WHAT IS STRUCTURED DECISION MAKING?

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- SDM Origins and Background
- SDM Techniques
- SDM Applications

SDM ORIGINS AND BACKGROUND

Based on principles of Decision Analysis and Multi-attribute Utility Theory (MAUT)

- Well developed axiomatic structure for how decisions should be made
- "The formal use of common sense for decision problems that are too complex for informal use of common sense" (Ralph Keeney, 1982)

Incorporates insights from Behavioral Decision Theory, Psychology, and Economics

- How we process information and evaluate options

FOUNDATIONAL ROLE OF SDM

- Adaptive management Technical Guide (DOI)

  "Adaptive management is framed within the context of structured decision making, with an emphasis on uncertainty about resource responses to management actions and the value of reducing that uncertainty…" (2007: Ex Summary)

- Decision making for the environment (NRC)

  "To strengthen the scientific infrastructure for evidence-based environmental policy, the federal government should pursue a research strategy that emphasizes decision relevance." (2005: Decision Making for the Environment, National Research Council)

SDM EXAMPLE

- You want to purchase a ticket for a flight to Vancouver.

SDM EXAMPLE

- Typical issues:
  - I don't want to spend much money
  - I don't want hidden fees
  - I don't want to spend an extra day in Vancouver
  - I want a direct flight
  - I want easy check-ins
  - I want decent leg room
  - I want an aisle seat
  - I want friendly service
  - I am concerned about all the airline crashes recently
  - I am not comfortable flying with a new airline

SDM EXAMPLE

Issues	Objectives	Evaluation Criteria
• I don't want to spend much money • I don't want hidden fees • I don't want to spend an extra day in Toronto	➔ Minimize Cost	$ Total
• I want a direct flight • I want easy check-ins	➔ Minimize Travel Time	Hours
• I want decent leg room • I want an aisle seat • I want friendly service	➔ Maximize Comfort	Scale (5 = best, 0 = Worst)
• I am concerned about all the airline crashes recently • I am not comfortable flying with a new airline	➔ Maximize Safety	# Accidents / 1 million take-offs (5 yr ave)

SDM EXAMPLE

Objective	**Indicator Units**	**Preferred Direction**	**A Air Canada**	**B Transat**	**C Vintage Air**
Minimize Cost	$	Lower is better			
Minimize Travel Time	Hours	Lower is better			
Maximize Comfort	(5 = best, 0 = worst)	Higher is better			
Maximize Safety	# Accidents / 1 million take-offs (5 yr ave)	Lower is Better			

SDM EXAMPLE

Objective	**Indicator Units**	**Preferred Direction**	**A Air Canada**	**B Transat**	**C Vintage Air**
Minimize Cost	$	Lower is better	$2,000	$1,500	$400
Minimize Travel Time	Hours	Lower is better	8-9	13-15	12-64
Maximize Comfort	(5 = best, 0 = worst)	Higher is better	4	4	? 0-5
Maximize Safety	# Accidents / 1 million take-offs (5 yr ave)	Lower is Better	3.8	2.6	? 0 – 40(?)

SDM EXAMPLE

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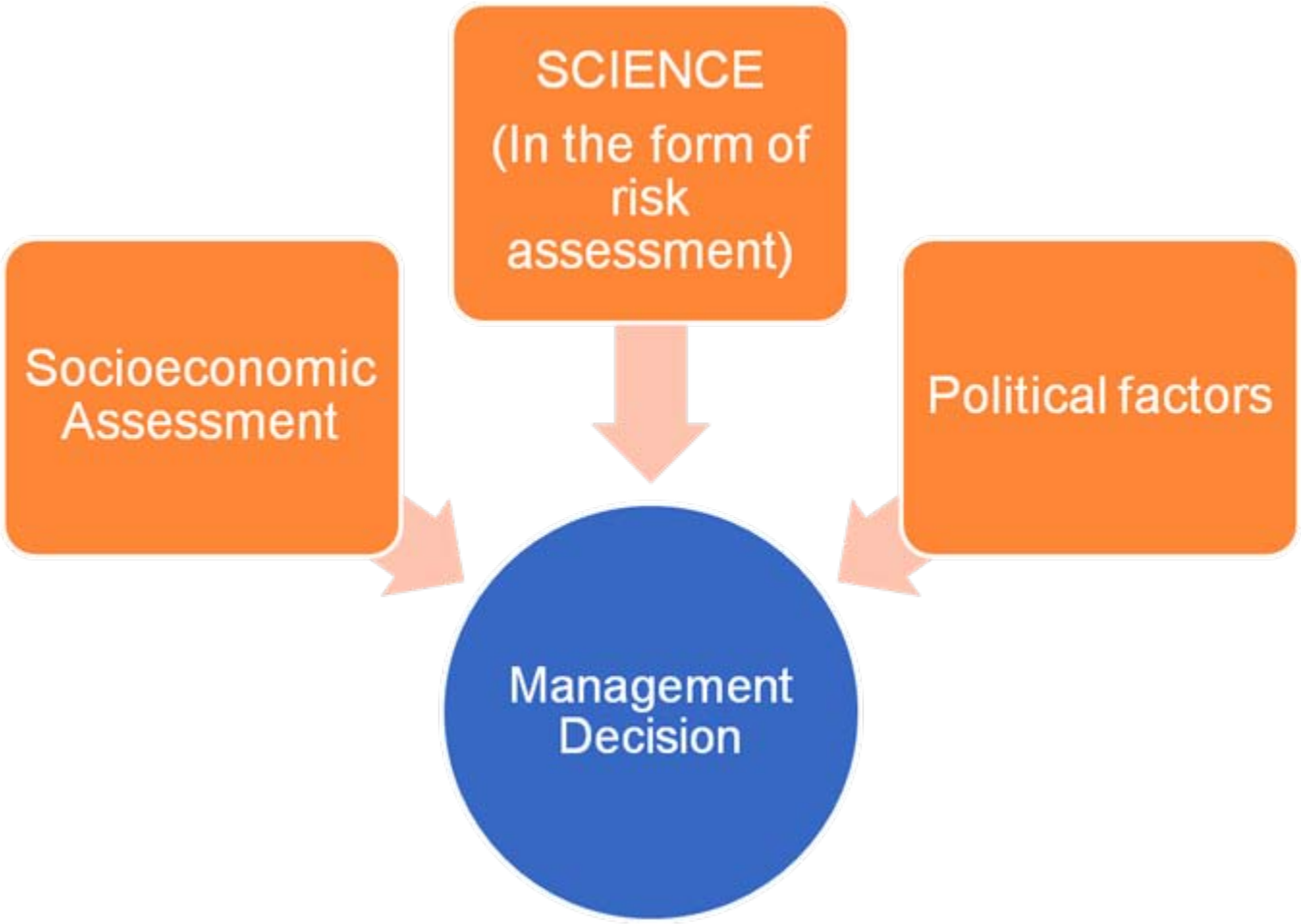
RISK ASSESSMENT OPTIONS

- There are many different ways to conduct a risk assessment: How to make this choice?
- There are many different aspects of a problem: How to decide what the RA should address?
- A RA provides a great deal of information, but:
  - It may not address stakeholder & public reactions (risk objectives/perceptions)
  - It may not address decision makers' needs in terms of risk management/regulation choices
  - It may not provide a defensible rationale for making clear tradeoffs

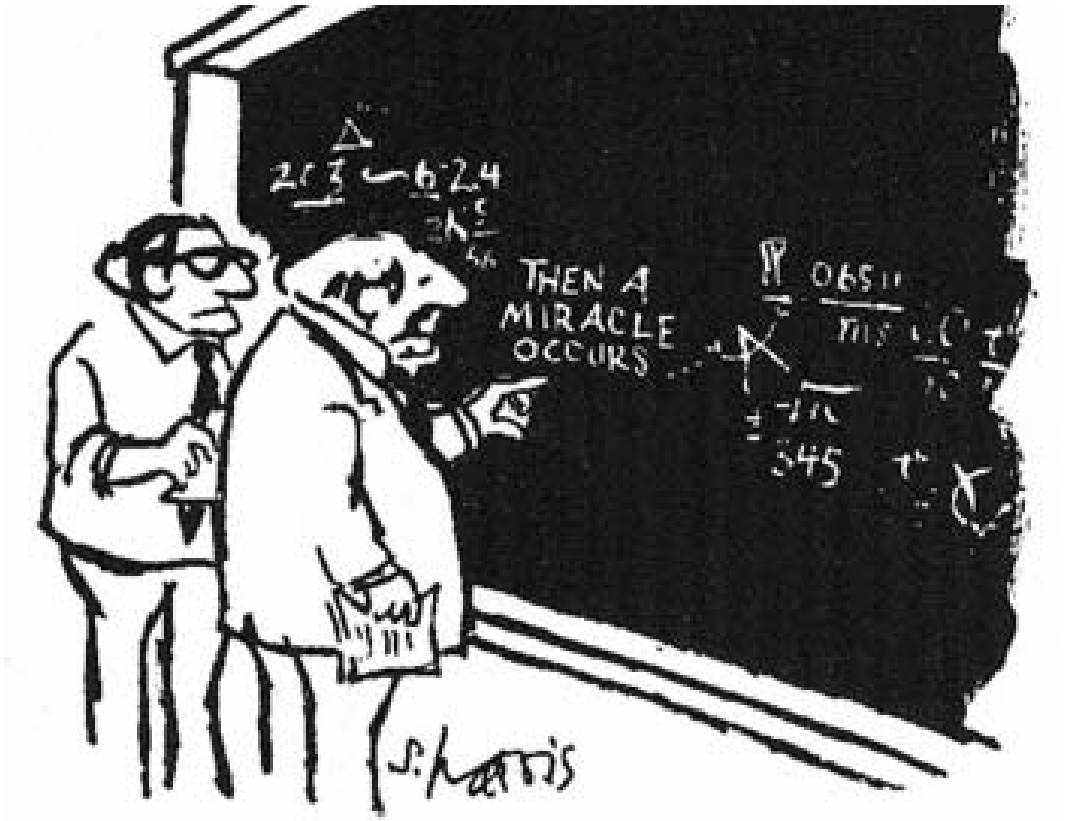
WHAT IS A RISK ASSESSMENT MEANT TO ACCOMPLISH?

