General outline for course

- Describe EPA’s approach to causal assessment
  - Introduction to philosophical foundations of causation
  - Step-by-step walk through Stressor Identification process

- Introduction to the Causal Analysis/Diagnosis Decision Information System
Causal assessment, Stressor Identification & CADDIS

- **Causal assessment**
  - Process to determine likely cause of an observed effect

- **Stressor Identification (SI)**
  - Method for determining most likely cause of observed biological impairments in aquatic systems

- **CADDIS**
  - Causal Analysis/Diagnosis Decision Information System
  - Website that provides information, methodology and tools to help users implement SI and conduct causal assessments of biological impairment
Three tiers of causal assessment

• **General** – Can C cause E?
  – Can smoking cause lung cancer?
  – Can Chemical Z cause fish lesions?

• **Contextual** – Under what conditions can C cause E?
  – Does smoking cause lung cancer when certain genetic factors are also present?
  – Does Chemical Z cause fish lesions only when it exceeds a particular concentration?

• **Specific** – Did C cause E in this case?
  – Did smoking cause lung cancer in Ronald Fisher?
  – Did Chemical Z cause fish lesions in my stream?
Why is specific causation important?

- Biological assessments are commonly used to identify if streams are impaired.
- In many cases, causes of impairment are unknown.
- To fix the problem, you have to know what to fix.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Impairment Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pathogens</td>
</tr>
<tr>
<td>2</td>
<td>Metals (other than Hg)</td>
</tr>
<tr>
<td>3</td>
<td>Nutrients</td>
</tr>
<tr>
<td>9</td>
<td>Cause unknown</td>
</tr>
<tr>
<td>14</td>
<td>Cause unknown: impaired biota</td>
</tr>
<tr>
<td>29</td>
<td>Cause unknown: fish kills</td>
</tr>
</tbody>
</table>
The Exercise River
Why use a formal method?

Because we make mistakes about causality...

- We form initial impressions quickly, based on readily available information. This can result in:
  
  **Overweighting chance events**
  - Every time I wash my car it rains.

  **Having biases**
  - All pollution is caused by industry.

  **Being “educationally” predisposed**
  - Hydrologists think hydrology.

  **Relying on intuition and past experience**
  - I have a hunch that it’s nitrogen. Last time I saw this, it was nitrogen.
Why use a formal method?

Because we make mistakes about causality...

• We gather information that supports our initial impression.  

  **HYPOTHESIS TENACITY**

• We confidently reach conclusions based on incomplete information.  

  **WYSIATI**

  “what you see is all there is”

“Science is a way of trying not to fool yourself. The first principle is that you must not fool yourself – and you are the easiest person to fool.” [Feynman 1964]
Establishing causation

- Causation is one of the most difficult and controversial concepts in philosophy.
- A **randomized, replicated, controlled** experiment is the **ONLY** reliable method for establishing causation...
- ...but environmental studies rarely randomize, replicate, or control exposures.
Our causal assessment approach

THE GOOD...

• Provides formal method that allows defensible & transparent evaluation
• Identifies causal relationships that may not be immediately apparent
• Minimizes biases and other lapses of logic
• Helps identify all available evidence
• Increases confidence that remedial or restoration effects can improve biological condition
Our causal assessment approach

...THE BAD...

• Conducting causal assessments is not necessarily easy or straightforward.

• Mechanisms driving biological impacts can be complex.

• The method relies on data – quantity and quality matter.

• Ultimately, a "smoking fish" may not be found, or multiple stressors may remain as likely causes.
Our causal assessment approach

...AND BACK TO THE GOOD

• Even when one likely cause is not identified, a causal assessment can narrow the universe of possible causes and point to promising data and analyses.

1. Low dissolved oxygen
2. Gill damage
3. Nitrate exposure
4. Infections
5. High pH
6. pH fluctuations
7. Ammonia toxicity
8. Other, unspecified toxic substances
9. Inadequate food resources
What triggers a causal assessment?

- Detection of a biological impairment, with no obvious or readily apparent cause
  - Fish kills
  - Organismal anomalies
  - Community structure changes
  - Low biotic index values
  - Violation of biocriteria
Before initiating a causal assessment...

• Verify the biological effects
  – Is there anecdotal information?
  – Was the appropriate reference/comparison site used?
  – Were the appropriate statistics used?

• Verify that there is no identified or apparent cause
  – Usual suspects may not be present.
  – May be lots going on in watershed, but not clear which factors are contributing, to what degree.
  – Others may need to be convinced of cause.
That brings us to Stressor Identification...

**Stressor Identification**

- Define the Case
- List Candidate Causes
- Evaluate Data from the Case
- Evaluate Data from Elsewhere
- Identify Probable Cause

**Management Action:**
Eliminate or Control Sources, Monitor Results

**Biological Condition Restored or Protected**

**Decision-maker and Stakeholder Involvement**

**As Necessary:**
Acquire Data and Iterate Process
Step 1 – Define the case

- Detect or Suspect Biological Impairment

  Stressor Identification
  
  Define the Case
  
  List Candidate Causes
  
  Evaluate Data from the Case
  
  Evaluate Data from Elsewhere
  
  Identify Probable Cause

- Decision-maker and Stakeholder Involvement

- Identify and Apportion Sources

- Management Action: Eliminate or Control Sources, Monitor Results

- Biological Condition Restored or Protected

- As Necessary: Acquire Data and Iterate Process

  • What specific biological effects were observed?
  • Where and when did they occur?
  • Where are the effects absent or different (i.e., where are comparison sites located)?
### Step 1 – Define the case

