DSRRN Adaptive Management workshop
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science for a changing world

Part 3. Deciding what to do

Uncertainty and Adaptive Management

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Approaches to uncertainty

- What do we do in the face of uncertainty?
  1. Pt. 2. Make decisions anyway – robust SDM
  2. Conduct research to reduce uncertainty; make a decision later
     - Value of Information
     - Delay tactic?
  3. Both, simultaneously
     - Adaptive management
     - Dual control problem
       - ‘Management as Experiment’
       - Where do we direct our research attention?

2. Reducing uncertainty through research & monitoring

Value of Information

Information

- We often seek information to reduce or eliminate uncertainty
- Information comes at a price
- Will that information change our decision and enhance performance?
- Comparing EV with and w/o uncertainty allows us to quantify value of research to reduce uncertainty

Value of information

- Expected value of perfect information (EVPI)
  - Allows you to assess how much your management might improve by resolving structural uncertainty
  - Alternatively… value foregone by making decisions under uncertainty
  - Can help you decide if it’s worth the cost of gathering information

Example: EVPI

You are trying to minimize lost revenue from a gypsy moth infestation. You have three alternatives. You have two different models of how the gypsy moths (and hence your timber sales) will respond to the actions. Based on previous research, you think the likelihood of model 1 is 0.3. How much would you pay to find out which model is true?

Lost Revenue		**Alternatives**		
Weight	**Models**	Do Nothing	Reduce Colonization	Eradicate Large Patches
0.3	Model 1	$ 299K	$ 202K	$ 140K
0.7	Model 2	$ 493K	$ 256K	$ 273K

Decision Analysis with Uncertainty – Expected Value (EV)

Weight	Models	Do Nothing	Reduce Colonization	Eradicate Large Patches
0.3	Model 1	$ 299K	$ 202K	$ 140K
0.7	Model 2	$ 493K	$ 256K	$ 273K
		299 x (*w*)	202 x (*w*)	140 x (*w*)
	+	493 x (*w*)	256 x (*w*)	273 x (*w*)
	EV =	$ 434.8K	$ 239.8K	$ 233.1K

