# An Introduction to Adaptive Resource Management

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# Recurrent decisions

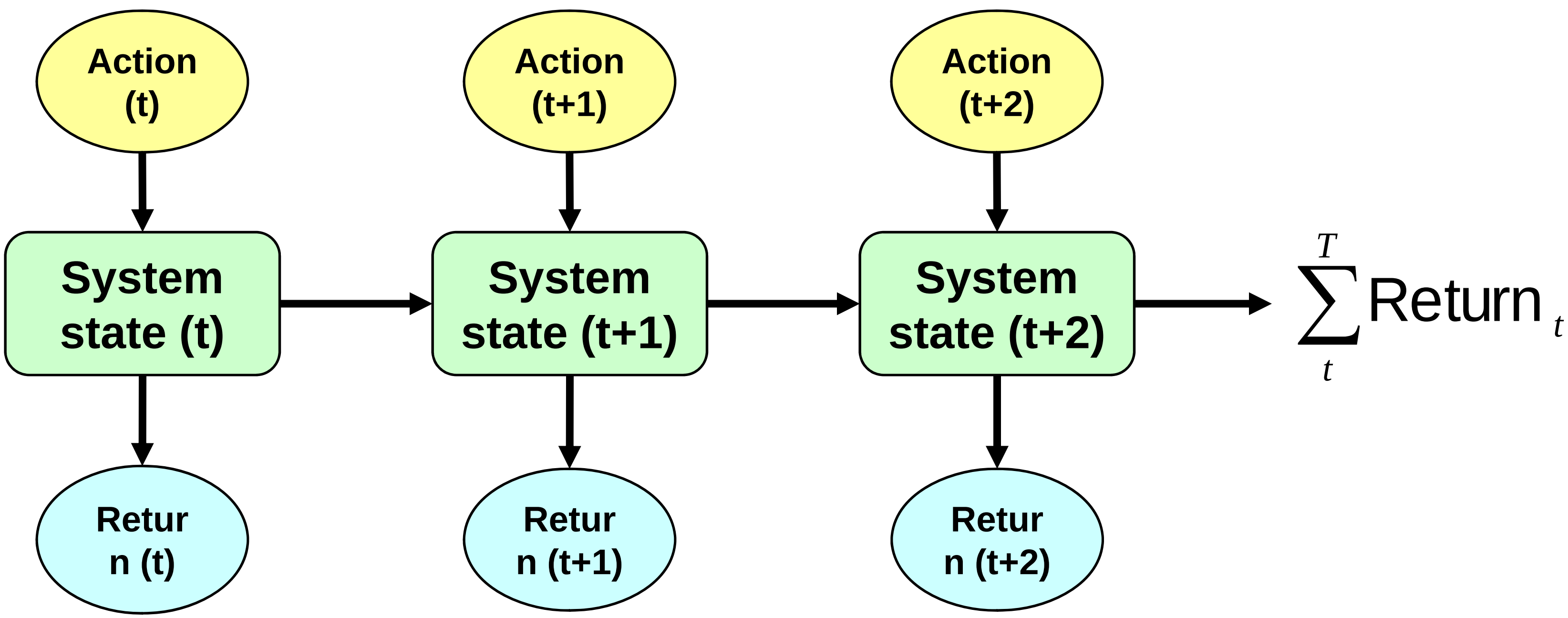
- Some decisions are repeated over time, at regular (or irregular) intervals

- What makes recurrent decisions different?