- Evaluates threats under uncertainty: addresses the potential for avoidance of adverse consequences to human health, the environment, economic concerns, or social systems.
- Key elements of an environmental RA:
  - Estimate likelihood and severity of positive or negative effects on species, populations, or habitats
  - Establish endpoints and measures of change
  - Understand interactions among multiple threats
  - Understand limits of management actions

CONVENTIONAL RISK ASSESSMENT FRAMEWORK



FROM RISK ASSESSMENT TO SDM



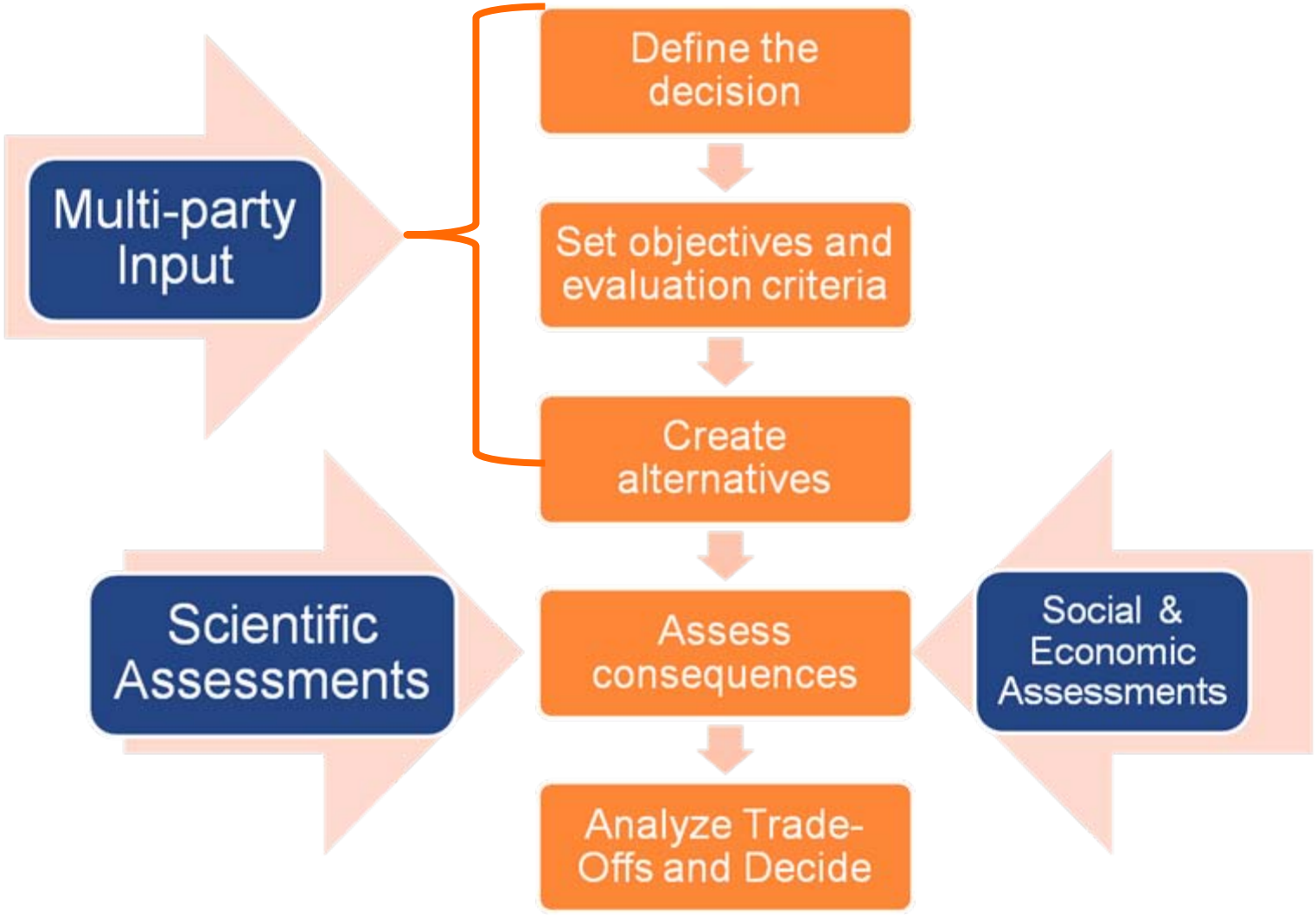
"I think you should be more explicit here in step two."

PROBLEMS WITH RISK ASSESSMENT AS AN AID TO MANAGEMENT CHOICES

- Decision making is opaque
  - Frustrating to scientists who provided the RA
  - Frustrating to people affected (stakeholders)
- No formal consideration of different perspectives or concerns, so analysis may omit key questions
- Hides value judgments: Risk is not value free!
  - Choice of env'tal endpoints & performance measures
  - Choice of analytical methods (e.g., uncertainty)
  - Determination of "acceptable" risk levels
- No framework for learning: precautionary or adaptive management, monitoring, new data?

So why not re-organize to make clear decisions?

FROM RISK ASSESSMENT TO SDM



FROM RISK ASSESSMENT TO SDM

- SDM process is designed to service the decision
- Science still has a central and uncompromised role, but:
  - Distinguishes between fact- and value-based inputs
  - Permits scientists to focus on the job of estimating consequences of alternative management decisions
- Provides explicit mechanism for consideration of objectives and linking objectives to alternatives
- Provides mechanisms for input from stakeholders
- Difficult choices throughout are shifted to where they belong – management – with tools for showing what factors were weighed in choices

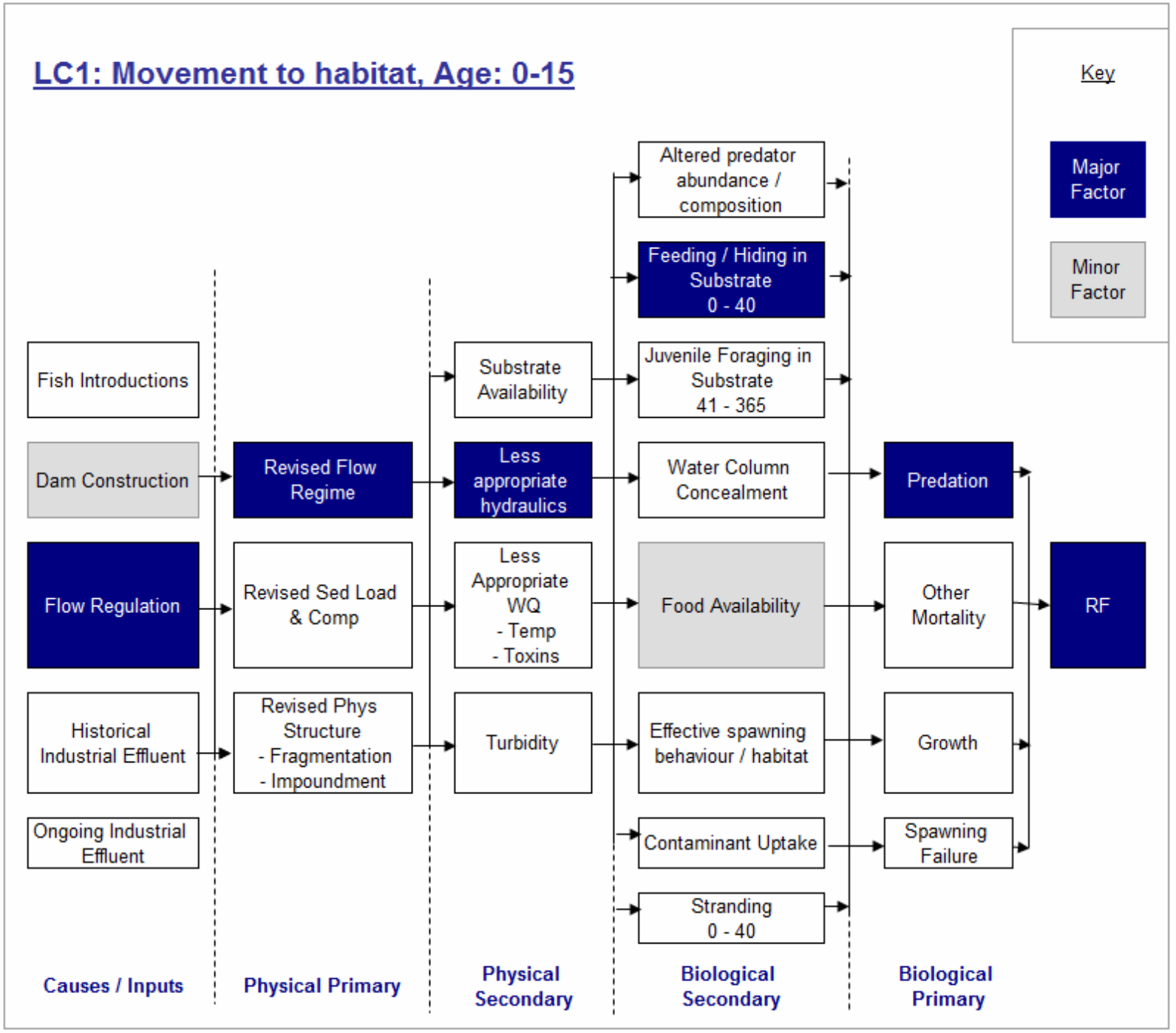
Steps in structured decision aiding

SDM TECHNIQUES

- Some SDM and techniques
  1. Influence diagrams (decision-focused)
  2. Analyzing and communicating uncertainty
  3. Improving judgments of experts
  4. Decision trees
  5. Trade-off analysis tools

SDM TECHNIQUES

1. Influence Diagrams
   - Conceptually link the things you can control (management actions) to the things that people care about, so as to make relationships visible
   - Distinguish between relationships that can and cannot be controlled
   - Assist in developing endpoints and evaluation criteria
   - Example: Columbia River White Sturgeon recruitment failure…


LC1: Movement to habitat, Age: 0-15
Key
Major Factor
Minor Factor
Fish Introductions
Dam Construction
Flow Regulation
Historical Industrial Effluent
Ongoing Industrial Effluent
Revised Flow Regime
Revised Sed Load & Comp
Revised Phys Structure - Fragmentation - Impoundment
Substrate Availability
Less appropriate hydraulics
Less Appropriate WQ - Temp - Toxins
Turbidity
Altered predator abundance / composition
Feeding / Hiding in Substrate 0 - 40
Juvenile Foraging in Substrate 41 - 365
Water Column Concealment
Food Availability
Effective spawning behaviour / habitat
Contaminant Uptake
Stranding 0 - 40
Predation
Other Mortality
Growth
Spawning Failure
RF
Causes / Inputs
Physical Primary
Physical Secondary
Biological Secondary
Biological Primary