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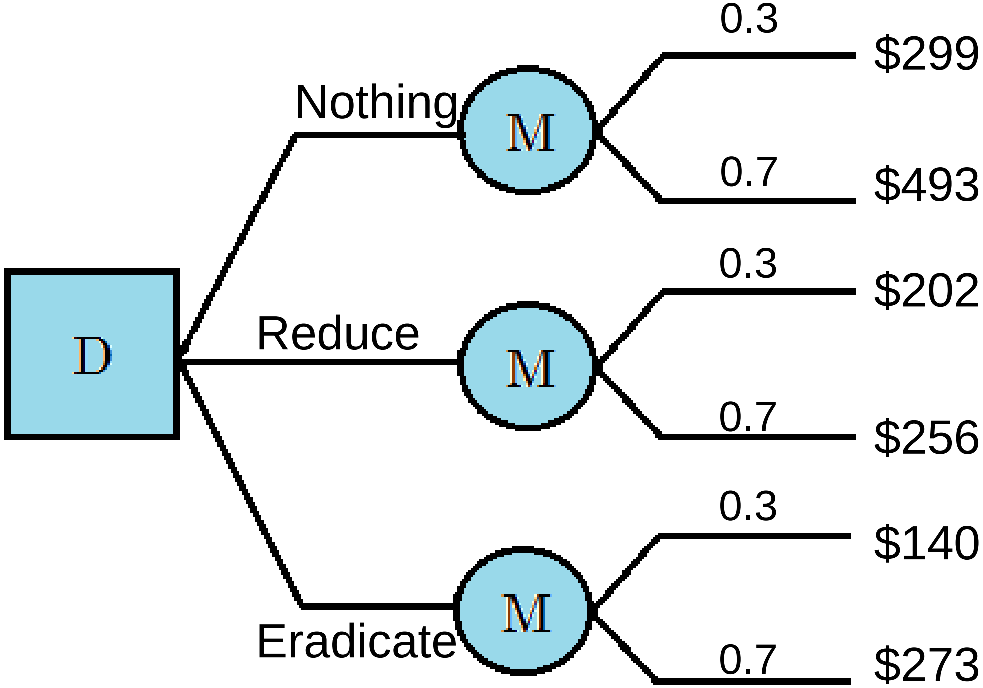
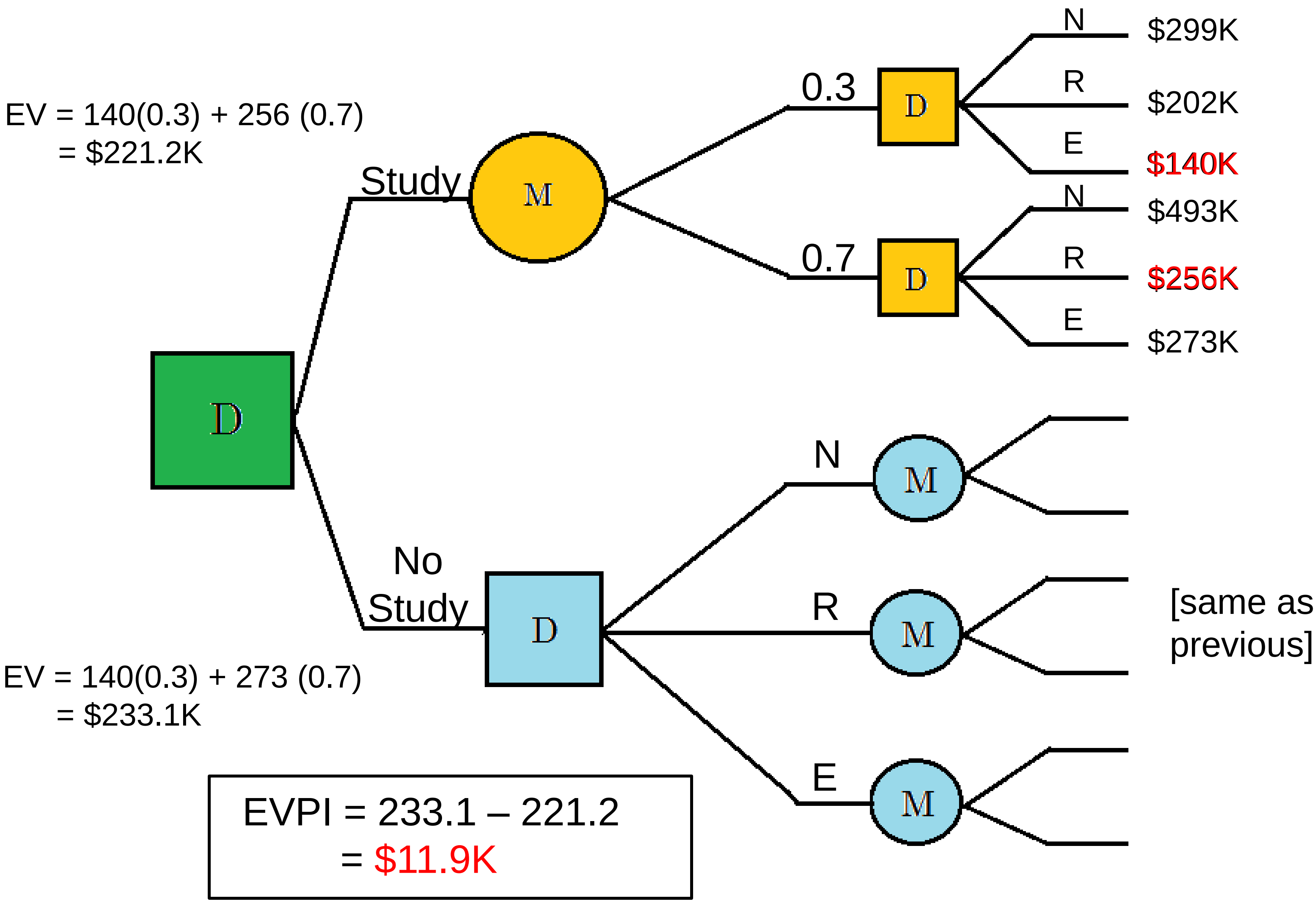