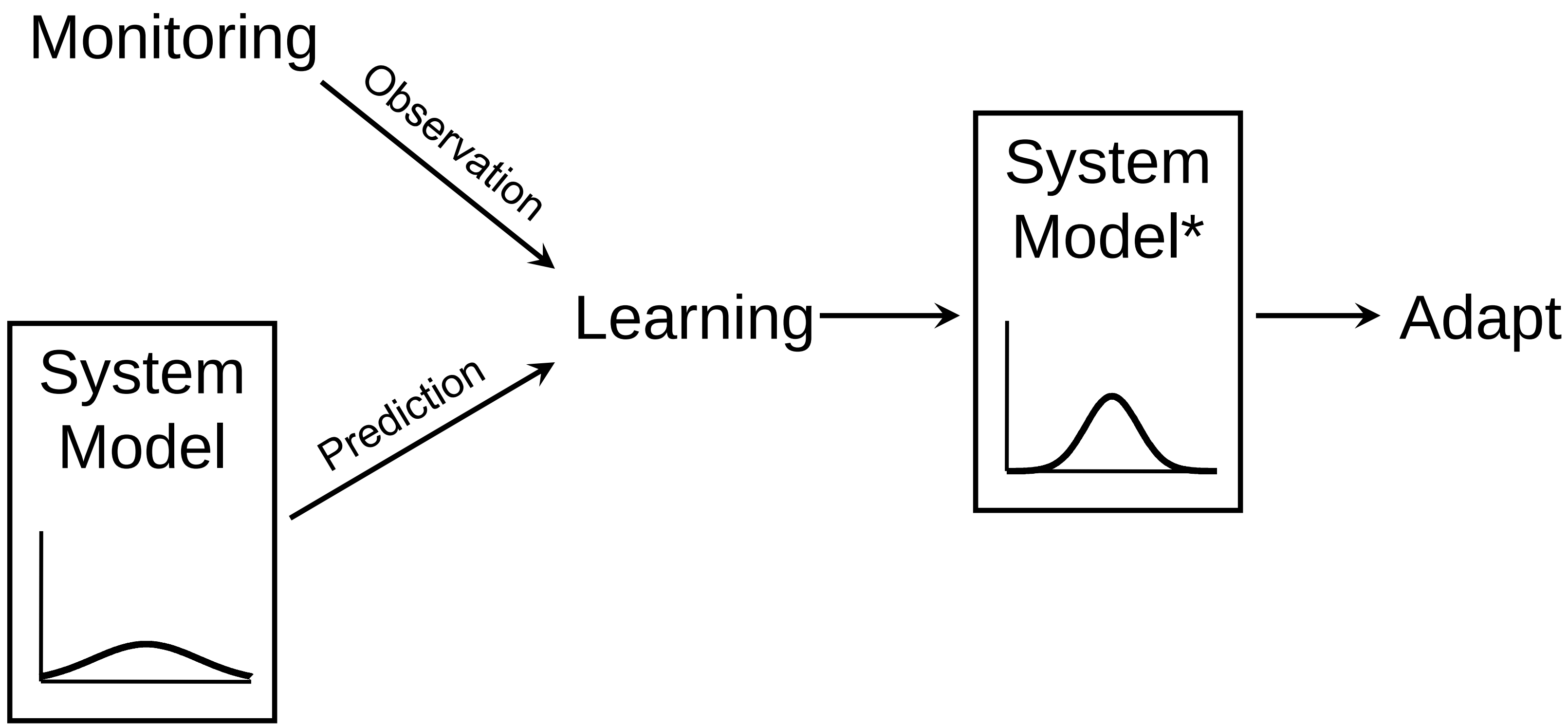
# Recurrent decisions: what's different?

- Added complexity
  - Current decisions influence future state(s) and, therefore, future actions
  - "Tomorrow is the price for yesterday." (Bob Seger 2007)
- Opportunity to learn
  - Comparison of model-based predictions with monitoring data permit learning

# Dynamic


Action
(t)
Action
(t+1)
Action
(t+2)
System
state (t)
System
state (t+1)
System
state (t+2)
$\sum_{t}^{T} \text{Return}_t$
Retur
n (t)
Retur
n (t+1)
Retur
n (t+2)

# Adaptive



Monitoring
Observation
System
Model
Prediction
Learning
System
Model*
Adapt

# SDM for recurrent decisions

- How do the elements of SDM need to be thought of for recurrent decisions?
  - Objectives
  - Actions
  - Models
  - Monitoring & Learning
  - Optimization

# Objectives

- As in SDM, objectives retain their primacy
  - Objectives drive the development of other aspects of the ARM framework
- For decisions by public agencies, there may be significant input from stakeholders in setting objectives
  - A careful process for developing these objectives is often needed
  - Balance regulatory responsibilities of agencies (legislative mandate) with current input from stakeholders

# Dynamic objectives

- For recurrent decisions, the objectives may need to reflect the accrual of benefits and costs over time
  - This can be explicit, e.g., $\max \sum_{t=0}^{\infty} H_t$
  - Or implicit, e.g., min Pr($E_{100}$)