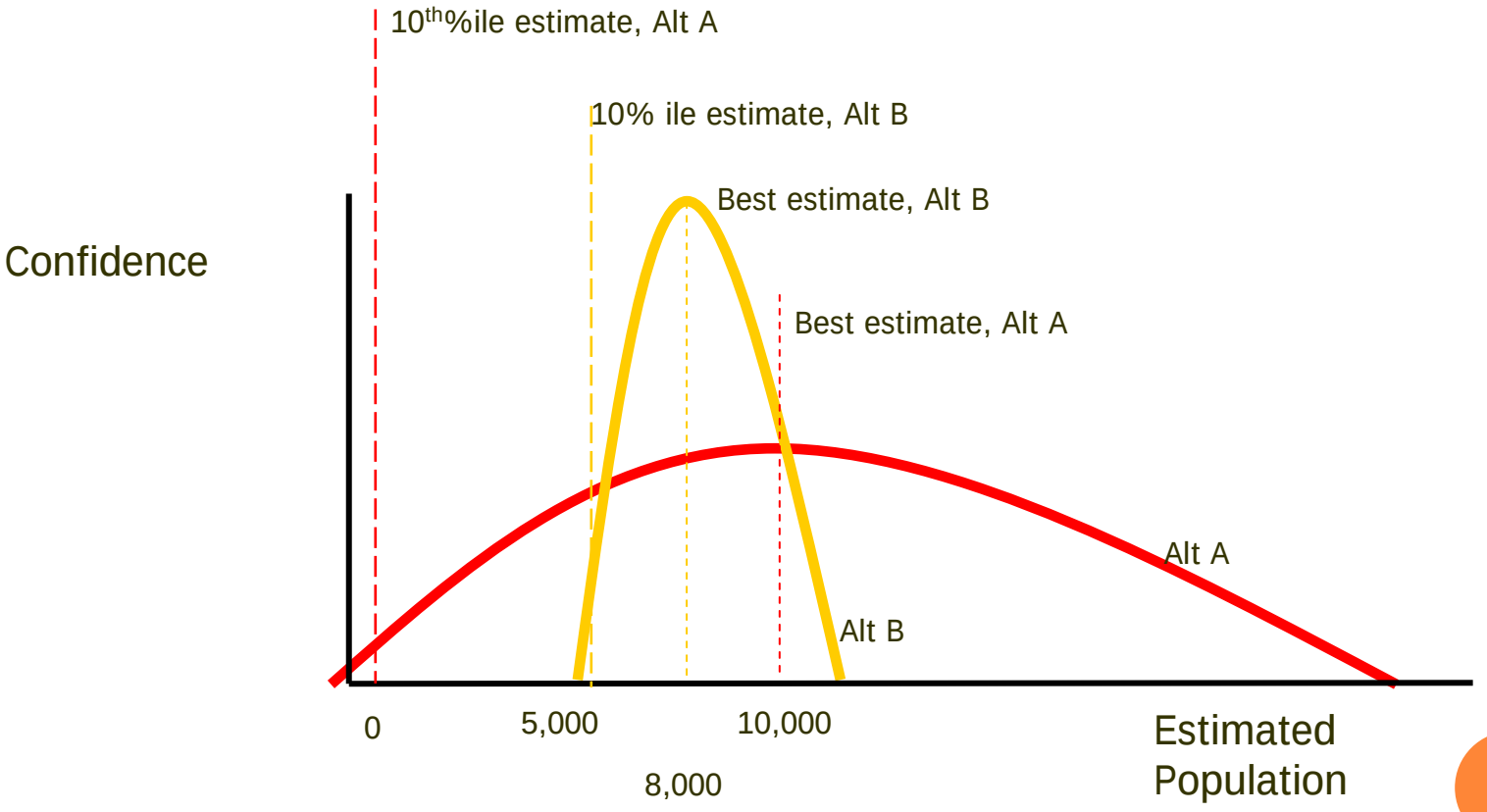
SDM TECHNIQUES

2. Analyzing and Communicating Uncertainty

- Example: which alternative is best?

	Alternative A	Alternative B
Best estimate of increase in sp X population (good)	10,000	8,000

SDM TECHNIQUES



SDM TECHNIQUES

Now which alternative is best?

	Alternative A	Alternative B
Median (50th %ile) estimate of species X population	10,000	8,000
Low (10th %ile) estimate of species X population	0	5,000

SDM TECHNIQUES

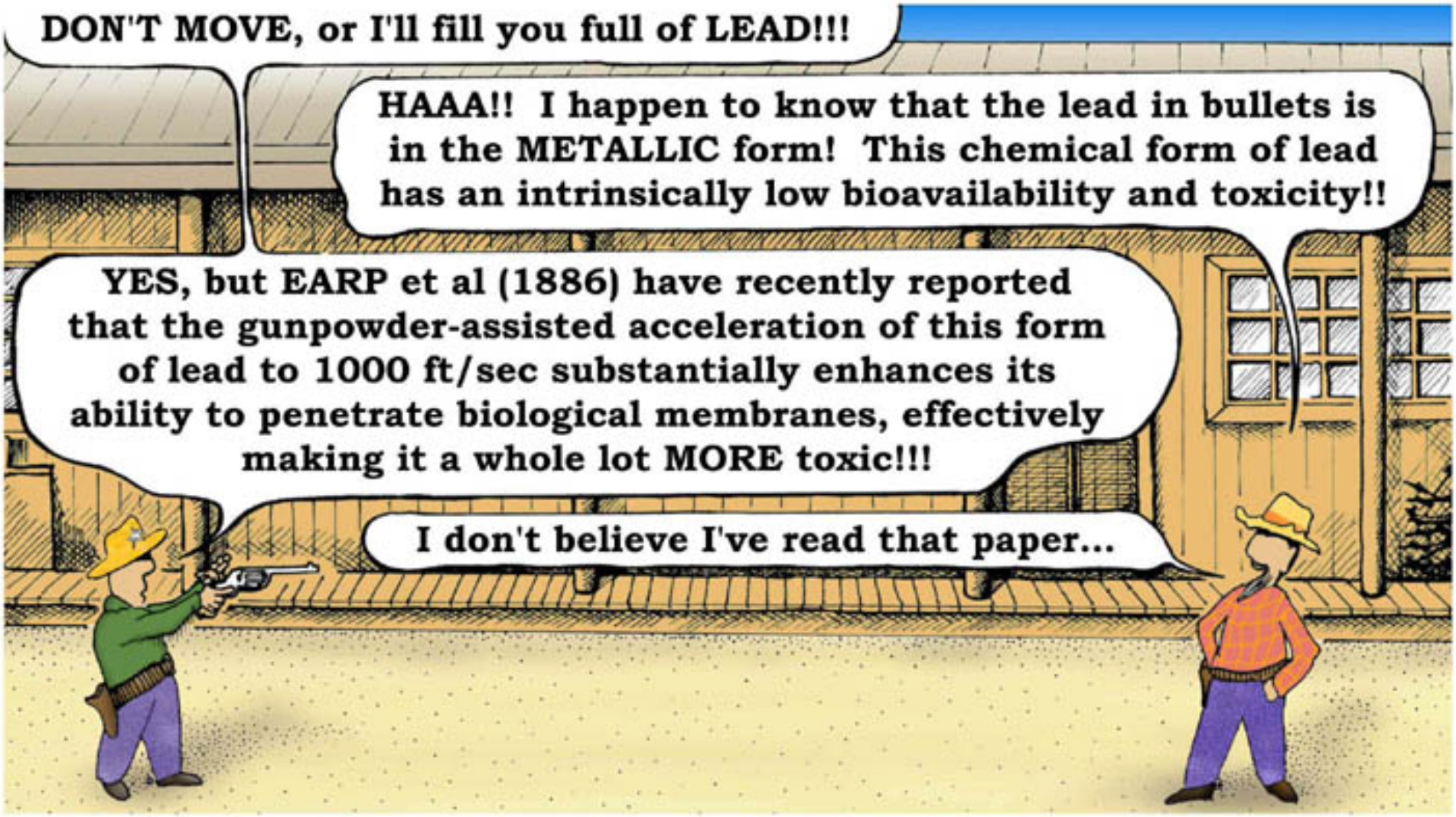
3. Expert judgment elicitations

Goal is to clarify basis of experts' judgments by

- identifying key sources of uncertainty
- eliciting probability judgments (or frequencies)
- using this as a basis for dialogue/further studies

Done poorly…

- Fail to question fundamental assumptions
- Lead to phenomenon of "dueling experts"
- Leads to court cases and litigation