$EV_{(n)} = 434.8$

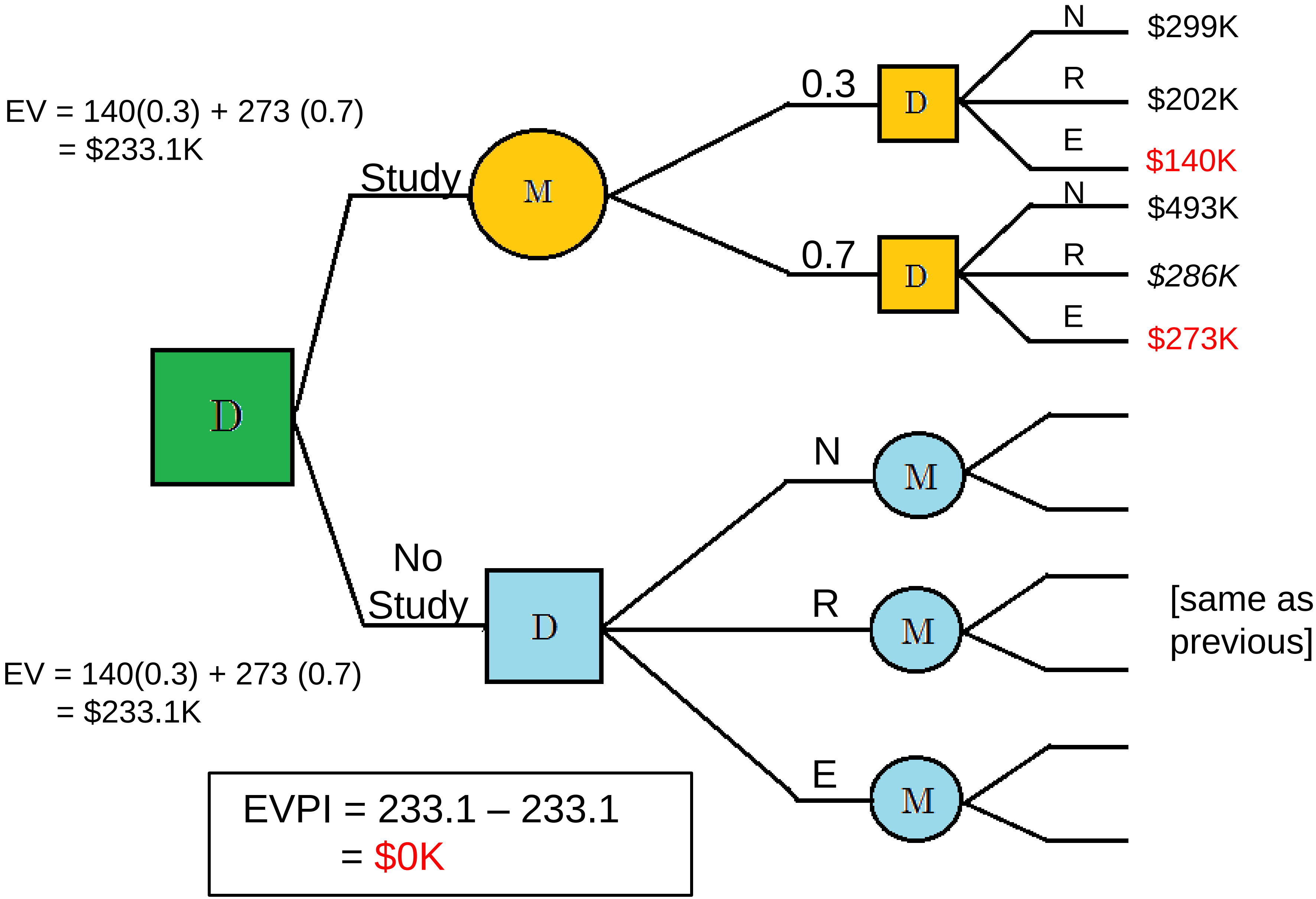
$EV_{(r)} = 239.8$

$Ev_{(e)} = 233.1$

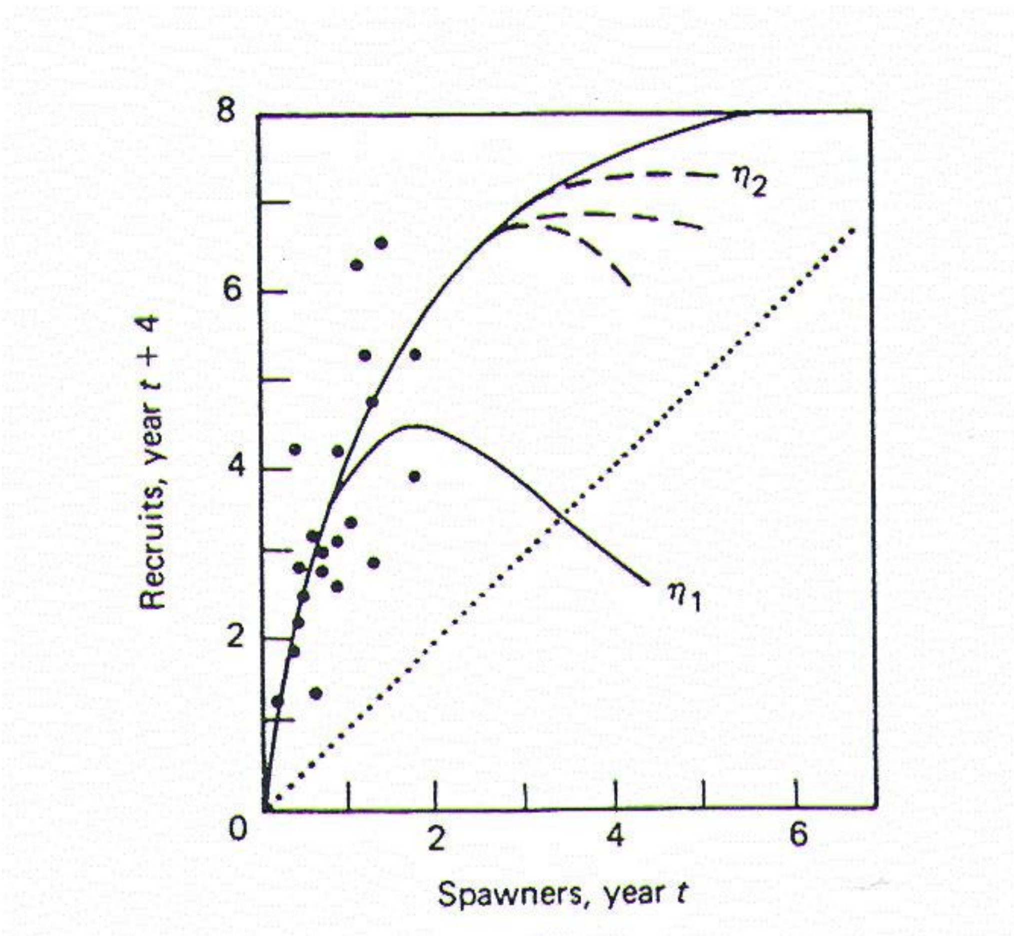
Resolve Uncertainty Before Deciding? EVPI



What is the VOI if the decision is insensitive to uncertainty?



Exercise: EVPI [from Walters (1986)]



Alternative states of nature:

n_1: Ricker

n_2: Beverton-Holt

$$n_1 : R = S \cdot e^{(1.96 - 0.44S + \omega)}$$

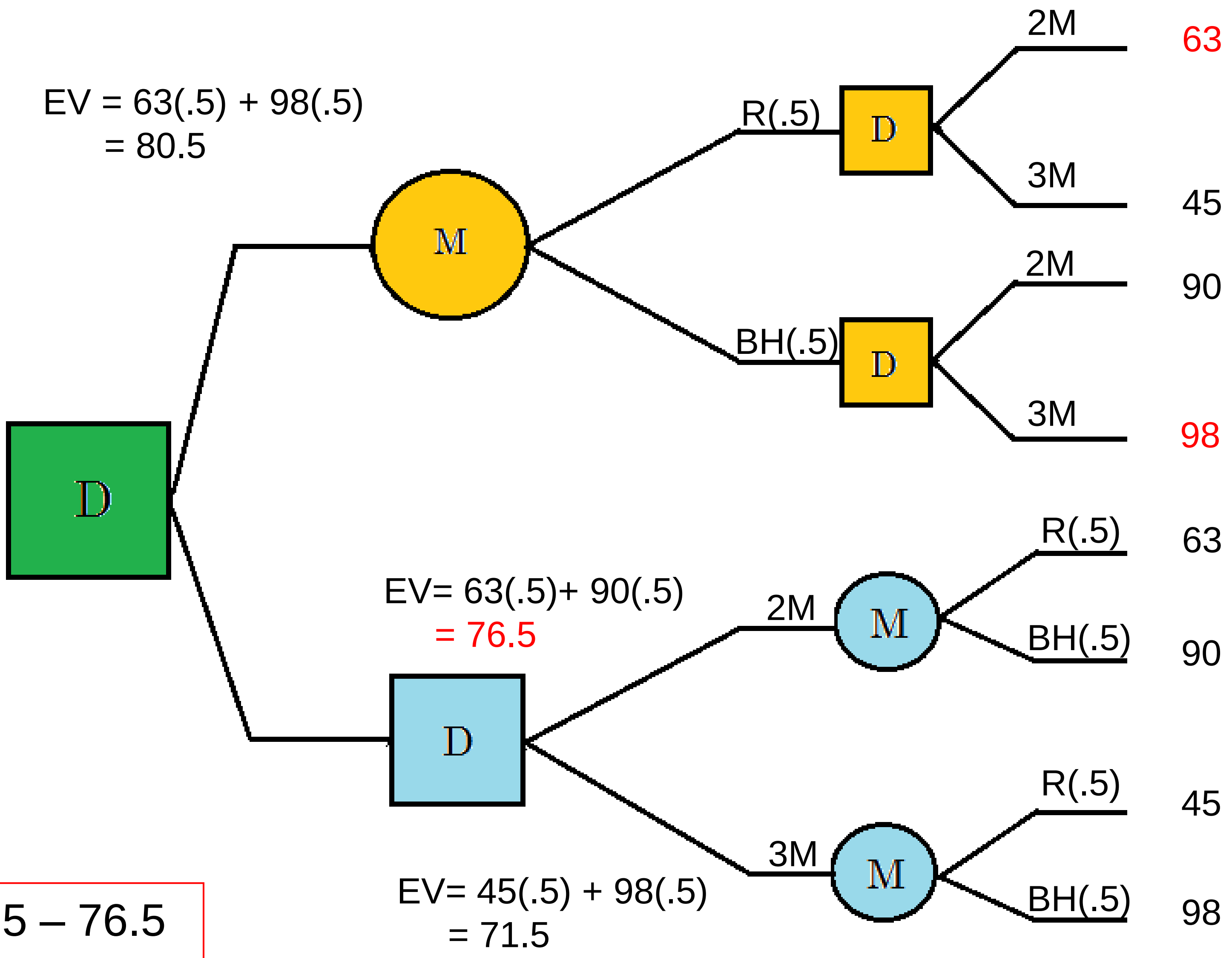
$$n_2 : R = \frac{S \cdot e^{\omega}}{(0.1237 + 0.07 \cdot S}$$

Exercise: Data

Harvest return (millions of fish over 20 years)

Model	Weight	Alternatives: escapement	
		2 Million	3 Million
Ricker	0.5	63	45
Beverton-Holt	0.5	90	98