# Actions

- For recurrent decisions, some consideration needs to be given to how the set of alternative actions may change over time

- Several scenarios
  - Fixed set of alternatives
  - Time-dependent set of alternatives (linked decisions)
  - Dynamic set of alternatives (known dynamics)
    - i.e., decision today affects options tomorrow, in known way
  - Developing an adaptive set of alternatives

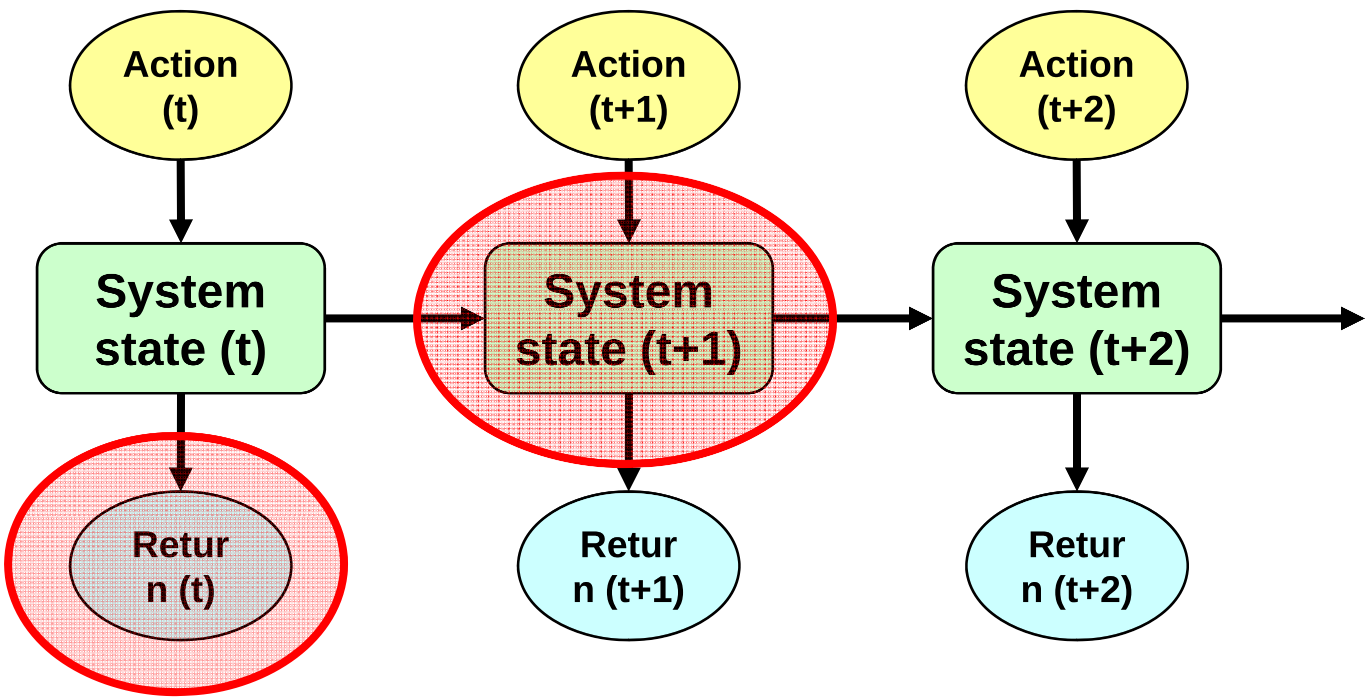
# Evolution of objectives and actions

- "Double-loop learning"
  - Experience with process and/or changes in stakeholder attitudes may make it useful to revisit objectives
  - Alternative management actions may evolve as the problem is re-framed