ENVIRONMENTAL SCIENTISTS IN THE WILD WEST

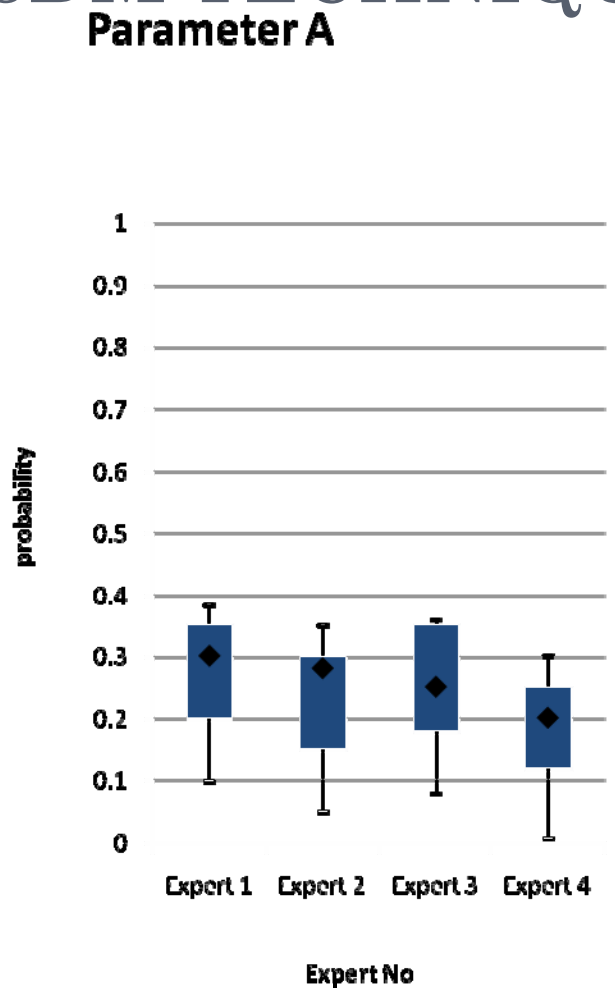
SDM TECHNIQUES

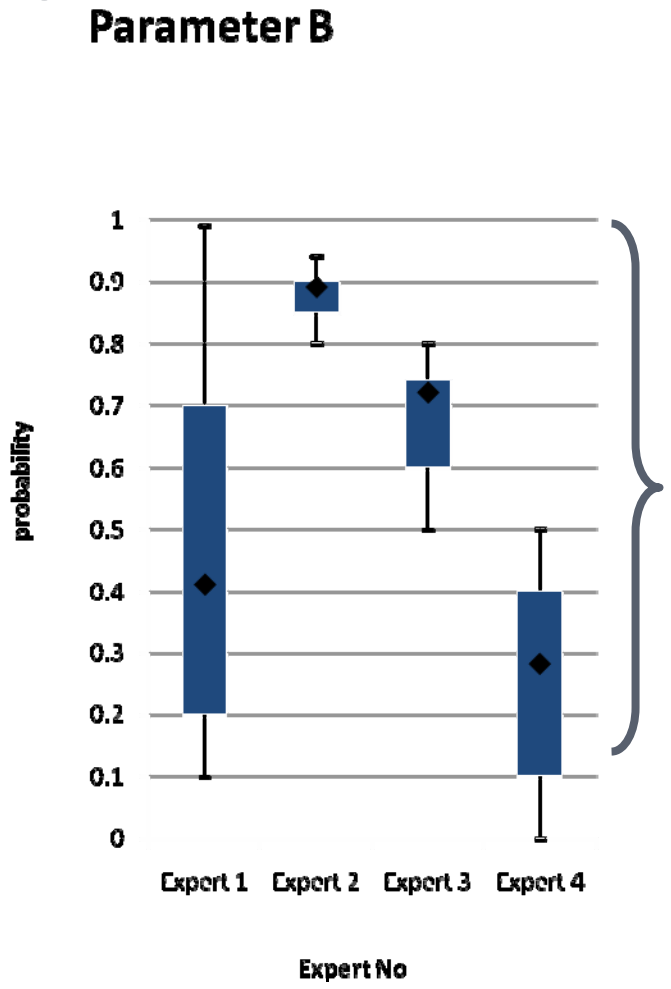
- Expert judgment elicitations

  Done well…

  - Expose fundamental assumptions regarding how a problem is thought about (mental models)
  - Encourage experts to reach agreement
  - Facilitate learning and incorporation of knowledge from different sources
  - Widely used

SDM TECHNIQUES





Wide range of judgements…

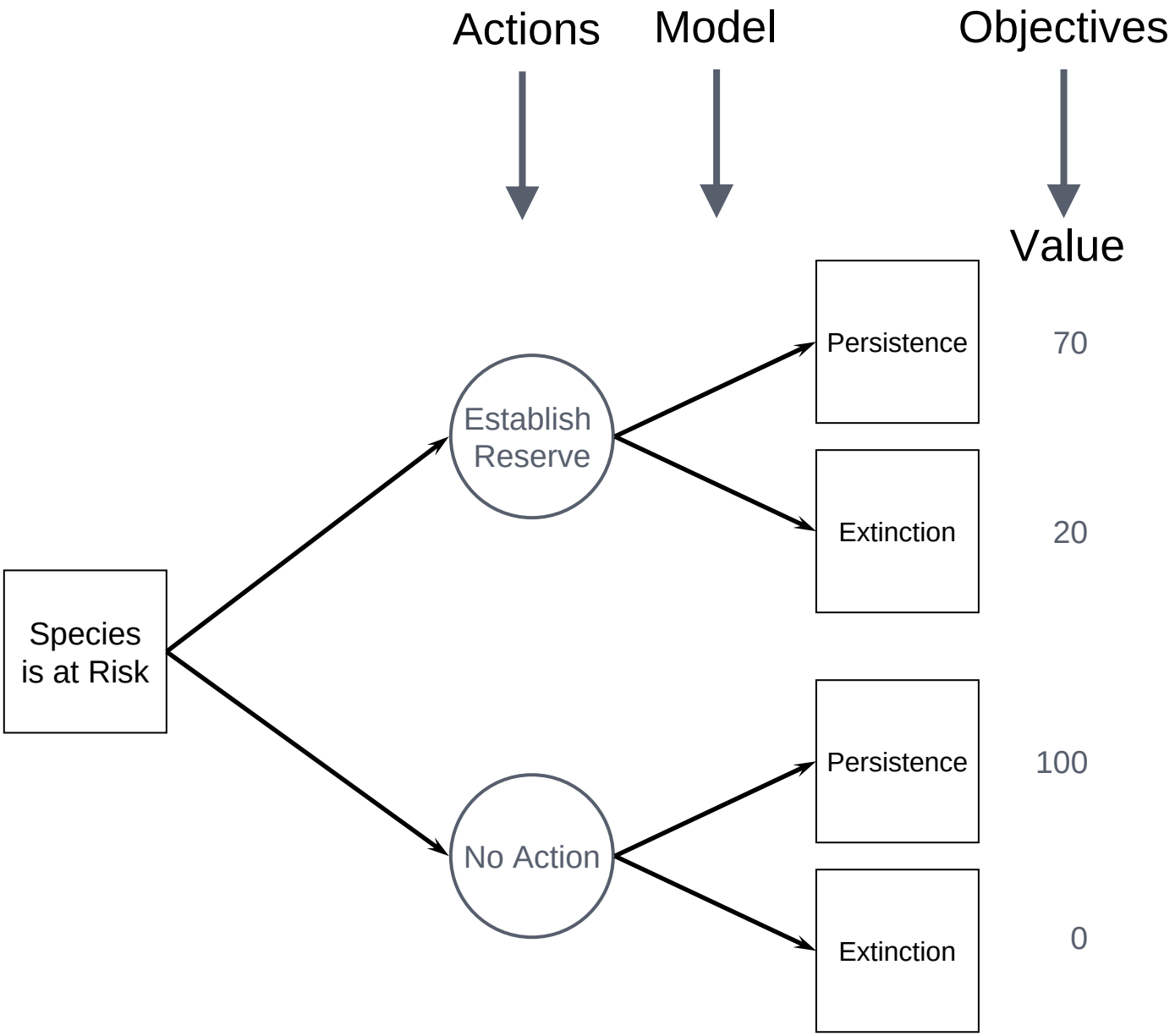
– priority for research?

- improved info on stakeholder risk tolerance?