- **Describe the undesirable biological effect**
  - Describe biological measure(s) that triggered causal assessment (i.e., the impairment)

- **Specify the effects of interest**
  - May be the same as the impairment, but better if more specific

<table>
<thead>
<tr>
<th>SPECIFICITY</th>
<th>EXAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>coarse</td>
<td>failure to meet biological criteria</td>
</tr>
<tr>
<td></td>
<td>↓ sensitive taxa</td>
</tr>
<tr>
<td></td>
<td>↓ EPT taxa</td>
</tr>
<tr>
<td>specific</td>
<td>↓ <em>Paraleptophlebia</em></td>
</tr>
<tr>
<td></td>
<td>absence of brook trout</td>
</tr>
</tbody>
</table>
Step 1 – Define the case

- Establish the spatial and temporal frames
  - Where were effects observed?
  - When were effects observed?
  - Again, be as specific as possible

March–May 2006
Acute phase noted by sudden death (mid-March)
Chronic phase noted by lesions preceding death (March–May)

smallmouth bass
redbreast sunfish
Step 1 – Define the case

• Establish comparison sites
  – Comparison sites may:
    o Lack the effect
    o Lack a particular source or stressor
    o Have well-characterized sources, stressors, or effects
  – Comparison ≠ reference
    o Comparison sites need not be highest quality
  – Usually identified using best professional judgment, but this is area of active research to find better ways

• Consider the management context and any other constraints
Case study – Pretend Creek

- Watershed land use: 5% urban, 20% agriculture
- % Sand & fines: 30%
- % Canopy cover: 20%
- NH$_3$-N: 0.9 mg/L

Photo by Eric Vance
Pretend Creek’s causal assessment trigger?

May 2012
macroinvertebrate IBI = 22

PC1

Pretend Creek

PC2

Nearby Creek

NC1

NC2
Defining the case at Pretend Creek

May 2010
macroinvertebrate IBI = 60

May 2012
macroinvertebrate IBI = 22

May 2012
macroinvertebrate IBI > 64

May 2010
macroinvertebrate IBI = 60
Defining the case at Pretend Creek

18 EPT genera
brook trout

8 EPT genera
no brook trout
Step 2 – List candidate causes

- Generate an initial list
- Gather information on potential sources, stressors, and exposures
- Develop conceptual diagram
- Develop the “final” list

Detect or Suspect Biological Impairment

Stressor Identification

- Define the Case
- List Candidate Causes
- Evaluate Data from the Case
- Evaluate Data from Elsewhere
- Identify Probable Cause
- Identify and Apportion Sources
- Management Action: Eliminate or Control Sources, Monitor Results
- Biological Condition Restored or Protected

Decision-maker and Stakeholder Involvement

As Necessary: Acquire Data and Iterate Process
Step 2 – List candidate causes

• Generate the initial list of candidate causes
  – Hypothesized causes of effect(s)
  – Sufficiently credible to be analyzed
  – Focus on proximate stressor (stressor directly contacting or co-occurring with organisms)
  – Causes may include sources, mechanisms of action, or several causes acting together
  – In developing list, use:
    o Observations and available data from site
    o Information on known or potential sources
    o Existing knowledge from site, region, and elsewhere
    o Stakeholder input
## Common aquatic stressors

<table>
<thead>
<tr>
<th><strong>CHEMICAL</strong></th>
<th><strong>PHYSICAL</strong></th>
<th><strong>BIOLOGICAL</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissolved oxygen</td>
<td>Water temperature</td>
<td>Interspecies competition</td>
</tr>
<tr>
<td>Herbicides</td>
<td>Bed sediment load</td>
<td>Invasive species</td>
</tr>
<tr>
<td>Pesticides</td>
<td>Habitat destruction</td>
<td>Overharvesting</td>
</tr>
<tr>
<td>Persistent toxic</td>
<td>Habitat fragmentation</td>
<td>Pathogens and parasites</td>
</tr>
<tr>
<td>substances (e.g.,</td>
<td>Hydrologic alteration</td>
<td>Predation</td>
</tr>
<tr>
<td>PCBs, PAHs)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endocrine disruptors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nutrients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspended solids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salinity</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Step 2 – List candidate causes

• Make a map
  – Potential pollution sources (point, non-point)
  – Other factors that may affect candidate causes

• Make a conceptual diagram
  – Diagram showing hypothesized cause-effect linkages among sources, stressors, and biological effects
  – Used for:
    o Brainstorming
    o Analysis framework
    o Communication tool
Advice for developing a conceptual diagram

- Think about causal pathways.
  - How do sources lead to stressors?
  - How do stressors lead to biological effects?

- Be as specific as possible.
  - You do not need data for every component in your diagram.
  - Try to identify potential data sources and types of evidence.
  - Think about general vs. specific impairments.

- Be thorough and inclusive.
  - You can always eliminate things later one, so do not want to limit initial brainstorming and potentially miss something important.
Pilfer from CADDIS!

CADDIS Volume 2: Sources, Stressors & Responses

Deciding which pathways to consider in a causal assessment—that is, listing candidate causes as described in Step 2 of the assessment process—sets the framework for causal assessment. This section of CADDIS provides background information on stressor sources, stressors, and responses for use in deciding which candidate causes to consider, as well as developing cases for or against those candidate causes in the actual assessment.