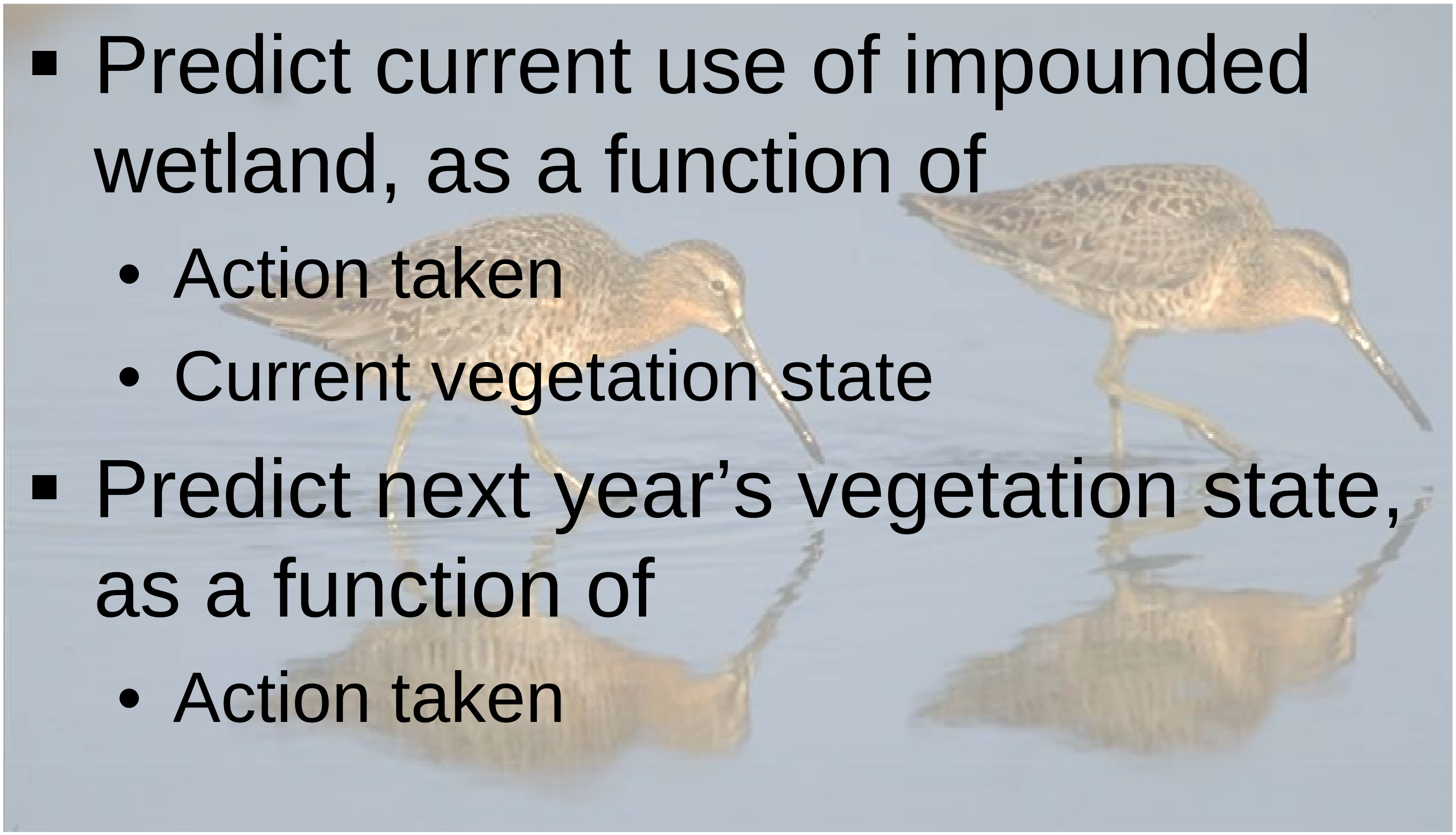
# Models for recurrent decisions

- Primary use: dynamic predictions
  - What is the expected current return (value) of a particular action?
  - How will the resource conditions change as a result of an action? (Hence, how will future returns change?)

