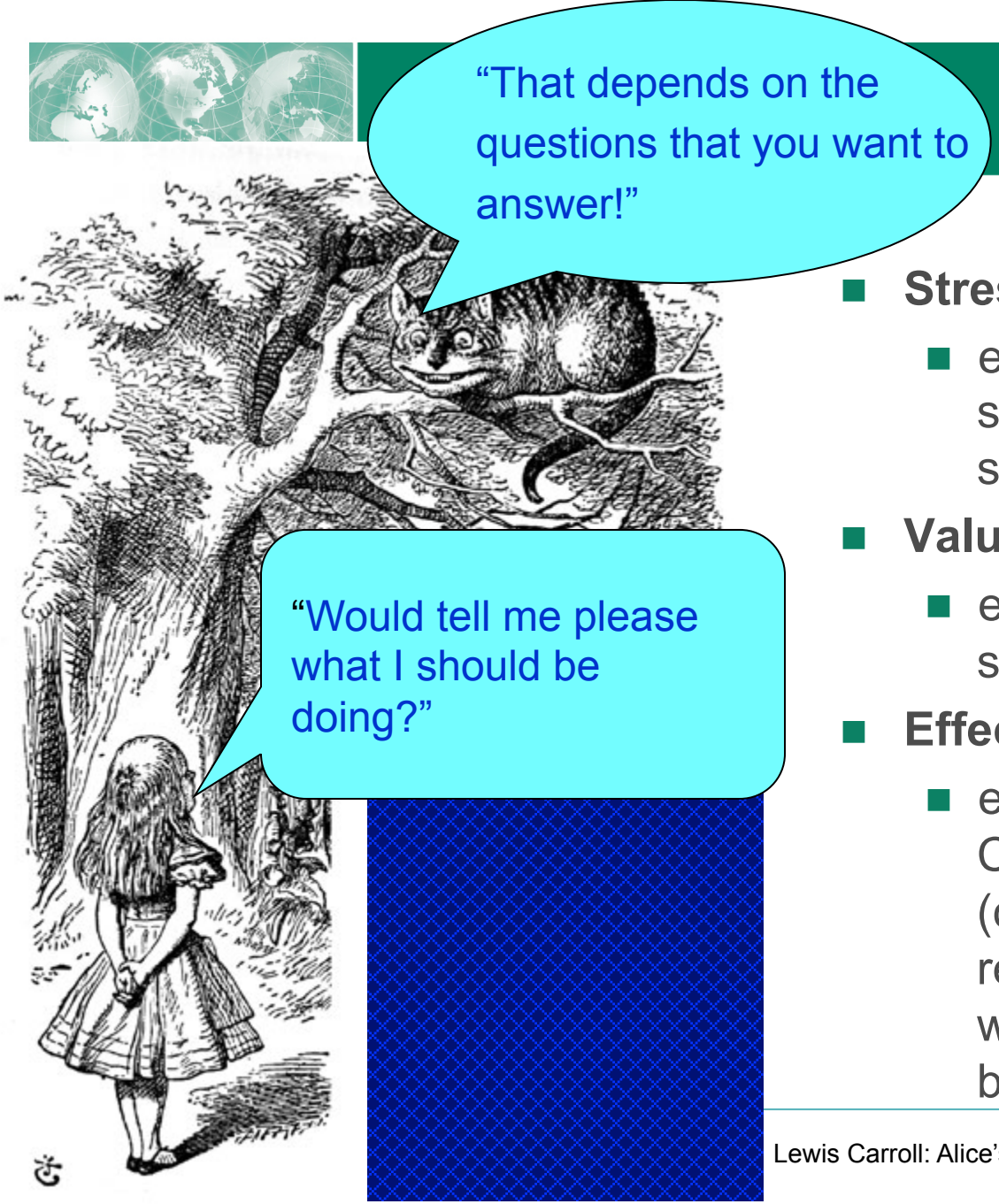
Hypothetical Example (cont'd)

- Now the exposure range has been truncated at 10 mg/kg
- Regression significance drops further – shows importance of the exposure range

When R^2 weak, need to ask whether the underlying relationship could in fact be ecologically significant (Type II error?)





- **Stressor-Based Assessment**
  - e.g., what is the effect of stressor(s) on ecosystem services?
- **Values-Based Assessment**
  - e.g., how to preserve ecosystem services?
- **Effects-Based Assessment**
  - e.g., are ecosystem services of Coastal Lagoon X below normal (compared to, for instance, reference conditions)? If so, what factors prevent them from being normal?