Each stressor module is organized into five sections, or tabs:

- **Introduction** provides a summary overview of the stressor, including a checklist of evidence that suggests including a given stressor in your assessment (i.e., listing it as a candidate cause).
- **When to List** provides more detailed information on the sources, activities, site evidence, and biological responses that suggest inclusion as a candidate cause.
- **Ways to Measure** details different methods for quantifying the stressor.
- **Conceptual Diagrams** illustrates hypothesized causal linkages among the stressor, its sources, and associated biotic responses.
- **References** lists the references cited throughout the module.

In addition, some stressor modules have a **Literature Reviews** tab, which presents an annotated bibliography of key references providing general background information, particularly regarding stressor-response relationships.

The source module for urbanization contains similar summary information on effects of urban development on stream ecosystems, but it is presented in a different format. The module is organized using a simple schematic of how urbanization affects streams. Users can click on any shape in the schematic to navigate through the module and focus on areas of interest; within each section (i.e., under each shape) the user can click on additional topic boxes for more detailed information.

<table>
<thead>
<tr>
<th>Ammonia</th>
<th>Dissolved Oxygen</th>
<th>Insecticides</th>
<th>pH</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Alteration</td>
<td>Herbicides</td>
<td>Ionic Strength</td>
<td>Physical Habitat</td>
<td>Unspecified Toxic Chemicals</td>
</tr>
<tr>
<td>Metals</td>
<td>Nutrients</td>
<td>Sediments</td>
<td>Urbanization</td>
<td></td>
</tr>
</tbody>
</table>
Listing candidate causes at Pretend Creek

- forest
- PC1
- dairy farm
- subdivision
- Pretend Springs
- city limit
- NC1
- NC2
- unimpaired site
- impaired site
- WWTP
- industrial facility
- dam
The Exercise River
The Exercise River – Defining the case

- Dark Creek
- Stony Creek
- Muddy Creek
- Bobwhite Creek
- Unnamed tributary
- Anthony’s Reservoir
- Site U
- Site A
- Site B
- Site C

282 km

upstream
downstream
The Exercise River – Defining the case

Schematic of Sources

Site U
- POTW
- Dry Creek

Site A
- Muddy Creek

Site B
- Bobwhite Creek
- Storm drain

Site C

Legend:
- Red: Urban
- Yellow: Channel Maintenance
- Gray: Industrial/Residential
- Green: Agriculture
- Blue: Tributary

85 km
### The Exercise River – Defining the case

#### Invertebrate Index Scores

<table>
<thead>
<tr>
<th></th>
<th>REG. REF.</th>
<th>U</th>
<th>C</th>
<th>C</th>
<th>B</th>
<th>A</th>
</tr>
</thead>
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<tr>
<td>Program</td>
<td>Feds</td>
<td>Feds</td>
<td>State</td>
<td>Feds</td>
<td>Feds</td>
<td>State</td>
</tr>
<tr>
<td>Index Score</td>
<td>34</td>
<td>30</td>
<td>29</td>
<td>24</td>
<td>19</td>
<td>14</td>
</tr>
<tr>
<td>Sampling Date</td>
<td>14 May</td>
<td>26 May</td>
<td>6 Jun</td>
<td>25 May</td>
<td>26 May</td>
<td>6 Jun</td>
</tr>
</tbody>
</table>
The Exercise River – Defining the case

• What are the affected sites?
  – Site A, Site B

• What are the comparison sites?
  – Site U (upstream reference)
  – Site C
  – Out-of-basin reference

• What specifically changed (biologically)?
  – ANSWER?
The Exercise River – Defining the case
## The Exercise River – Defining the case

<table>
<thead>
<tr>
<th>Count (RA%)</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>C</th>
<th>U</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>State</td>
<td>Feds</td>
<td>Feds</td>
<td>State</td>
<td>Feds</td>
<td>Feds</td>
</tr>
<tr>
<td>Chironomidae</td>
<td>178 (36%)</td>
<td>312 (63%)</td>
<td>262 (52%)</td>
<td>22 (37%)</td>
<td>134 (38%)</td>
<td>51 (10%)</td>
</tr>
<tr>
<td>Oligochaeta</td>
<td>246 (49%)</td>
<td>168 (34%)</td>
<td>21 (4%)</td>
<td>3 (5%)</td>
<td>12 (3%)</td>
<td>21 (4%)</td>
</tr>
<tr>
<td>Tricorythodes</td>
<td>2 (&lt;1%)</td>
<td>3 (1%)</td>
<td>61 (12%)</td>
<td>7 (12%)</td>
<td>68 (19%)</td>
<td>217 (43%)</td>
</tr>
<tr>
<td>Centroptilum</td>
<td>29 (6%)</td>
<td>7 (1%)</td>
<td>136 (27%)</td>
<td>11 (19%)</td>
<td>32 (9%)</td>
<td>12 (2%)</td>
</tr>
<tr>
<td>Acentrella</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>1 (2%)</td>
<td>63 (18%)</td>
<td>11 (2%)</td>
</tr>
<tr>
<td>Hydropsyche</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>2 (1%)</td>
<td>70 (14%)</td>
</tr>
<tr>
<td>Total Count</td>
<td>497</td>
<td>498</td>
<td>500</td>
<td>59</td>
<td>356</td>
<td>500</td>
</tr>
</tbody>
</table>
The Exercise River – Listing candidate causes

1. Increased sediments
2. Increased ionic strength
3. Increased pesticides
4. Decreased dissolved oxygen
5. Increased metals
6. Nutrient enrichment and toxicity
7. Flow alteration
8. Physical habitat alteration
Steps 3 & 4 – Evaluating the data

Detect or Suspect Biological Impairment

Stressor Identification

- Define the Case
- List Candidate Causes
- Evaluate Data from the Case
- Evaluate Data from Elsewhere
- Identify Probable Cause

As Necessary: Acquire Data and Iterate Process

Decision-maker and Stakeholder Involvement

Identify and Apportion Sources

Management Action:
Eliminate or Control Sources, Monitor Results

Biological Condition Restored or Protected

DATA

EVIDENCE
Let’s talk about evidence...