# Dynamic models

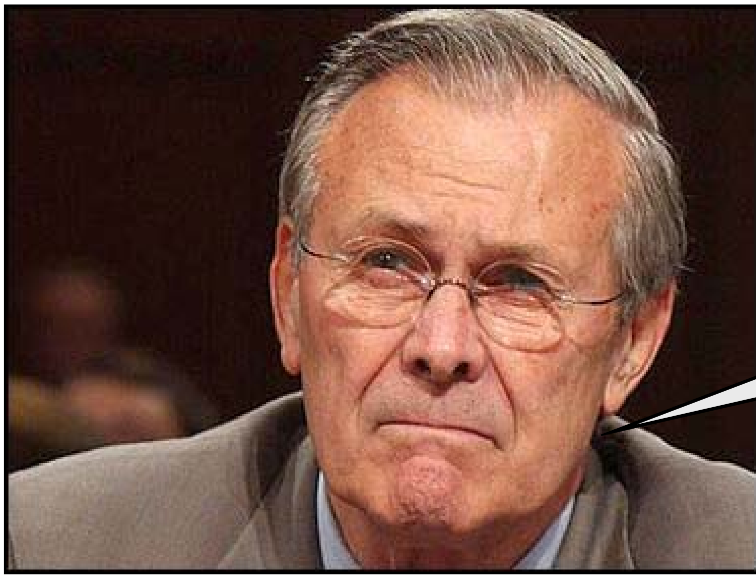


# Shorebird use of wetlands



- Predict current use of impounded wetland, as a function of
  - Action taken
  - Current vegetation state
- Predict next year's vegetation state, as a function of
  - Action taken