Lewis Carroll: Alice's Adventures in Wonderland

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Comprehensive Assessment

+

Investigative Studies

(as required to **establish causation**)

+

Proactive Adaptive Management

- **Stressor-Based Assessment**
  - Status and trends of natural and anthropogenic stressors

+

- **Values-Based Assessment**
  - Status and trends of what you are trying to protect, including stochasticity

- **Effects-Based Assessment**
  - Ecosystem-level status and trends

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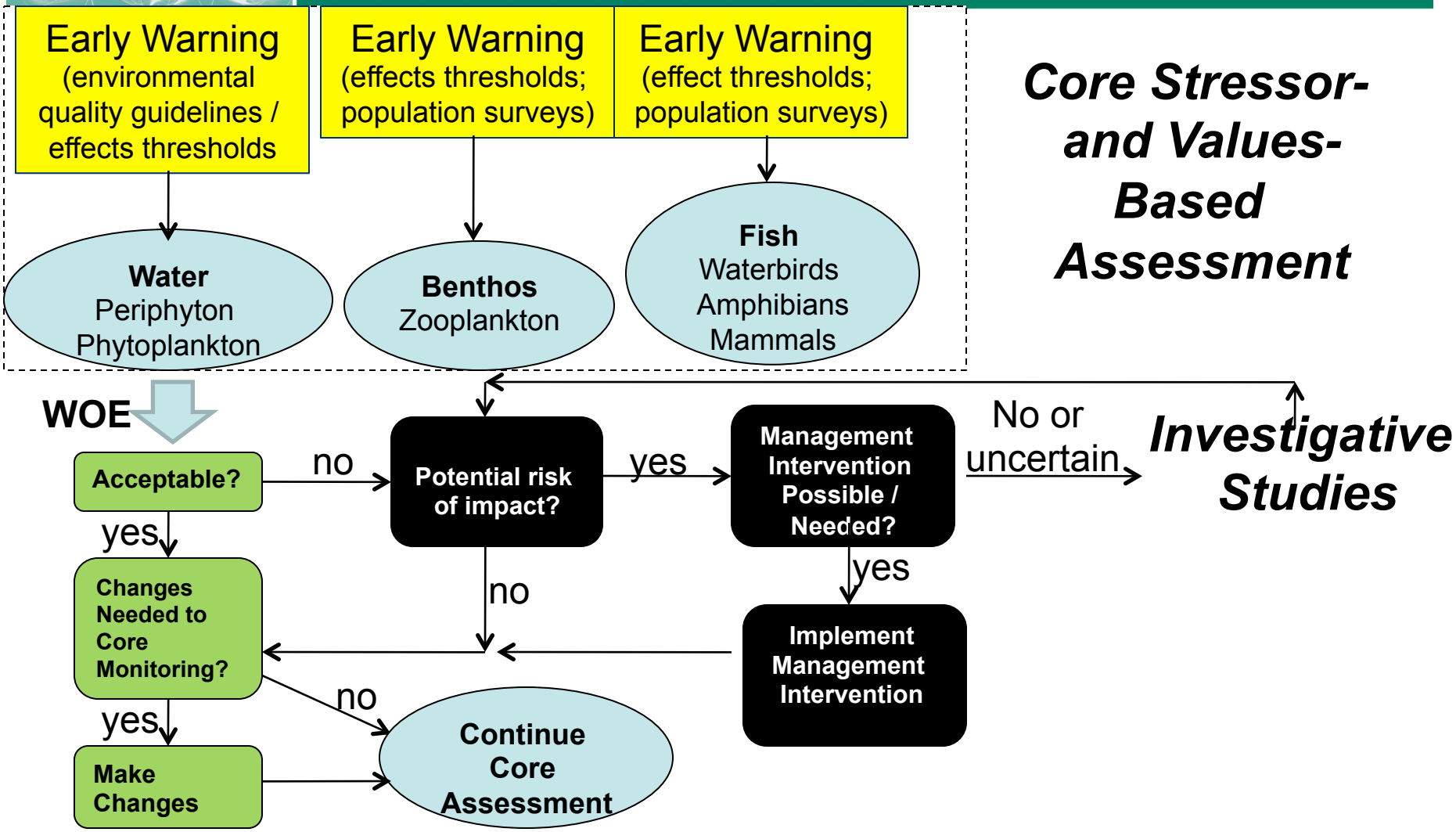
Example Integrative Assessment Framework



WOE = weight of evidence

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Effectiveness of management and restoration need to be assessed

US Natl Res Council Dredging Review

National Research Council. 2007. Sediment Dredging at Superfund Megasites: Assessing the Effectiveness. National Academies Press, Washington, DC, USA

- **Characterize** pre-remedial trends
- **Compare** post-remediation
- **Sufficient time-scale** to capture recovery
- Ensure proper **reference sites**

- Is dredging alone capable of long-term risk reduction?
  - Not determined; **assessment generally not adequate**; dredging used with other remedies
- Is dredging itself harmful?
  - Yes, can have short-term acute effects if inadequate containment methods (resuspension, contaminant release)
- **Environmental assessment is an essential part of <u>any</u> remedy** - necessary to establish success, not an extra "add-on" activity