• What is evidence?
  
  – Available information that indicates whether belief or proposition is valid.
  
  – If Cause X produced Effect Y, then we would expect to observe Result Z.
  
  – Information used to determine whether we actually observe Result Z is a piece of evidence.
  
  – Individual pieces of evidence are combined into the overall body of evidence.
An example

- **IF** effluent from a WWTP discharge caused the observed effect on macroinvertebrates, **THEN** we would **expect** that this effect would have occurred only after effluent was first discharged.

- Data showing when WWTP began discharging, relative to when effect was observed, are a **piece of evidence**.
  - Evidence **supports** argument for effluent as cause if effect was observed after, but not before, discharge began.
  - Evidence **weakens** the argument for effluent as cause if effect was observed both before and after discharge began.
What are our expectations based on?

- Causal relationships exhibit certain fundamental characteristics:
  - Time order
  - Co-occurrence, interaction, sufficiency
  - Alteration
  - Antecedence
## Causal characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
<th>Expect To Observe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Co-occurrence</strong></td>
<td>The cause co-occurs with the susceptible entity in space and time.</td>
<td>The presence of both the cause and the effect and the potential for exposure.</td>
</tr>
<tr>
<td><strong>Sufficiency</strong></td>
<td>The intensity, frequency, and duration of the cause are adequate, and the entity is sufficiently susceptible to produce the type and magnitude of the effect.</td>
<td>Enough of the cause and a sufficiently susceptible entity that can result in the level of the observed effect.</td>
</tr>
<tr>
<td><strong>Time order</strong></td>
<td>The cause precedes the effect.</td>
<td>Change in the entity after interaction with the cause and not before.</td>
</tr>
<tr>
<td><strong>Interaction</strong></td>
<td>The cause interacts with the entity in a way that can induce the effect.</td>
<td>Signs of initiation of the change by the causal agent such as contact or uptake.</td>
</tr>
<tr>
<td><strong>Alteration</strong></td>
<td>The entity is altered by interacting with the cause.</td>
<td>Changes in the entity attributable to or at least appropriate to the cause.</td>
</tr>
<tr>
<td><strong>Antecedence</strong></td>
<td>The causal relationship is a result of a larger web of antecedent cause-and-effect relationships.</td>
<td>Earlier events that led to the particular causal event.</td>
</tr>
</tbody>
</table>
Where does evidence come from?

<table>
<thead>
<tr>
<th>Source of Samples</th>
<th>Type of Investigation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Field observations</td>
</tr>
<tr>
<td>From the case under investigation</td>
<td></td>
</tr>
<tr>
<td>From other cases</td>
<td></td>
</tr>
</tbody>
</table>

No piece of evidence is perfect – so want to develop as many pieces of evidence as possible.
“From the case” vs. “from elsewhere”

- **“From the case”** = data collected from affected location and nearby comparison sites
  - Most relevant evidence
  - Best chance of isolating causal processes, minimizing confounding factors

- **“From elsewhere”** = data collected from other field locations, the laboratory, or process models
  - Compare data from the case to data from elsewhere to derive pieces of evidence
## Types of evidence in CADDIS

### Data from the case
- *Spatial/temporal co-occurrence*
- Evidence of exposure or biological mechanism
- *Causal pathway*
- *Stressor-response relationships from the field*
- Manipulation of exposure
- Laboratory tests of site media
- Temporal sequence
- Verified predictions
- Symptoms

### Data from elsewhere
- *Stressor-response relationships from other field studies*
- *Stressor-response relationships from laboratory studies*
- Stressor-response relationships from ecological simulation models
- Mechanistically plausible cause
- Manipulation of exposure at other sites
- Verified predictions
- Analogous stressors

*italics* indicates commonly available types of evidence
Step 3 – Evaluating data from the case

- Co-occurrence
- Stressor-response associations from field
- Causal pathway
- Lab tests of site media

- Exposure or mechanism
- Manipulation
- Temporal sequence
- Verified predictions
- Symptoms
Spatial / temporal co-occurrence

**SUPPORTS**
Impairment occurs where or when exposure to stressor occurs

**WEAKENS**
Impairment does not occur where or when exposure to stressor decreases
Example plots

**dot plots**

- Dissolved Oxygen (mg/L)
  - Comp
  - Subj

- Conductivity (uS/cm)
  - Comp
  - Subj

**q-q plots**

- Subject DO (mg/l) vs. Comparator DO (mg/l)

**mean difference plots**

- Subject conductivity (uS/cm) vs. Comparator conductivity (uS/cm)
  - Mean difference plots

*Example plots*
Issues and recommendations

• Only use measures of proximate stressor
  – Other measures considered under “Causal pathway” evidence

• Simple comparison – is exposure to proximate stressor greater where/when effect occurs?