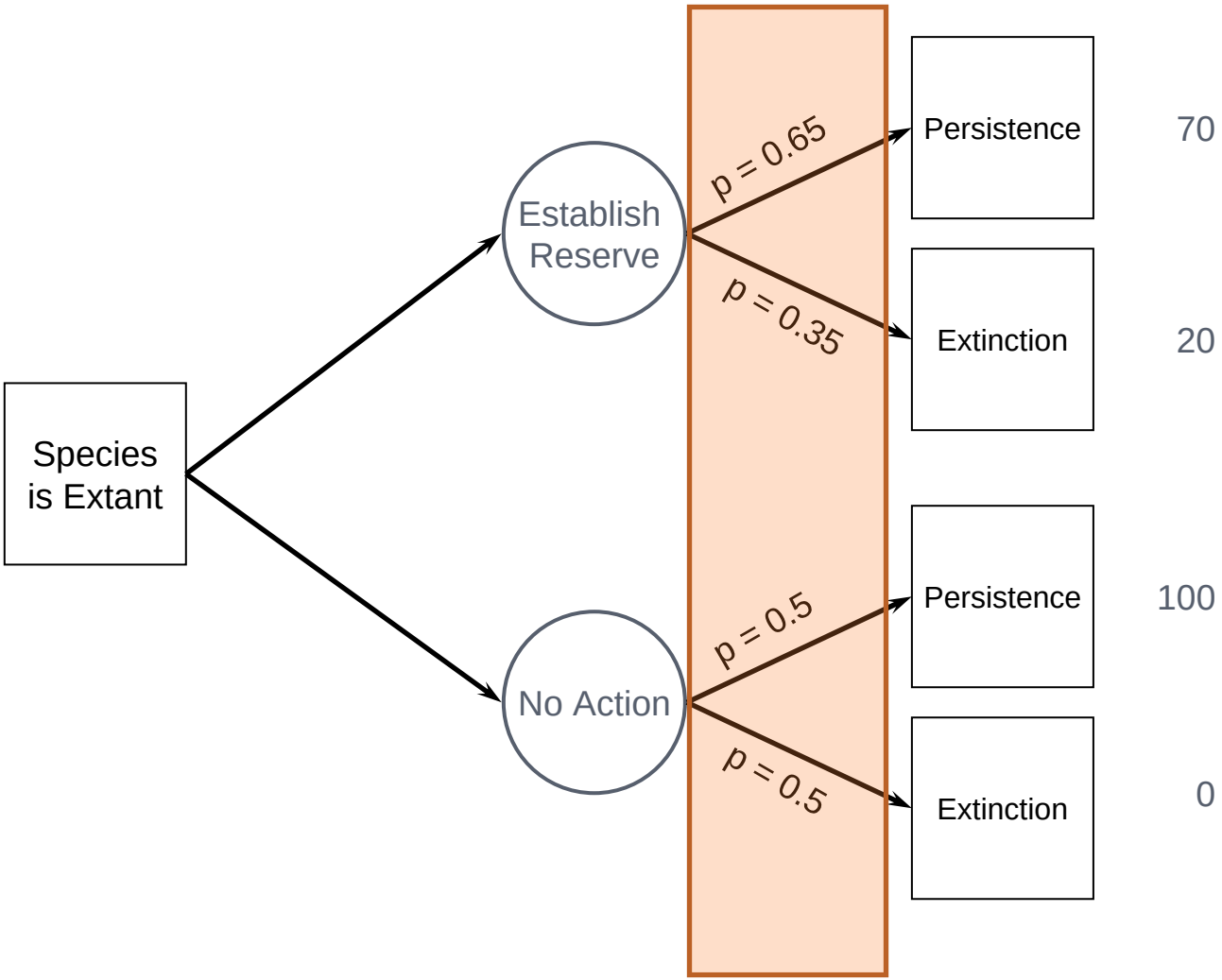
SDM TECHNIQUES

4. Decision Trees

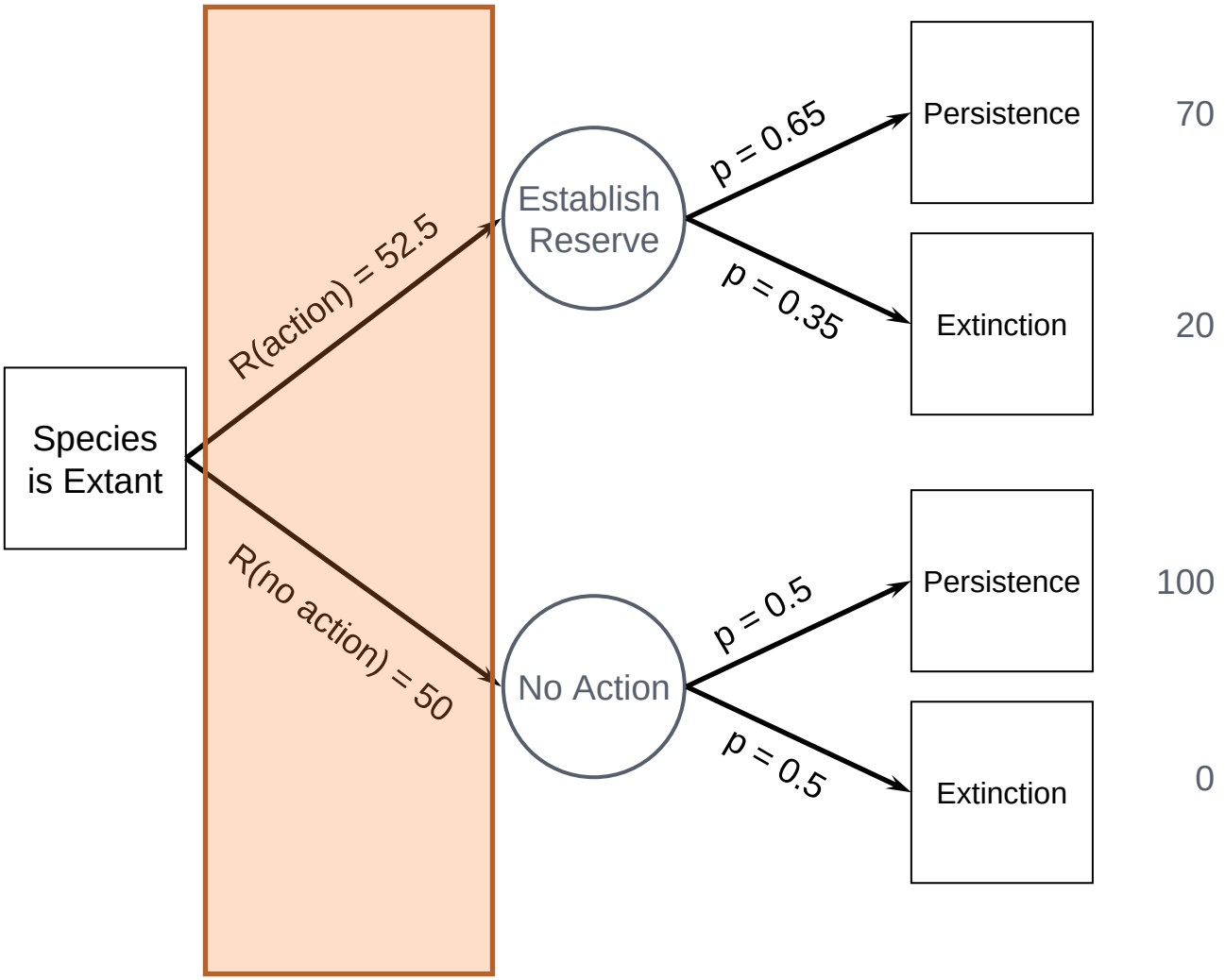
- Help structure expert judgments and test decision sensitivity to them
- Example courtesy Michael C. Runge, USGS


Actions
Model
Objectives
Value
Species is at Risk
Establish Reserve
No Action
Persistence
Extinction
Persistence
Extinction
70
20
100
0

SDM TECHNIQUES



SDM TECHNIQUES



TOOLS & TECHNIQUES

5. Trade-off analysis tools

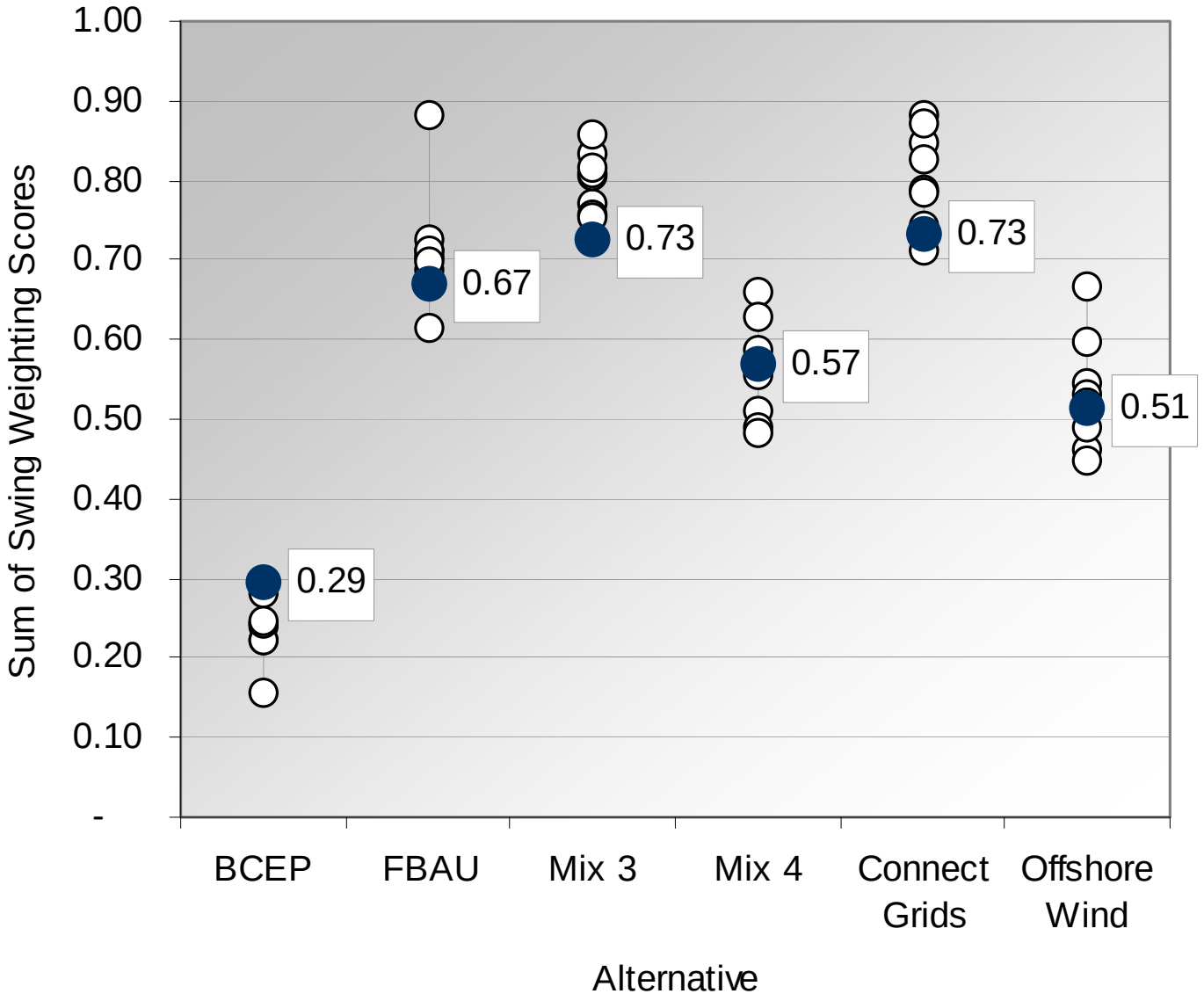
- Understanding the trade-offs between complex alternatives can be challenging
- Value elicitation tools can help structure values just as we structure facts…
- Structuring values helps to inform and clarify when situations require unfamiliar choices or decisions across multiple dimensions
- Use of different techniques (e.g., swing weighting, pricing out) can help to clarify value tradeoffs and lead to more informed choices – both within and across individuals and groups

TOOLS & TECHNIQUES

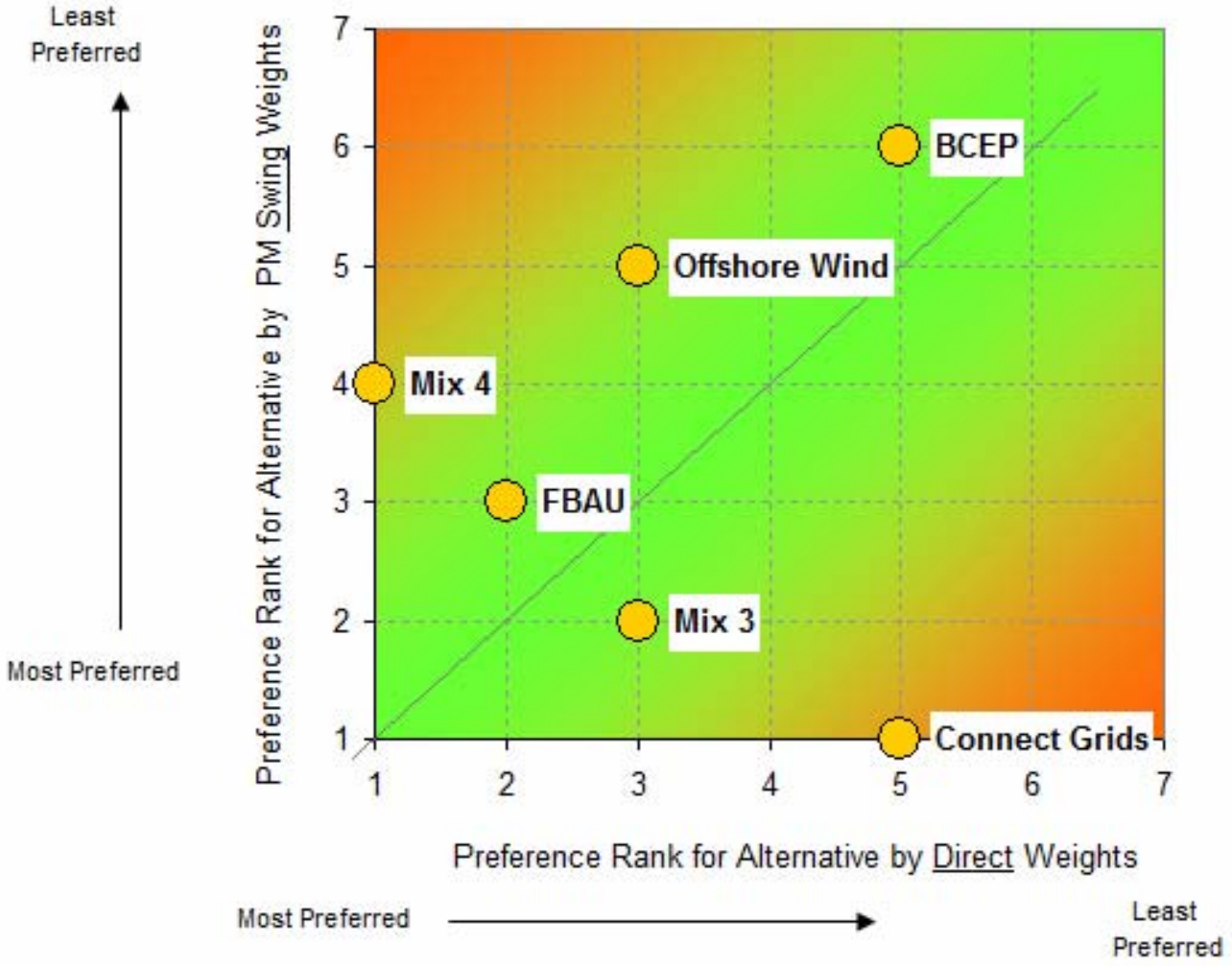
Swing Weighting **Name:**

	PM	Direction	Units	Worst	Best	Rank	Weight
Cost	Unit Energy Cost	L	$/MWh	149	108		
GHG Emissions	CO2 equivalent emissions	L	kilotons/yr CO2e	31	8		
Local Air Emissions	PM10	L	tons/yr (PM10)	25	8		
Land Area	Land Area	L	m2 (000)	30	3		
Aquatic Area	Aquatic Area	L	m2 (000)	35	0		
Jobs - Temp	Construction Jobs	H	Person-years	66	119		
Jobs	Permanent Jobs	H	FT equivalent	49	84		
Noise	Noise Scale	L	Scale	7	3		
Visual Impacts	Visual Impact Scale	L	Scale	3	1		
Food Harvesting Impacts	Food Harvesting Impact Scale	L	Scale	3	0		
Innovation	Innovation Scale	H	Scale	0%	147%		
Sustainability	% Dependable Peak By Renewables	H	%	$ 0.11	$ 0.26		