Exercise: EVPI



EVPI = 80.5 – 76.5
= 4.0

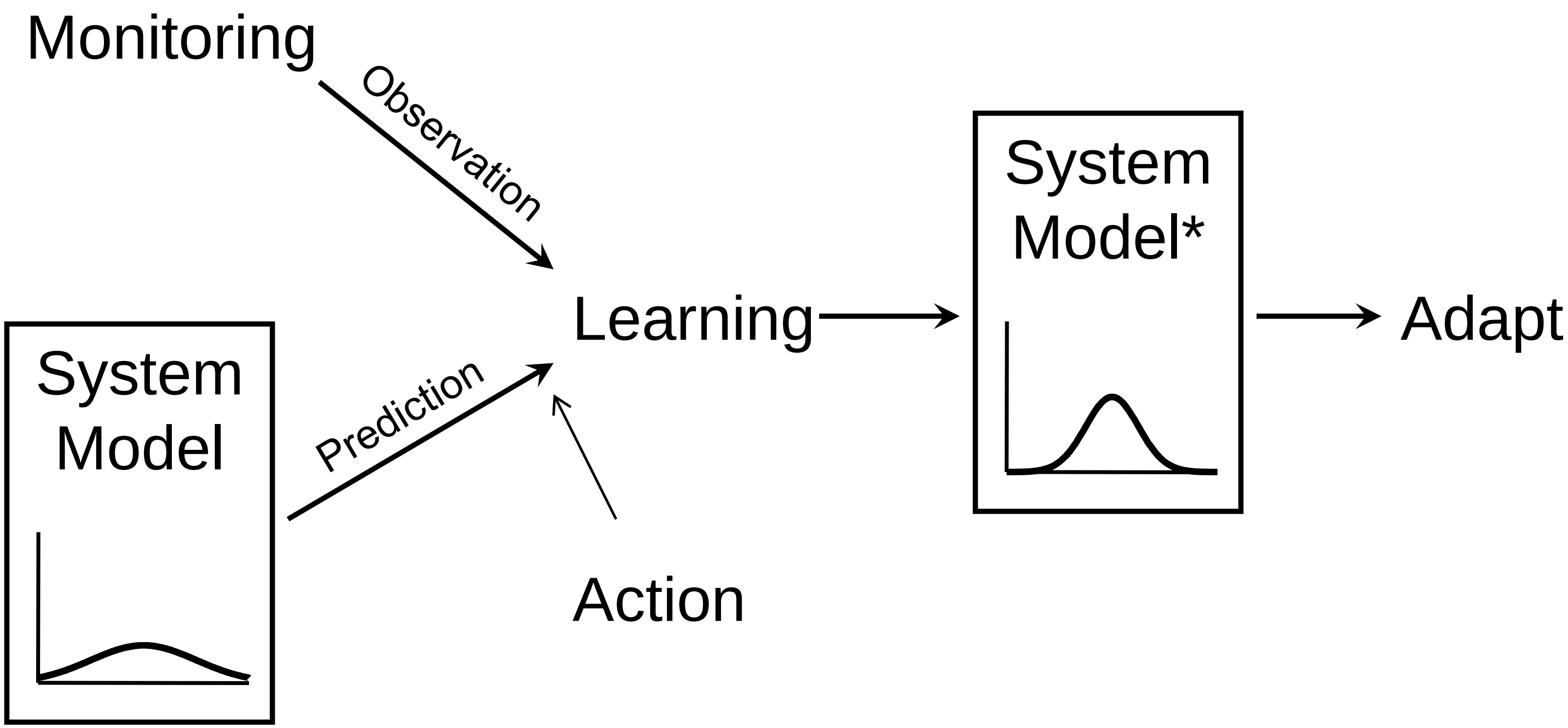
3. Reducing uncertainty while making decisions

Adaptive Management

Adaptive management

- Seeks to optimize management decisions, with value accrued over time, in the face of uncertainty,
- using learning at one stage to refine understanding and influence decisions at subsequent stages,
- while considering the acquisition of information in the optimization (dual control problem).

Adaptation



Monitoring
Observation
System
Model
Prediction
Learning
Action
System
Model*
Adapt

Model Weights

- We can express structural uncertainty with a discrete set of alternative models
- Weights associated with those models reflect relative degrees of faith
- Weights sum to 1 for all members of model set
- Updating model weights
  - Each model makes a prediction
  - Comparison of those predictions to the observed result (monitoring) allows updating
  - Bayes Theorem used to update based on:
    - Previous weights
    - Comparison (prediction versus monitoring)

Ex: AHM - four population models

Hunting Mortality	Density Dependence: Weak	Density Dependence: Strong
Additive	★ additive hunting ★ weakly d-d recruitment (SaRw)	★ additive hunting ★ strongly d-d recruitment (SaRs)
Compensatory	★ compensatory hunting ★ weakly d-d recruitment (ScRw)	★ compensatory hunting ★ strongly d-d recruitment (ScRs)

Adaptive Management & Learning

1. For all possible actions, predict outcome based on each model

E.g

- Mallard harvest package
  - Model input: Current pop. size, #ponds
  - Harvest Packages (alternatives): 1) liberal 2) mod. 3) conservative
  - Output (prediction): Pop. size in year t+1

Adaptive Management & Learning

2. Select best management option, based on weighted model predictions.

   [Where do we get model weights?]