• Don’t consider whether magnitude is sufficient
  – Sufficiency considered under other types of evidence (e.g., “Stressor-response relationships from elsewhere” evidence)

• Consider uncertainty and variability, but do not rely on statistical tests
Why no hypothesis tests?

**SCENARIO 1**
- DO measured upstream & downstream over 9 months
  - Upstream mean = 9.3 mg/L
  - Downstream mean = 8.4 mg/L
- Difference significant at P<0.05

**SCENARIO 2**
- DO measured upstream & downstream over 3 months
  - Upstream mean = 7.9 mg/L
  - Downstream mean = 4.2 mg/L
- Difference not significant at P<0.05

Which scenario presents a stronger case for DO causing impairment?
Use caution in interpreting differences

- Look at **magnitude** and **consistency** of differences, rather than statistical significance.

- Statistical significance detects differences exceeding natural variance:
  - Does not detect stressor effects.
  - Does not equal biological significance.
  - Small $n = $ limited power to detect differences.

- Can use statistics, but also use your head:
  - Think about relationship between minimum detectable difference (power) and biologically relevant difference.
Stressor-response from the field

**SUPPORTS**
Impairment decreases as exposure to stressor decreases

**WEAKENS**
Impairment increases as exposure to stressor decreases
Example plots

**SUPPORT**

- EPT Richness vs. Conductivity (uS/cm)
  
- % Non-insects vs. Conductivity (uS/cm)
  
- HBI vs. Conductivity (uS/cm)

**WEAKEN**

- EPT Richness vs. Nitrate + nitrite (mg/l)
  
- % Non-insects vs. Nitrate + nitrite (mg/l)
  
- HBI vs. Nitrate + nitrite (mg/l)
Interpreting correlations

- Correlations and slopes quantify degree of association between stressor and response in group of sites – but say nothing about where observations from impaired site fall within that relationship.

- Only evaluate S-R from field for stressors with supporting evidence for co-occurrence.

- Visually confirm that association supports case by identifying impaired and comparison sites on scatterplots.
Causal pathway

**SUPPORTS**
Steps in causal pathway observed and coincide with impairment

**WEAKENS**
Steps in causal pathway not observed or do not coincide with impairment
Issues and recommendations

• Causal pathway similar to spatial/temporal co-occurrence, but uses data from entire causal chain

• When in doubt, assume a step exists

• Evidence of a missing step is powerful; evidence of many intermediate steps increases confidence

• May be able to eliminate one pathway, but rarely can eliminate all pathways
Step 4 – Evaluating data from elsewhere

- Spatial co-occurrence compared with regional reference sites
- Stressor-response relationships from lab, other field studies, or ecosystem models
- Mechanistically plausible cause
- Manipulation
- Temporal sequence
- Verified predictions
- Symptoms

Detect or Suspect Biological Impairment

Stressor Identification
- Define the Case
- List Candidate Causes
- Evaluate Data from the Case
- Identify Probable Cause

Evaluate Data from Elsewhere

As Necessary: Acquire Data and Iterate Process

Identify and Apportion Sources

Management Action: Eliminate or Control Sources, Monitor Results

Biological Condition Restored or Protected
Extrapolating “from elsewhere” to your site

Use care when extrapolating from test systems → your system!

OTHER FIELD STUDIES
- taxa differ (EPT ≠ EPT)
- co-varying stressors
- confounding factors

LAB STUDIES
- different test organisms
- single-stressor exposures
- not representative of field conditions
- no biotic interactions
- criteria often protective, not effects-based
Spatial co-occurrence and regional reference sites

Coal Fork (tributary): biological impairment co-occurs with low pH, supports case that pH is causal factor

“Normal” pH range (from state-wide database)

pH in Clear Fork, West Virginia and its tributaries

KC47 Clear Fork subwatershed

Downstream ← Upstream
Stressor-response relationships from lab studies
Species Sensitivity Distributions (SSDs)

- Represent relative sensitivities of organisms to stressor of interest
- Basis for US National Ambient Water Quality Criteria
- Can be used in many ways (e.g., to predict taxa richness declines expected at impaired site)

Each point is LC$_{50}$ for that species.
Species Sensitivity Distributions (SSDs)

- Constructed in 3-step process
  - List stressor-effect levels (e.g., LC50s, LOELs)
  - Order from lowest to highest exposure
  - Plot and fit a curve or interpolate

- Download the SSD generator from CADDIS
  - Calculates and plots proportion of species affected at different exposure levels in lab toxicity tests
Stressor-response relationships from other field studies
Stressor-response relationships from other field studies

West Virginia Ecoregion 69
pH > 5.5  R² = 0.42

Conductivity

EPT genera

Reference  Clear Fork  Other Eco 69
Issues and recommendations

• Beware interpretation of parameter estimates when multiple stressors co-vary

• Some treatment of confounding factors is usually necessary
  – Bundle stressors using PCA
  – Trimming
  – Stratification
  – Propensity scores
The Exercise River – List of candidate causes

1. Increased sediments
2. Increased ionic strength
3. Increased pesticides
4. Decreased dissolved oxygen
5. Increased metals
6. Nutrient enrichment and toxicity
7. Flow alteration
8. Physical habitat alteration
The Exercise River – Evaluating data

- To which candidate cause are the data relevant?
- How do NTU compare between comparison and impaired sites?
- Does this evidence support or weaken the case for the relevant candidate cause?
- How would you judge the quality of this piece of evidence?