Greg M's Swing Total Scores (Blue) Relative to Others' (White)



Greg M's Relative Preference for Alternatives Using Two Weighting Techniques



SDM APPLICATIONS

- SDM approaches are widely used:
  - DOE: cleanup of nuclear sites
  - EPA: National Estuary Program
  - FWS: hatchery risks to wild stocks, Atlantic salmon recovery, white sturgeon recruitment failure
  - State fish and wildlife agencies
    - Great Lakes fisheries
    - Florida everglades
  - Europe: EU, HM Treasury
  - Canada:
    - BCHydro Water Use Plans(relicensing hydroelectric facilities)
    - DFO Species at risk (salmon), Stock allocation (Fraser R)

CASE STUDIES

Example case studies to demonstrate SDM methods and link from analysis to policy / decision aiding

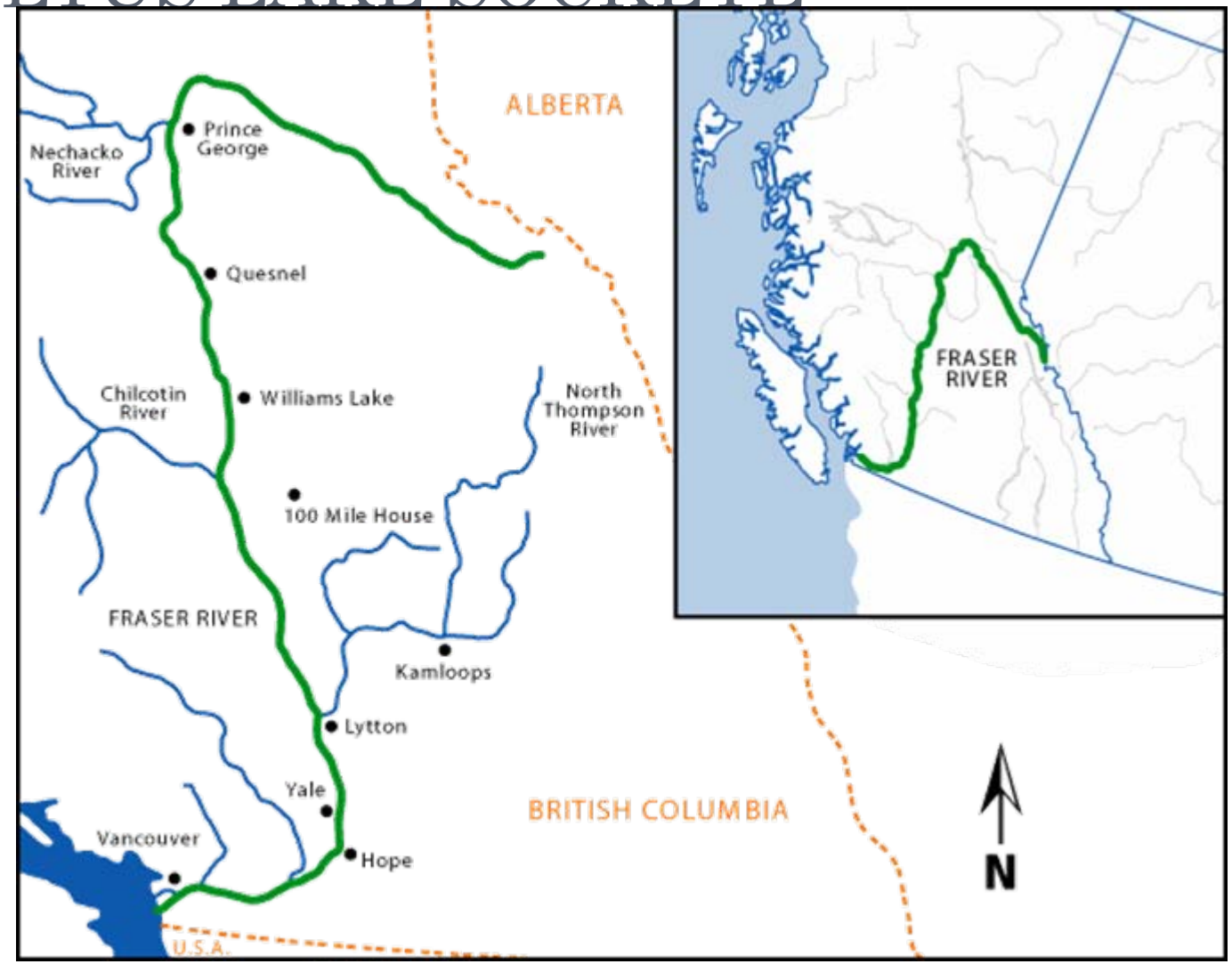
CASE STUDIES

- Picked two case studies to discuss, for these reasons:
  - To give you an idea of the application of SDM approaches
    - remembering that every situation is different
    - remembering that SDM is flexible
  - To show that SDM need not require a long time and/ or cost lots of money
  - To demonstrate that SDM, when used properly, can assist sound science to be heard because it
    - helps to distinguish between scientific facts and values
    - helps to focus scientific studies around key decisions
    - helps to identify institutional constraints to the application of sound risk assessments

CASE STUDY 1: Cultus Lake Sockeye

- Cultus Lake Sockeye
  - Features
    - Iconic endangered species, not listed for political reasons
    - Multi-million dollar commercial interests at stake
    - Legal aboriginal rights issues at play
    - Significant biological uncertainties
    - Keen interest from NGOs
    - Overlapping jurisdictions
    - Decision timeline: 4 weeks!

CULTUS LAKE SOCKEYE



CULTUS LAKE SOCKEYE

- Client: Fisheries and Oceans Canada
- Worked with multi-stakeholder committee (approx. 20 people) over 1 month period
- Key risk tradeoff:
- Environmental protection
  - of endangered stocks vs
- Economic
  - commercial fishing revenues

CULTUS LAKE SOCKEYE

- Multiple interests:
  - High visibility species, high importance to Conservation, commercial fishers, and First Nations
- Data quality variable (and underlying science often controversial)
- Data inputs from agency scientists/consultants as well as other stakeholders (e.g., resource users)
- Multiple management options (exploitation rate, captive breeding, predator removal) but uncertainty about consequences of actions

CULTUS LAKE SOCKEYE: Objectives

- Sockeye conservation
  - Probability of meeting Recovery Plan objectives 1 and 2
  - Returns in years 2010 and average of 2016-19
  - Probability of extirpation by 2036
  - % Enhanced in 2010 and average of 2016-19
- Costs
  - Total costs over 12 years, levelized
  - No cost allocation attempted
- Catch
  - Traditional commercial catch
  - Commercial TAC available upstream of Vedder
  - Total First Nations FSC
- Jobs
  - Employment opportunities directly related to enhancement and freshwater projects

CULTUS LAKE SOCKEYE

- Alternatives created by assembling 'blocks' of options:
  - Cultus Exploitation Rate %
  - Enhancement options
  - Freshwater projects options

- Make use of strategy tables to encourage creative thinking. Two examples:

CULTUS LAKE SOCKEYE

Cultus Exploitation Rate %	Enhancement	Freshwater projects options
5	None	None
10	Current Captive Brood	Current Milfoil Removal
20	Double Current Capacity	Current Pikeminnow
30	Maximum Enhancement	Large Milfoil Removal
40		Large Pikeminnow Removal

Alternative 1: "Status Quo"