2. Implement decision and monitor population response

Adaptive Management & Learning

4. Calculate likelihood of observing data under each model (i.e. comparison of predicted vs. obs.)

$$L(\text{data} \mid \text{model}_i)$$

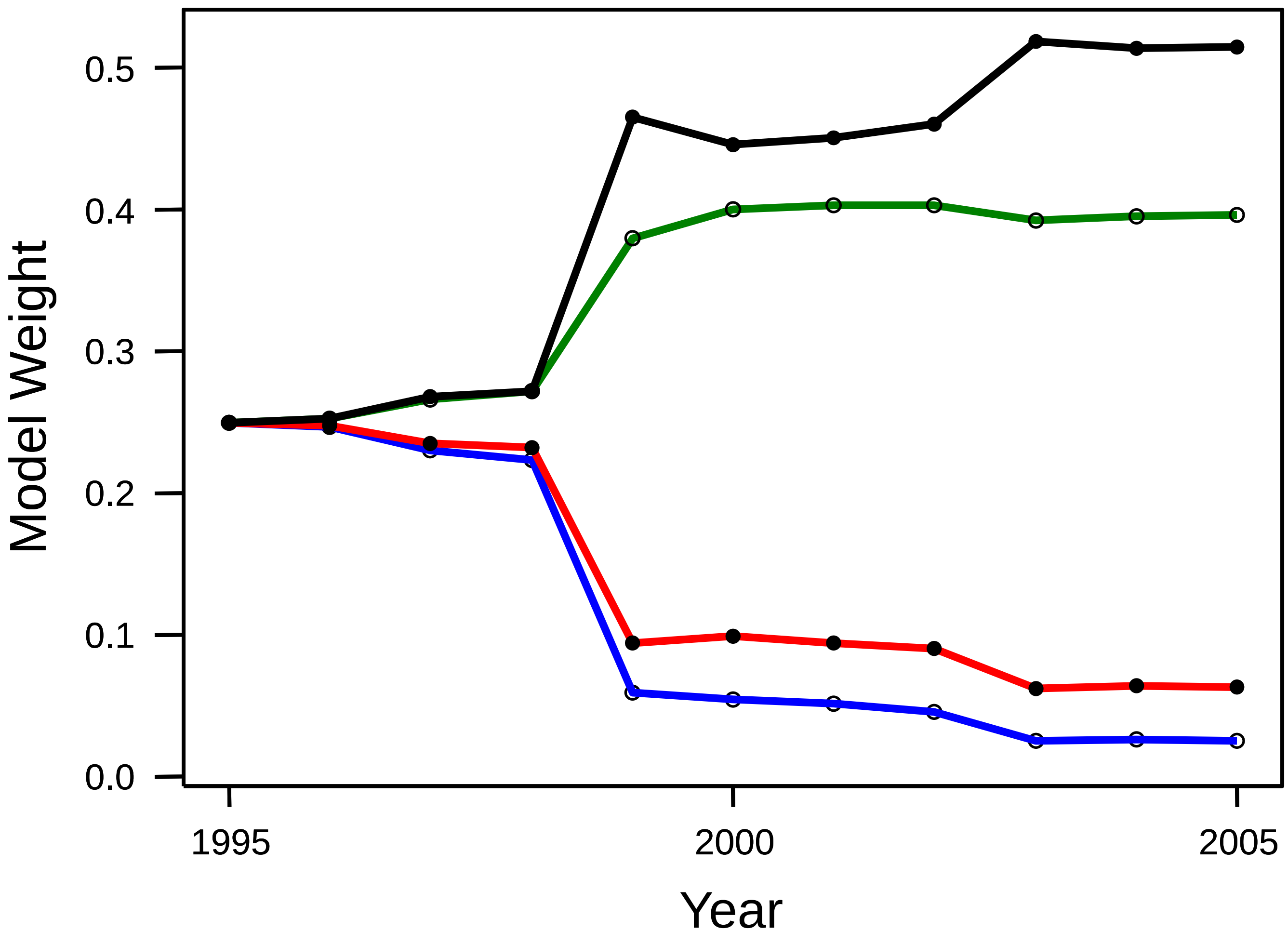
5. Update model weights via Bayes Theorem

$$\Pr(\text{model}_i \mid \text{data}) = \frac{L(\text{data}|\text{model}_i)\Pr(\text{model}_i)}{\sum(\text{data}|\text{model})\Pr(\text{model})}$$

Adaptive Management & Learning

6. Select next optimal decision based on:
   - current system state (Pop & pond #s)
   - outcome predicted by each model, weighted by updated model confidence