Based on state monthly water quality sampling (grab samples, Jan-June 2006)
The Exercise River – Evaluating data

• To which candidate cause are the following data relevant?

• How do maximum concentrations at Sites A and B compare to the SSD?

• Does this evidence support or weaken the case for the relevant candidate cause?

• How would you judge the quality of this piece of evidence?
The Exercise River – Evaluating data

Data source: ECOTOX
Taxa type: Invertebrates

Chlorpyrifos

Observed max concentration 2006 at Sites A and B (0.001 μg/L)
Observed concentration range in Example River (previous years)

DRAFT
Step 5 – Identify probable cause

- Weigh the evidence for each cause
  - Eliminate if possible
  - Diagnose if possible
- Compare evidence across all causes
Step 5 – Identify probable cause

- Weigh each piece of evidence using a scoring system
- Weigh body of evidence for each candidate cause
- Compare evidence across candidate causes
- Identify candidate cause(s) that are best supported by available evidence
- Identify candidate cause(s) that are not supported by available evidence
The CADDIS scoring system

+++ convincingly supports (or weakens - - -)
++ strongly supports (or weakens - -)
+ somewhat supports (or weakens -)
0 neither supports nor weakens
R refutes
D diagnoses
NE no evidence
General principles for scoring evidence

- First $+ \text{ or } - \text{ or } 0$
  - Based on logical implication of evidence that passes basic quality and relevance test

- Second $+ \text{ or } -$
  - Based on strength of association (e.g., large differences)

- Third $+ \text{ or } -$
  - Based on reliability of association (e.g., high sample sizes, excellent study design, control of confounders)

- Each type of evidence has strengths and weaknesses, which are reflected in the CADDIS scoring system
### Example of evidence scoring table

#### Summary Table of Scores

<table>
<thead>
<tr>
<th>Type of Evidence</th>
<th>Finding</th>
<th>Interpretation</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Types of Evidence that Use Data from the Case</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Spatial/Temporal Co-occurrence</strong></td>
<td>The effect occurs where or when the candidate cause occurs, <strong>OR</strong> the effect does not occur where or when the candidate cause does not occur.</td>
<td>This finding <em>somewhat supports</em> the case for the candidate cause, but is not strongly supportive because the association could be coincidental.</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>It is uncertain whether the candidate cause and the effect co-occur.</td>
<td>This finding <em>neither supports nor weakens</em> the case for the candidate cause, because the evidence is ambiguous.</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>The effect does not occur where or when the candidate cause occurs, <strong>OR</strong> the effect occurs where or when the candidate cause does not occur.</td>
<td>This finding <em>convincingly weakens</em> the case for the candidate cause, because causes must co-occur with their effects.</td>
<td>- - -</td>
</tr>
<tr>
<td></td>
<td>The effect does not occur where and when the candidate cause occurs, <strong>OR</strong> the effect occurs where or when the candidate cause does not occur, and the evidence is indisputable.</td>
<td>This finding <em>refutes</em> the case for the candidate cause, because causes must co-occur with their effects.</td>
<td>R</td>
</tr>
</tbody>
</table>
### Scoring the evidence for all candidate causes

#### Scoring summary table

<table>
<thead>
<tr>
<th>Types of Evidence that Use Data from the Case</th>
<th>Metals</th>
<th>NH₃</th>
<th>Flow</th>
<th>Silt</th>
<th>Low DO</th>
<th>Temp</th>
<th>Food</th>
<th>Episodic Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial/Temporal Co-Occurrence</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>- - -</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Evidence of Biological Mechanism</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Causal Pathway</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Stressor-Response from the Field</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manipulation of Exposure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+ + +</td>
</tr>
<tr>
<td>Verified Predictions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+ + +</td>
</tr>
</tbody>
</table>

#### Types of Evidence that Use Data from Elsewhere

<table>
<thead>
<tr>
<th>Types of Evidence that Use Data from Elsewhere</th>
<th>Metals</th>
<th>NH₃</th>
<th>Flow</th>
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<th>Low DO</th>
<th>Temp</th>
<th>Food</th>
<th>Episodic Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stressor-Response from Other Field</td>
<td>- -</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stressor-Response from Laboratory</td>
<td>+ +</td>
<td>-</td>
<td></td>
<td></td>
<td>-</td>
<td>+</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Weighing the evidence

- Weigh the body of evidence for each candidate cause
  - Evaluate quantity and quality of evidence
  - Identify compelling evidence
  - Evaluate consistency and credibility of evidence

<table>
<thead>
<tr>
<th>Consistency of Evidence</th>
<th>Description</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>All available types of evidence support the case for the candidate cause.</td>
<td>+ + +</td>
<td></td>
</tr>
<tr>
<td>All available types of evidence weaken the case for the candidate cause.</td>
<td>- - -</td>
<td></td>
</tr>
<tr>
<td>All available types of evidence support the case for the candidate cause, but few types are available.</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>All available types of evidence weaken the case for the candidate cause, but few types are available.</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>The evidence is ambiguous or inadequate.</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Some available types of evidence support and some weaken the case for the candidate cause.</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
# Scoring Summary Table