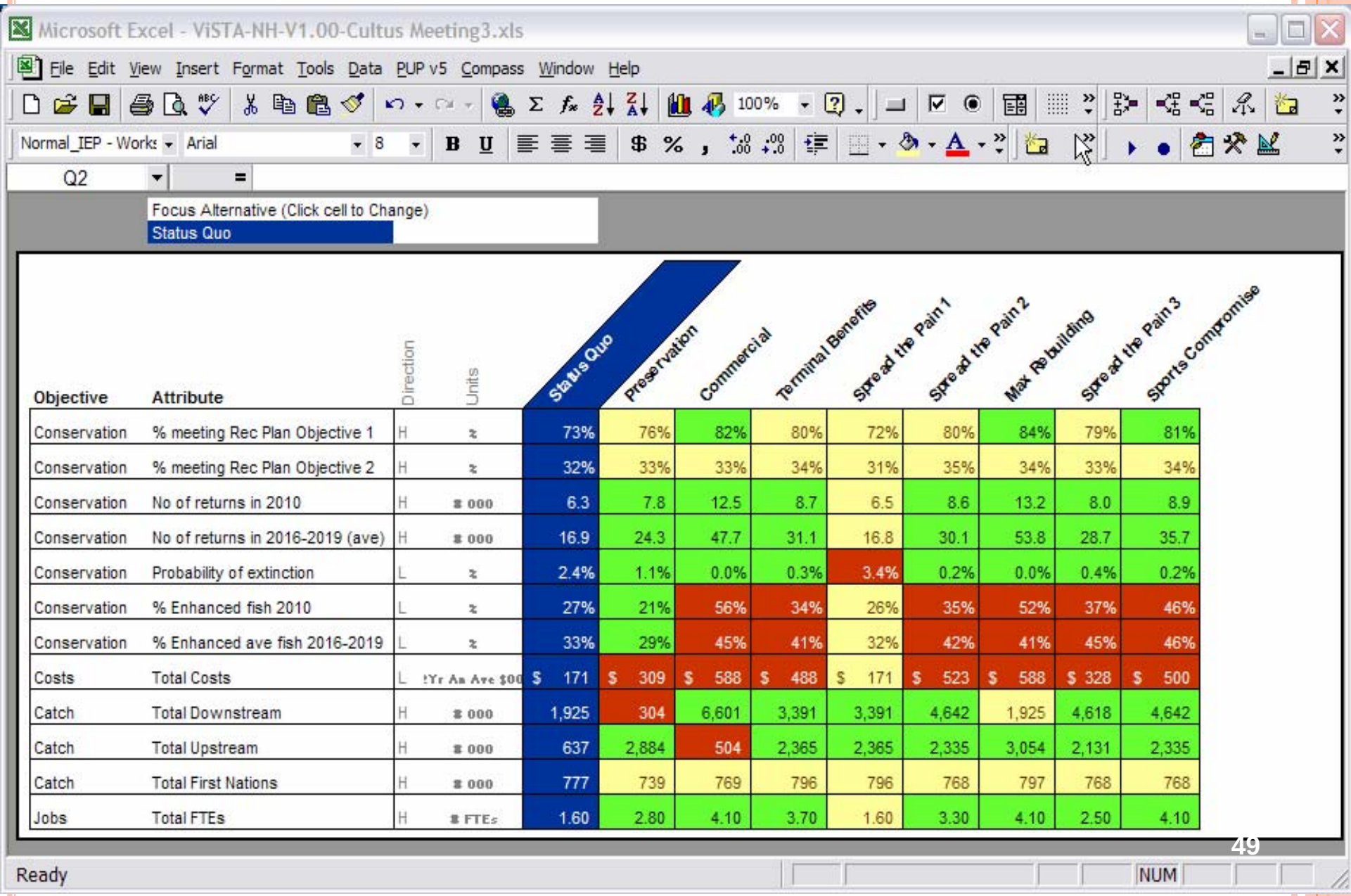
CULTUS LAKE SOCKEYE

Cultus Exploitation Rate %	Enhancement	Freshwater projects options
5	None	None
10	Current Captive Brood	Current Milfoil Removal
20	Double Current Capacity	Current Pikeminnow
30	Maximum Enhancement	Large Milfoil Removal
40		Large Pikeminnow Removal

Alternative 2: “Spread the Pain 2”

CULTUS LAKE SOCKEYE

- Exploration of alternatives through iterative SDM process: creation, analysis, elimination
  - Step 1
    - Created 6 alternatives
  - Step 2
    - Reviewed these 6 and created 3 more
  - Step 3
    - Reviewed all 9, eliminated 6 because they were dominated (others the same or better on objectives)
    - Agreed on several key components for all alternatives



Objective	Attribute	Direction	Units	Status Quo	Preservation	Commercial	Terminal Benefits	Spread the Pain 1	Spread the Pain 2	Max Rebuilding	Spread the Pain 3	Sports Compromise
Conservation	% meeting Rec Plan Objective 1	H	%	73%	76%	82%	80%	72%	80%	84%	79%	81%
Conservation	% meeting Rec Plan Objective 2	H	%	32%	33%	33%	34%	31%	35%	34%	33%	34%
Conservation	No of returns in 2010	H	# 000	6.3	7.8	12.5	8.7	6.5	8.6	13.2	8.0	8.9
Conservation	No of returns in 2016-2019 (ave)	H	# 000	16.9	24.3	47.7	31.1	16.8	30.1	53.8	28.7	35.7
Conservation	Probability of extinction	L	%	2.4%	1.1%	0.0%	0.3%	3.4%	0.2%	0.0%	0.4%	0.2%
Conservation	% Enhanced fish 2010	L	%	27%	21%	56%	34%	26%	35%	52%	37%	46%
Conservation	% Enhanced ave fish 2016-2019	L	%	33%	29%	45%	41%	32%	42%	41%	45%	46%
Costs	Total Costs	L	!Yr An Ave $00	$ 171	$ 309	$ 588	$ 488	$ 171	$ 523	$ 588	$ 328	$ 500
Catch	Total Downstream	H	# 000	1,925	304	6,601	3,391	3,391	4,642	1,925	4,618	4,642
Catch	Total Upstream	H	# 000	637	2,884	504	2,365	2,365	2,335	3,054	2,131	2,335
Catch	Total First Nations	H	# 000	777	739	769	796	796	768	797	768	768
Jobs	Total FTEs	H	# FTEs	1.60	2.80	4.10	3.70	1.60	3.30	4.10	2.50	4.10

CULTUS LAKE SOCKEYE

- Recognition of need to simplify the decision problem through elimination of less relevant objectives and alternatives.
- Do this via exploration of
  - Redundancy: where performance measures do not vary across alternatives
  - Dominance: where one alternative is better than or equal to all (or, by collective agreement, nearly all) aspects of another

CULTUS LAKE SOCKEYE

- Three alternatives remained at the end of this process

Objective	Attribute	Direction	Units	Commercial	Spread the Pain 1	Spread the Pain 3
Conservation	% meeting Rec Plan Objective 1	H	%	82%	72%	79%
Conservation	No of returns in 2016-2019 (ave)	H	# 000	47.7	16.8	28.7
Conservation	Probability of extinction	L	%	0.0%	3.4%	0.4%
Conservation	% Enhanced fish 2010	L	%	56%	26%	37%
Conservation	% Enhanced ave fish 2016-2019	L	%	45%	32%	45%
Costs	Total Costs	L	!Yr Av Ave $00	$ 588	$ 171	$ 328
Catch	Traditional Commercial	H	# 000	5,877	3,088	3,878
Catch	Available Comm TAC Above Vedder	H	# 000	131	2,920	2,130
Jobs	Total FTEs	H	# FTEs	4.10	1.60	2.50

CULTUS LAKE SOCKEYE

- After three meetings, key elements of one alternative favoured by all participating stakeholders, including
  - Agreement on structure of problem (as basis for discussions in future years)
  - Agreement on many common features:
    - Freshwater projects
    - Habitat treatment (invasive species)
    - Predator treatment
    - Enhancement options
- Remaining issues (e.g., exploitation rates) settled through additional talks that also included other parties who had not participated in initial SDM

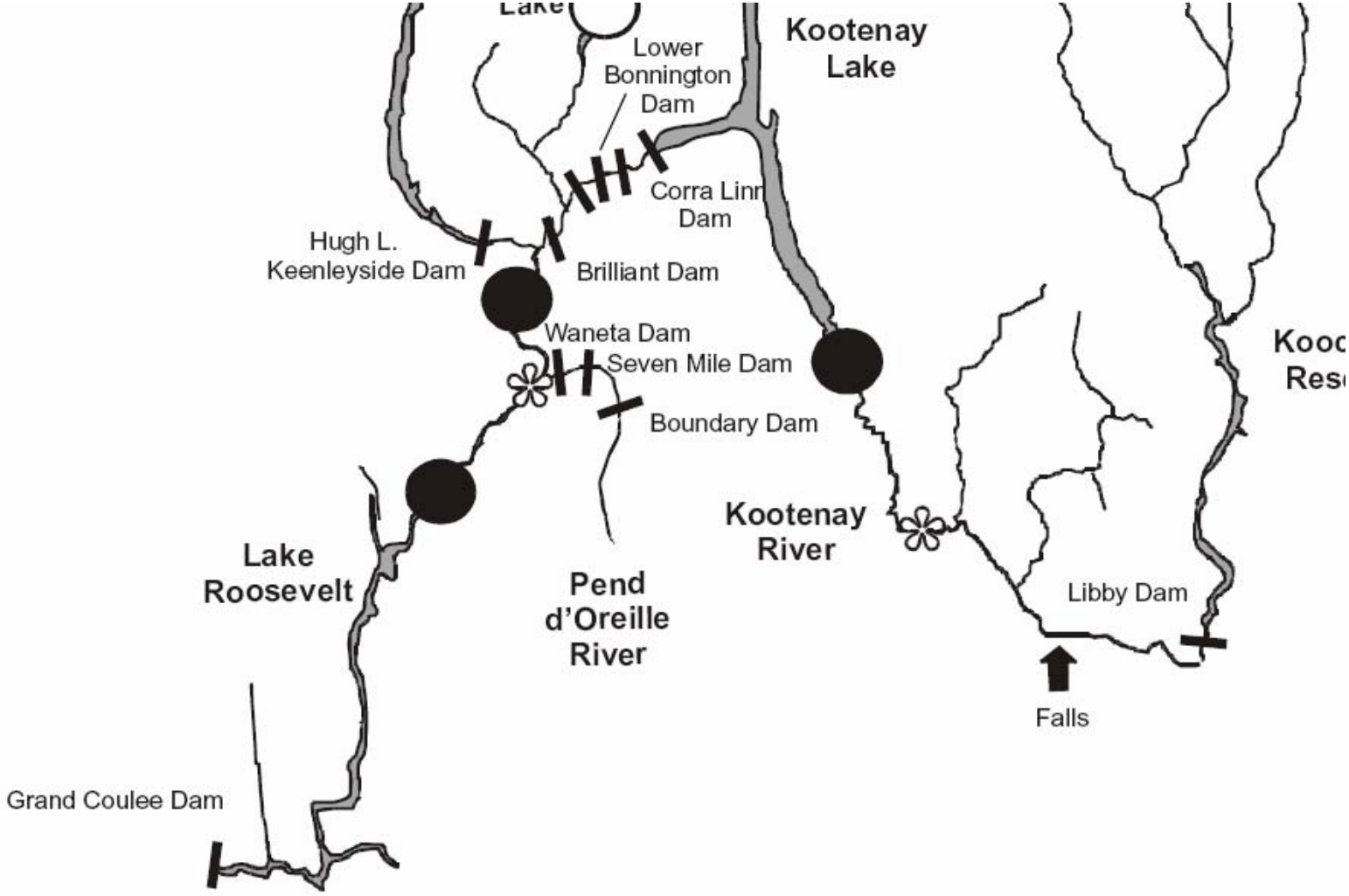
CULTUS LAKE SOCKEYE

- Key Messages
  - Although an ES problem, SDM examined trade-offs across ALL significantly affected objectives
  - Defined endpoints for key sources of risk
  - Considered a large number of risk management alternatives, some more precautionary than others
  - Used best science (to complete consequence matrix)
  - Reached agreement on problem structure, which sets basis for discussions about disagreement about values / tradeoffs
  - Established transparent process for future consultations (link from short-term to long-term)
  - Established defensible basis for choices by managers

CASE STUDY 2: Upper Columbia River White Sturgeon Recruitment Failure

- Upper Columbia River White Sturgeon
  - Features
    - Iconic endangered species (listed)
      - No recruitment in last 40 years
    - Overlapping jurisdictions
      - Canadian Federal, Provincial, USFWS, State of Washington
    - Major industrial interests
      - Mining corporation, hydroelectric utility corporation
    - Serious scientific uncertainties
    - Recovery plan with too many 'priority actions'
    - Little activity for several years on Action Plan

UPPER COLUMBIA WHITE STURGEON



UPPER COLUMBIA WHITE STURGEON

- Problem: Apparent failure of White Sturgeon to recruit in Upper Columbia River following construction of hydroelectric dams in 1960s and 1970s
- How to aid recruitment through
  - altering flows (volume, temperature, turbidity, timing);
  - restoring habitat (food availability, substrate for spawning, rearing, feeding);
  - removing predators
  - other means?