# But, we acknowledge uncertainty

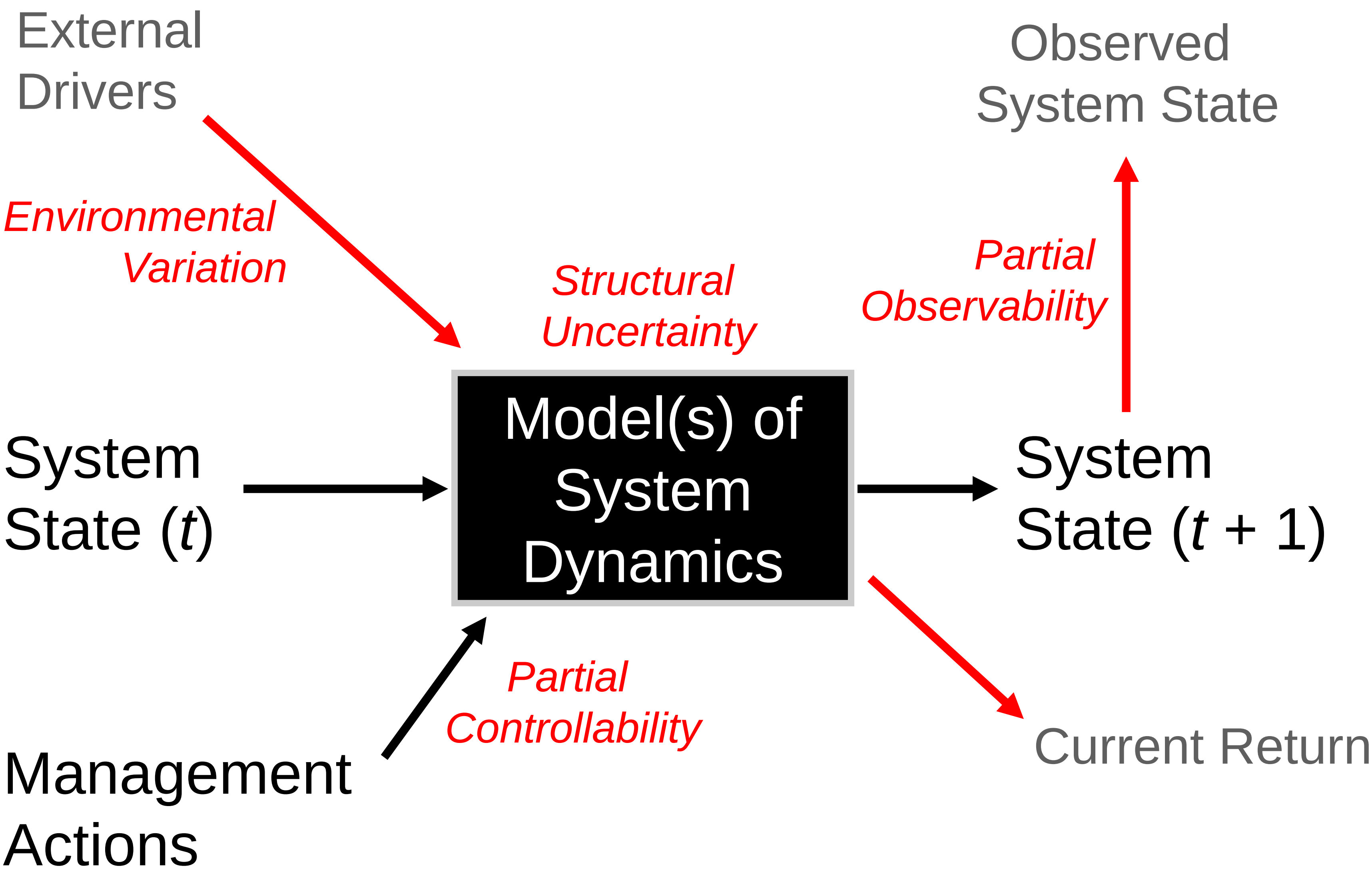


"…as we know, there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns -- the ones we don't know we don't know…"

# Forms of uncertainty

- Environmental variation
- Partial controllability
- Partial observability
- Structural uncertainty
  - a form of epistemic uncertainty about the effects of management actions
  - a focus of adaptive management

# Forms of uncertainty

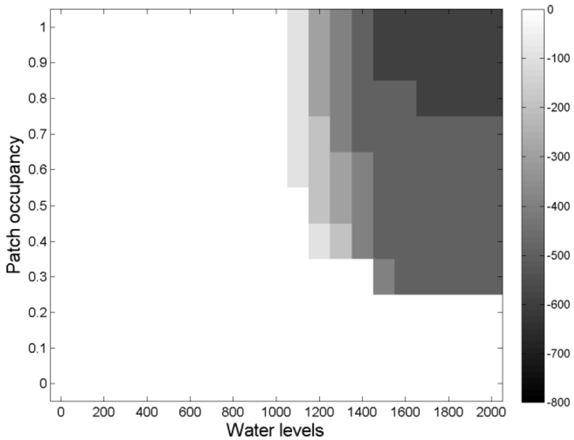


# Model (structural) uncertainty

- Ecological (structural) uncertainty
  - Nature of system dynamics is not completely known
  - Competing ideas about system response to management actions
- The focus needs to be on uncertainty about the effects of alternative actions
  - Uncertainty that matters to your ability to achieve your objectives

# Multiple models in optimization

T=1500

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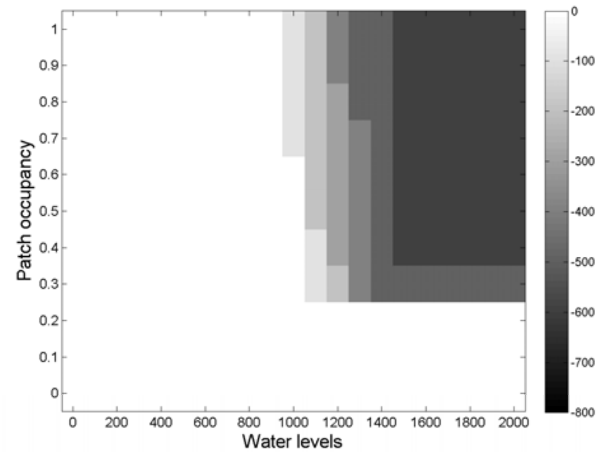
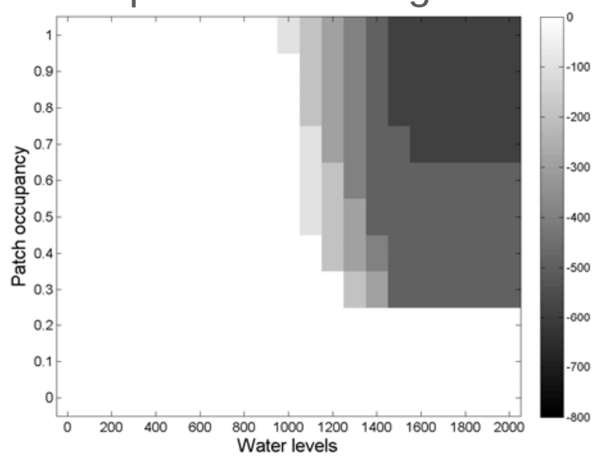



Equal Model Weights



# Monitoring

- Purposes
  - To assess the state of the system for the purpose of making state-dependent decisions
  - To determine if the objectives are being met
  - To resolve uncertainty