<table>
<thead>
<tr>
<th>Types of Evidence that Use Data from the Case</th>
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<th>Flow</th>
<th>Silt</th>
<th>Low DO</th>
<th>Temp</th>
<th>Food</th>
<th>Episodic Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial/Temporal Co-Occurrence</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Evidence of Biological Mechanism</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Causal Pathway</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Stressor-Response from the Field</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manipulation of Exposure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+ + +</td>
</tr>
<tr>
<td>Verified Predictions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+ + +</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Types of Evidence that Use Data from Elsewhere</th>
<th>Stressor-Response from Other Field</th>
<th>Stressor-Response from Laboratory</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- -</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Evaluating Multiple Types of Evidence</th>
<th>Metals</th>
<th>NH₃</th>
<th>Flow</th>
<th>Silt</th>
<th>Low DO</th>
<th>Temp</th>
<th>Food</th>
<th>Episodic Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consistency of Evidence</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+ + +</td>
</tr>
</tbody>
</table>
Comparing evidence and forming conclusions

• Compare the evidence across candidate causes, even when there is a “smoking gun”
  – Determine if there is more than one likely cause
  – Determine your level of confidence in the results

• Identify cause(s) best supported by the evidence

• Classify causes (e.g., likely, unlikely, uncertain)

• Refine your hypotheses
  – Consider multiple causes
  – Revisit conceptual diagrams
The Exercise River – Scoring evidence and forming conclusions

- Using the scoring table on the following slide
  - Score each candidate cause for consistency
  - Determine which candidate causes are likely contributors, unlikely contributors, and which are too uncertain to call
### The Exercise River – Scoring evidence and forming conclusions

#### Site A compared with Site C

<table>
<thead>
<tr>
<th></th>
<th>Decreased DO</th>
<th>Increased Pesticides</th>
<th>Metals</th>
<th>Increased Nutrients</th>
<th>Increased Ionic Strength</th>
<th>Increased Sediment (Bed)</th>
<th>Increased Sediment (Susp)</th>
<th>Altered Flow Regime</th>
<th>Altered Physical Habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spatial/Temporal Co-Occurrence</strong></td>
<td>-</td>
<td>NE</td>
<td>NE</td>
<td>+</td>
<td>***</td>
<td>***</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Causal Pathway</strong></td>
<td>0</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>+</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td><strong>Stressor-Response from the Field</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>++</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Laboratory Test of Site Media</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Temporal Sequence</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

#### Types of Evidence that Use Data from the Case

- **Spatial/Temporal Co-Occurrence**
- **Causal Pathway**
- **Stressor-Response from the Field**
- **Laboratory Test of Site Media**
- **Temporal Sequence**

#### Types of Evidence that Use Data from Elsewhere

- **Stressor-Response from Other Field Studies**
- **Stressor-Response from Laboratory**

#### Evaluating Multiple Types of Evidence

- **Consistency of Evidence**
What comes after the causal assessment?

Causal assessments are typically conducted in a sequence of assessments:

1. Is there a problem?
2. What is the cause?
3. What is the best course of action?
4. Did the action work?
5. Desired condition restored

- Assess biological condition
- Assess causes
- Assess options
- Implement option(s)
- Assess outcomes
The Kent Dam removal

Tuckerman and Zawiski 2007

- assess biological condition
- assess causes
- assess options
- implement option(s)
- assess outcomes
- desired condition restored

<table>
<thead>
<tr>
<th>Index</th>
<th>Fish</th>
<th>Dissolved Oxygen</th>
<th>Habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warm Water Criteria</td>
<td>40</td>
<td>4 (avg)</td>
<td>60</td>
</tr>
<tr>
<td>Pre- Remediation</td>
<td>28.0</td>
<td>0-3 (minimums)</td>
<td>51.0</td>
</tr>
<tr>
<td>Post-Remediation</td>
<td>44</td>
<td>5-7 (range)</td>
<td>79.5</td>
</tr>
</tbody>
</table>

Deoxygenated water (0 - 3 mg/L) due to algal and bacterial respiration and lack of re-aeration by mixing and turbulence.

- Decrease nutrient loads from waste water treatment plant
- Increase flows from upstream reservoir
- Remove dams
Causal assessment applied more broadly...

- **Candidate cause 1:** Low dissolved oxygen
- **Candidate cause 2:** Increased phosphorus
- **Candidate cause 3:** Increased peak flows

**Sources:**
- **Source 1:** Atmospheric deposition
- **Source 2:** Stormwater runoff
- **Source 3:** Sediment remobilization

**Biological impairment**
Vol 1: Stressor Identification
Vol 2: Sources, Stressors & Responses
Vol 3: Examples & Applications
Vol 4: Data Analysis
Vol 5: Causal Databases
Vol 1: Stressor Identification

- Step-by-Step Guide
- Causal Assessment Background
The first step of the Stressor Identification (SI) process is to define the subject of the analysis (i.e., the case), by determining the geographic scope of the investigation and the effects that will be analyzed. The case definition sets the foundation for the rest of the causal analysis: it influences the information that will be assembled, the causes that will be considered, and the way in which conclusions will be presented. For this reason, it is important to get input from managers and stakeholders at this early stage of the process.

Causal analysis is triggered by the observation of a biological effect, including:

- Kills of fish, invertebrates, plants, domestic animals, or wildlife;
- Anomalies in any life form, such as tumors, lesions, parasites, or disease;
- Changes in community structure, such as loss of species or shifts in species abundance (e.g., increased
Spatial/Temporal Co–occurrence

Concept

The biological effect must be observed where and when the cause is observed, and must not be observed where and when the cause is absent.

Additional illustrations

Examples

Consider increased suspended solid concentrations as a candidate cause of reduced aquatic invertebrate abundance. What findings support or weaken the case for increased suspended solids as the cause, based on spatial/temporal co-occurrence?