UPPER COLUMBIA WHITE STURGEON

- Biological status: Est. 1,400 adult WS, < ES criteria of 2,500 (WCU). Functional extinction within 25 years.
- Institutional status: Cooperative management effort among Canadian and US agencies and Tribes. Produced "WS Recovery Initiative" in 2002.
- Since 2002, little action on WS Recovery Initiative. Why? Need to move from science to decision focus.

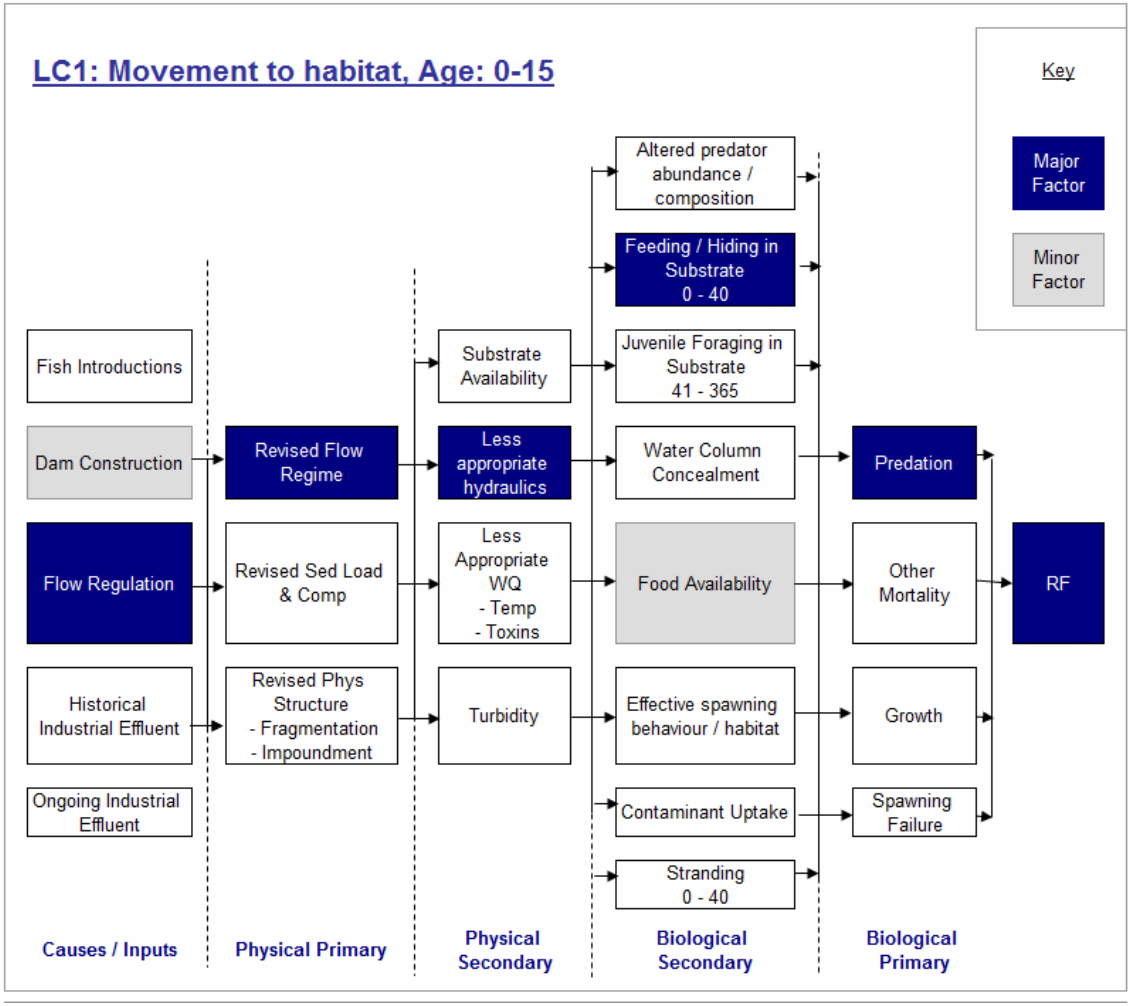
UPPER COLUMBIA WHITE STURGEON

- Our work, using SDM:
  - Organize and group ("bin") competing hypotheses
  - Develop precise meaning for each hypothesis
  - Help experts reach a common understanding of relative importance of hypotheses via "science court" arguments, for and against (presentation plus discussion)
  - Clarify ties between hypotheses and management actions
  - Link management actions to existing and proposed research
  - Prioritize and sequence management and research actions (in progress)
  - Clarify extent to which new work would reduce uncertainty

UPPER COLUMBIA WHITE STURGEON

- Use of SDM to clarify uncertainty
  - Differences across technical experts
  - Reasons for these differences
  - Consensus position or agreement to disagree?
  - Used influence diagrams to clarify "hypothesis pathways"

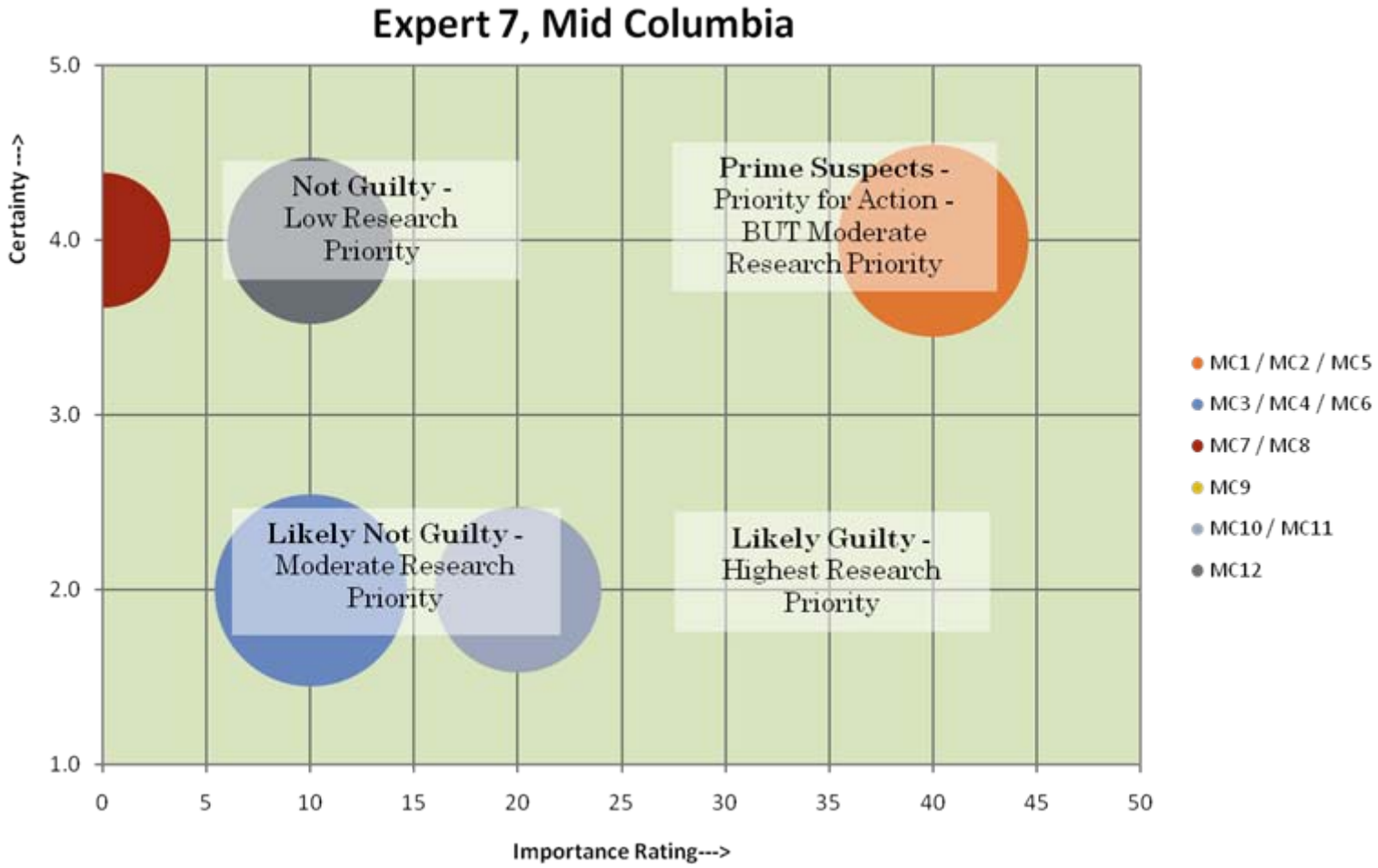
UPPER COLUMBIA WHITE STURGEON



UPPER COLUMBIA WHITE STURGEON

Q1	Q2	Q3
What % of ongoing RF is attributed to this H, based on current knowledge?	**How certain are you in your assessment for Q1?**	**How likely is it that further research could 'confirm' that this H accounts for <u>at least</u> 20% of ongoing RF?**
Distribute 100% points	5 = I expect I could be wrong by up to ±10% points	1 = Very unlikely (<20% chance)
	4 = I expect I could be wrong by up to ±20% points	2= Unlikely (20-40% chance)
	3 = I expect I could be wrong by up to ±30% points	3= As likely as not (40-60% chance)
	2 = I expect I could be wrong by up to ±40% points	4 = Likely (60-80% chance)
	1 = I expect I could be wrong by more than ±40% points	5 = Very likely (>80% probability)

UPPER COLUMBIA WHITE STURGEON



UPPER COLUMBIA WHITE STURGEON: work in progress (April 08)

- Key benefits of SDM process:
  - improved understanding of uncertainty about RF
  - more clarity about value of immediate mitigation vs. additional learning for key sources of RF
  - better understanding of consequences (WS life-stage, program cost, timing, permitting)
  - improved dialogue among participants
- Work still underway:
  - prioritize specific research / mitigation actions
  - establish rationale for sequencing of actions
  - contribute to revised recovery plan (U.S. / Canada joint actions)

CONCLUSION: HOW MIGHT SDM ASSIST ASSESSMENT OF WIND/WILDLIFE RISKS?

- Establishes consistent structure for understanding problem and for dialogue
- Links analysis and deliberation
- Provides forum for sound science
- Explicitly identifies desired endpoints / objectives
- Explicitly recognizes uncertainty
- Aids transparency & defensibility
- Aids communication, internal & external
- Aids implementation (reduces litigation?)
- Incorporates learning (e.g., adaptive strategies)