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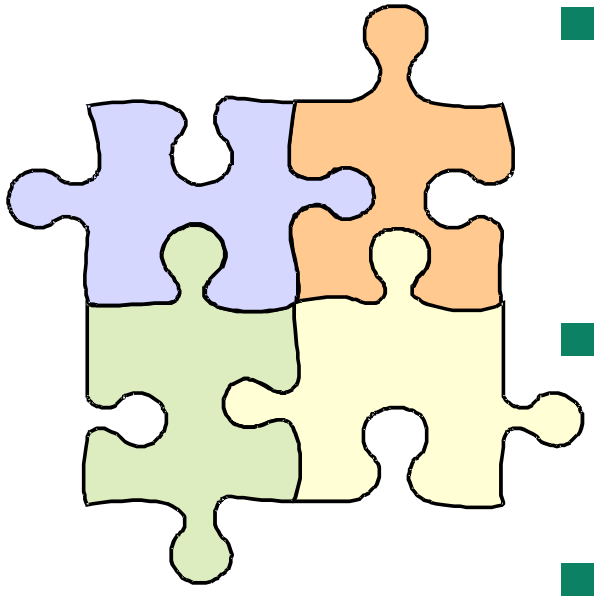
Post-remedy Assessment

Confirmatory assessment to ensure that remedial objectives have been met during and immediately following implementation of management and restoration

Long-term assessment to verify that remedial objectives will be met for the foreseeable future; monitoring is terminated when this has been verified

Final Comments



- Coastal lagoons are shaped by a very large and changing set of environmental conditions, <u>including</u> anthropogenic stressors
- Assessment is site- and context-dependent, and will vary in response to question(s) to be answered
- Focus is on protecting ecosystems – integrative - not individuals (except for humans and endangered/particularly valued species) by:
  - Understanding those ecosystems
  - Preserving ecosystem services

And… Don't rely on indices!

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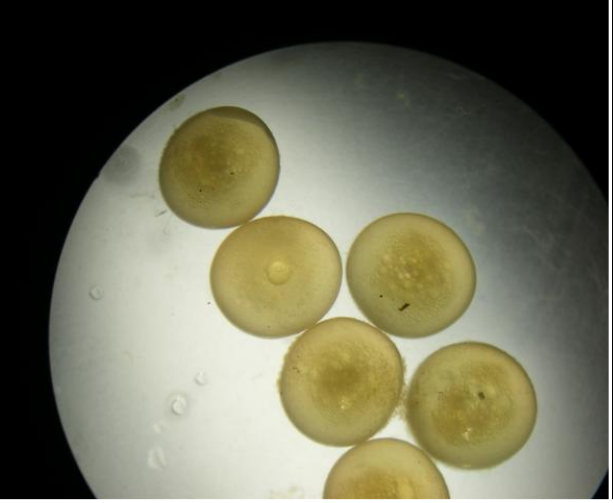
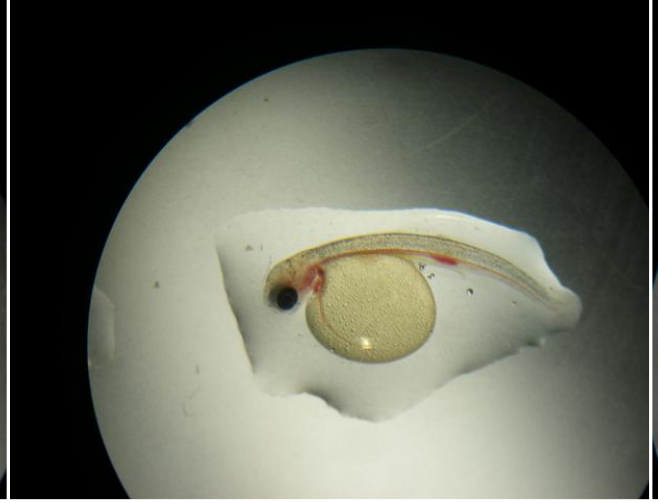

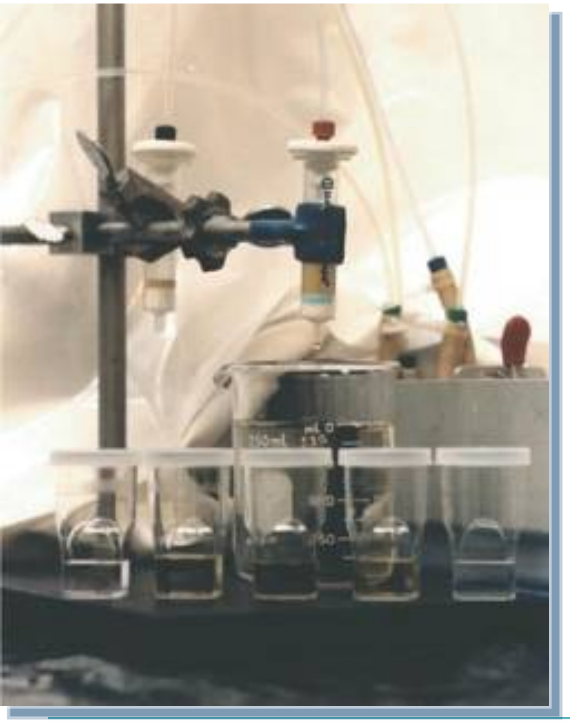

Thank you for Listening!

Questions / Discussion?

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