- The development of the monitoring system should be tailored to these needs & driven by the decision context

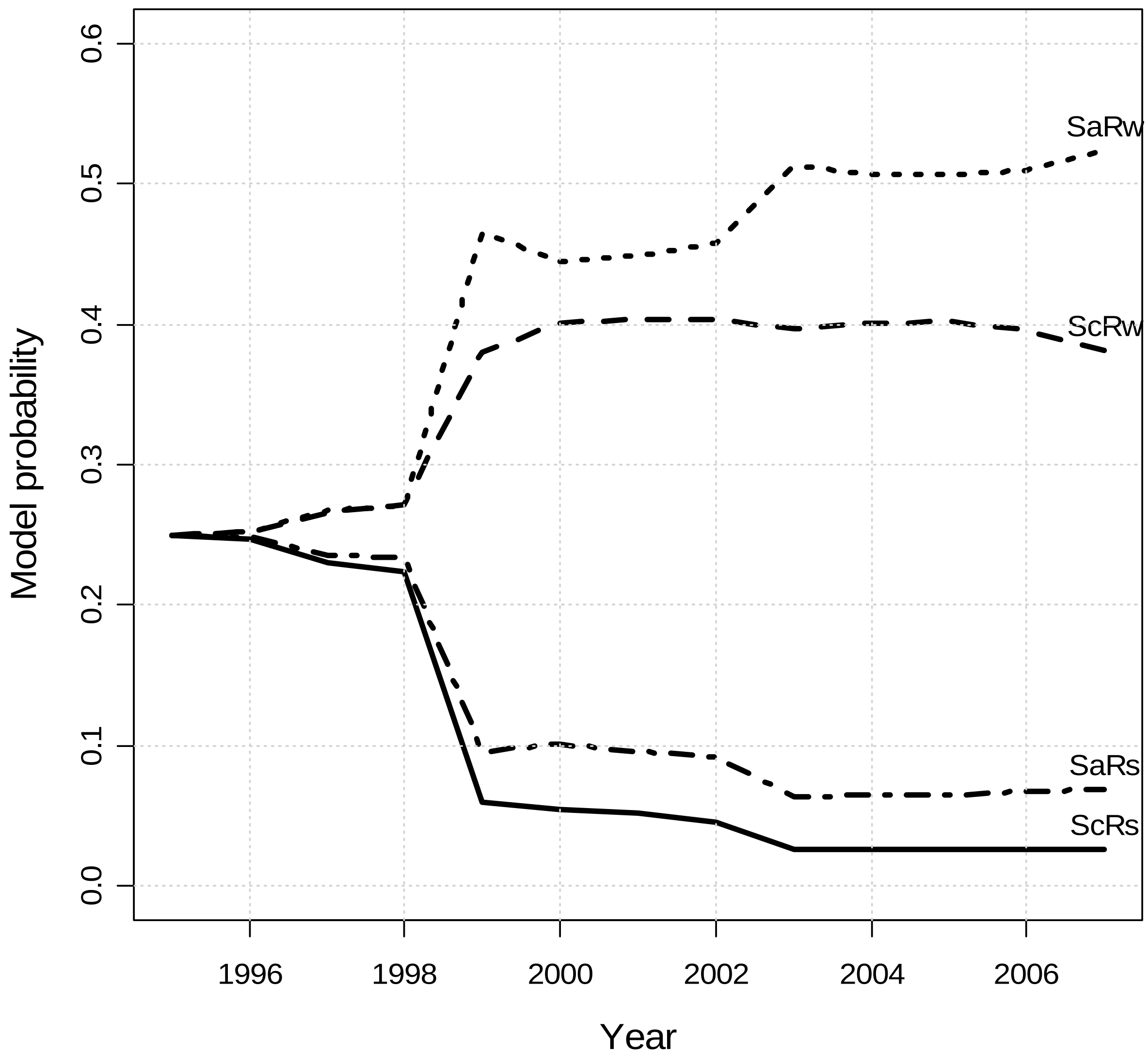
# Learning

- Learning
  - Resolution of structural uncertainty over time
- In a management setting
  - Learning is not the ultimate goal, although it might be a proximate goal
  - How will learning be applied to subsequent decisions?
- In essence, the way to grapple with uncertainty:
  - Make short-term predictions you can test, then reassess the situation
  - But have a clear plan for how learning will change future decisions