Learning: AHM



Additive,
Weak DD

Compens.,
Weak DD

Additive,
Strong DD

Compens.,
Strong DD

4. Extensions to Adaptive Management and Learning

'Smarter learning while doing'

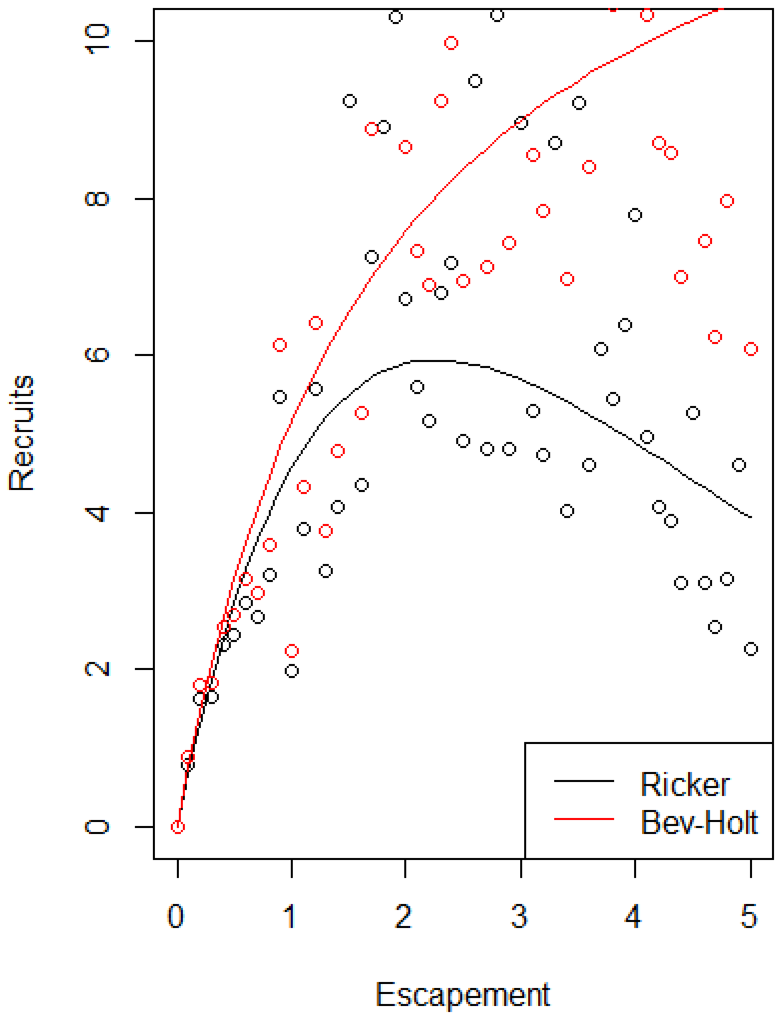
Partial EVPI (EVPXI)

- Typical AM does not include a priori analysis of which uncertainties are worth reducing!
- What is the value to mgmt. of minimizing a given source of uncertainty?
- EVPXI compares importance of different sources of uncertainty
  - ex: is reducing uncertainty about survival rates more valuable for mgmt. than uncertainty about recruitment?

Imperfect Information – EVSI

- Unlikely that we can eliminate uncertainty altogether through research or monitoring
- Measures expected improvement from a sample of information
- Can inform experimental design and which actions (i.e., sub-optimal) might have largest impact on uncertainty

Ex: EVSI



- Selection of small escapement 0~2 has low EVSI
- Larger escapement may be sub-optimal, but high EVSI
- Dual control: short-term cost for long-term gain
  - Is ‘probing’ warranted?

VOI - references

Yokota & Thompson (2004) *Medical Decision Making*.

Runge, Converse & Lyons (2011) *Biological Conservation*.

Williams, Eaton & Breininger (2011) *Environmental Modelling*.

Walters (1986) Adaptive Management of Renewable Resources.

Raiffa & Schlaifer (1961) Applied Statistical Decision Theory.

Conclusion: AM & uncertainty

- All management decisions made with imperfect information.
- Sometimes, delaying a decision to learn is warranted (EVPI)…but, doing nothing *IS* a decision! Should be evaluated.
- AM allows us to make optimal decisions with current uncertainty & learn while doing.
- We can do it smarter! (EVPXI, EVSI)