- Supporting evidence (spatial co-occurrence) – Suspended solid concentrations are higher at the impaired site(s) than at unimpaired reference sites.
- Supporting evidence (temporal co-occurrence) – Suspended solid concentrations are episodic, and insect abundance decreases during periods with high suspended solids.
Deciding which pathways to consider in a causal assessment—that is, listing candidate causes as described in Step 2 of the SI process—sets the framework for causal assessment. This section of CADDIS provides background information on commonly encountered sources, stressors, and responses for use in deciding which candidate causes to consider, as well as in developing cases for or against those candidate causes in the actual assessment.

Each stressor module is organized into five sections, or tabs:

- **Introduction** provides a summary overview of the stressor, including a checklist of evidence that suggests including a given stressor in your assessment (i.e., listing it as a candidate cause).
- **When to List** provides more detailed information on the sources, activities, site evidence, and biological responses that suggest inclusion as a candidate cause.
- **Ways to Measure** details different methods for quantifying the stressor.
- **Conceptual Diagrams** illustrates hypothesized causal linkages among the stressor, its sources, and associated biotic responses.
- **References** lists the references cited throughout the module.
Ammonia

Ammonia (NH₃) is a common toxicant derived from wastes (Figure 1), fertilizers, and natural processes. Ammonia nitrogen includes both the ionized form (ammonium, NH₄⁺) and the unionized form (ammonia, NH₃). An increase in pH favors formation of the more toxic unionized form (NH₃), while a decrease favors the ionized (NH₄⁺) form. Temperature also affects the toxicity of ammonia to aquatic life. Ammonia is a common cause of fish kills, but the most common problems associated with ammonia relate to elevated concentrations affecting fish growth, gill condition, organ weights, and hematocrit (Milne et al. 2000). Exposure duration and frequency strongly influence the severity of effects (Milne et al. 2000).

Ammonia in sediments typically results from bacterial decomposition of natural and anthropogenic organic matter that accumulates in sediment. Sediment microbiota mineralize organic nitrogen or (less commonly) produce ammonia by dissimilatory nitrate...
This volume provides examples that illustrate different aspects of a causal analysis.

- The **Analytical Examples** section provides examples illustrating the use of different data analyses to inform particular types of evidence. If you are interested in seeing how data analysis techniques can be applied in causal assessment, start with this section.
- The **Worksheets** section provides examples from the Little Scioto River in Ohio, one of the first Stressor Identification–based causal analyses conducted. These examples are presented as "worksheets" that one might complete as one conducts a causal analysis, so this section is a good place to start if you are planning on...
This volume of CADDIS was developed as a reference for users seeking information on different analytical techniques that can be applied to causal analysis.

Data analysis is a key phase of a causal assessment. In many cases, statistical analyses can be used to inform different types of evidence and strengthen confidence in the results of causal assessments.

- **Selecting an Analysis Approach**: initial guidance for selecting appropriate analyses that can inform different phases of a causal analysis.
- **Getting Started**: things to think about before you start analyzing data.
- **Basic Principles & Issues**: basic concepts to keep in mind while analyzing observational data.
- **Exploratory Data Analysis**: techniques for becoming familiar with your data.
Vol 5: Causal Databases

This section of CADDIS provides two tools (at right) to help users access and apply literature–based evidence in their causal assessments. These tools are designed for users interested in finding and compiling scientific literature (peer-reviewed and other) to support or weaken the cases for particular causal pathways.

A key part of causal assessment is taking what has been learned about causal pathways in other systems and using that knowledge to inform the current assessment. In the Stressor Identification process, this application of previous research typically occurs in Step 2: List Candidate Causes and Step 4: Evaluate Data from

- The Interactive Conceptual Diagram (ICD) application uses conceptual diagrams as an organizing framework to provide supporting literature for linkages among different sources, stressors, and responses. Users can view literature linked to existing diagrams by clicking on diagram shapes, as well as create and populate their own diagrams with supporting literature.

- The CADDIS Literature Resource (CADLit) contains information on stressor–response associations reported in the peer-reviewed scientific literature. Currently, the stressors
CAADIS Volume 5: Causal Databases

You are here: EPA Home → CAADIS → Causal Databases → CADLink

CADLink

CADLink is a database of literature-based evidence—that is, evidence extracted from the scientific literature, typically peer-reviewed publications. It contains information on the cause-effect relationships evaluated in each publication, along with relevant details such as study design, location, and analytical results. This evidence can be used to develop and evaluate the causal pathways included in environmental assessments.

Users can search for information in the database via an Oracle Application Express (APEX) interface. The database can also be used with CAADIS' Interactive Conceptual Diagram (ICD) tool, which allows users to link entries to specific causal pathways shown in user-developed conceptual model diagrams. In the future, registered users will be able to input new information into the database.

Please note that this is a beta (test) version of the CADLink database. We welcome your feedback on potential improvements as we continue development; please contact us with any problems you encounter or to suggest changes.

CADLink replaces CADLit, the original CAADIS literature database. CADLit information can be searched and downloaded via the CADLink APEX interface, but data no longer be entered into CADLit.

Username: betatester
Password: cadlink2016
CADStat lives!
- Available for download from CRAN
- Contact Sue Norton for installation instructions
Contact us

Sue Norton  norton.susan@epa.gov
Kate Schofield  schofield.kate@epa.gov