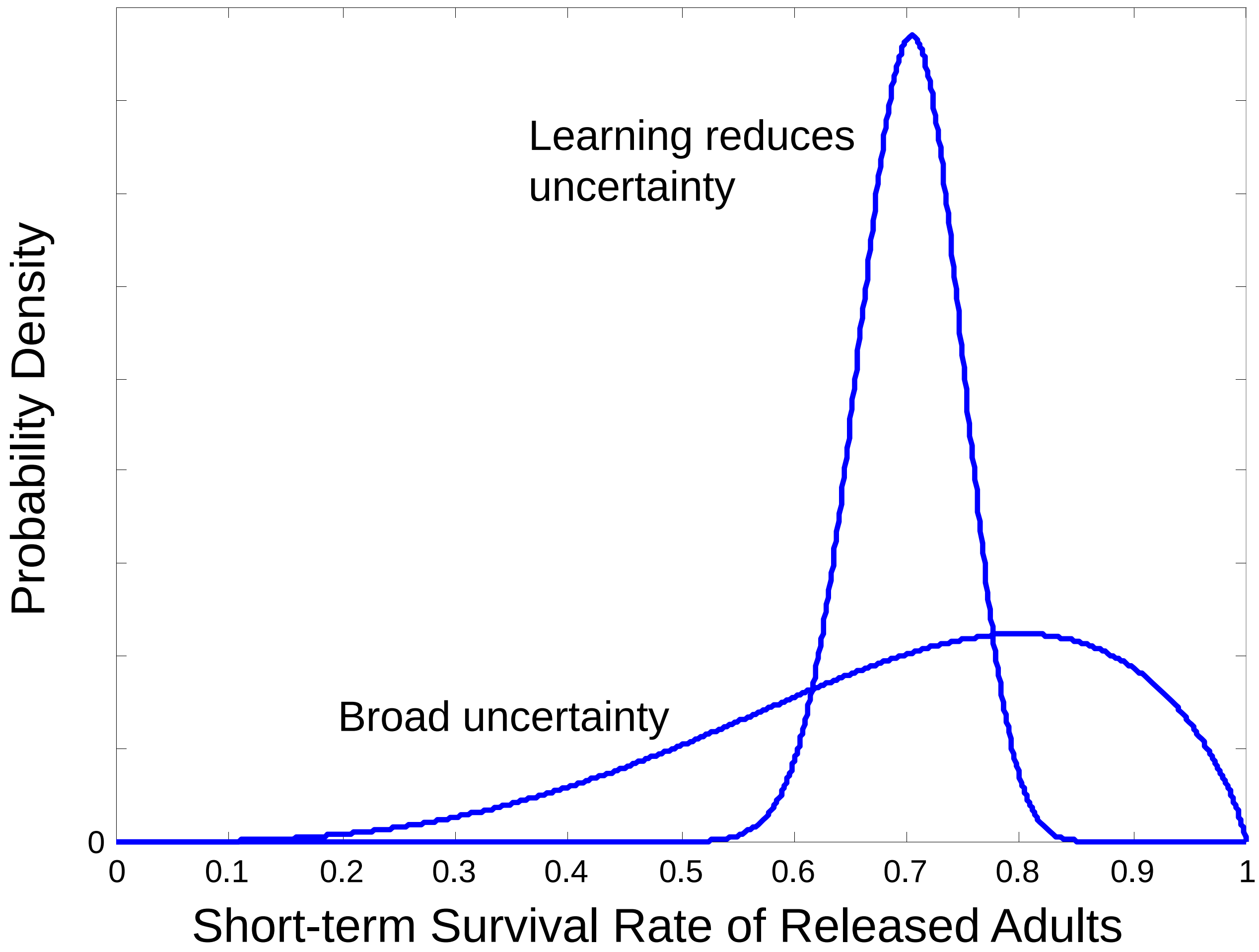
# Model weights

- Often, we can express structural uncertainty with a discrete set of alternative models
- Weights associated with those models reflect relative degrees of faith
- 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 comparison

# Adaptive Harvest Management



# Continuous set of models

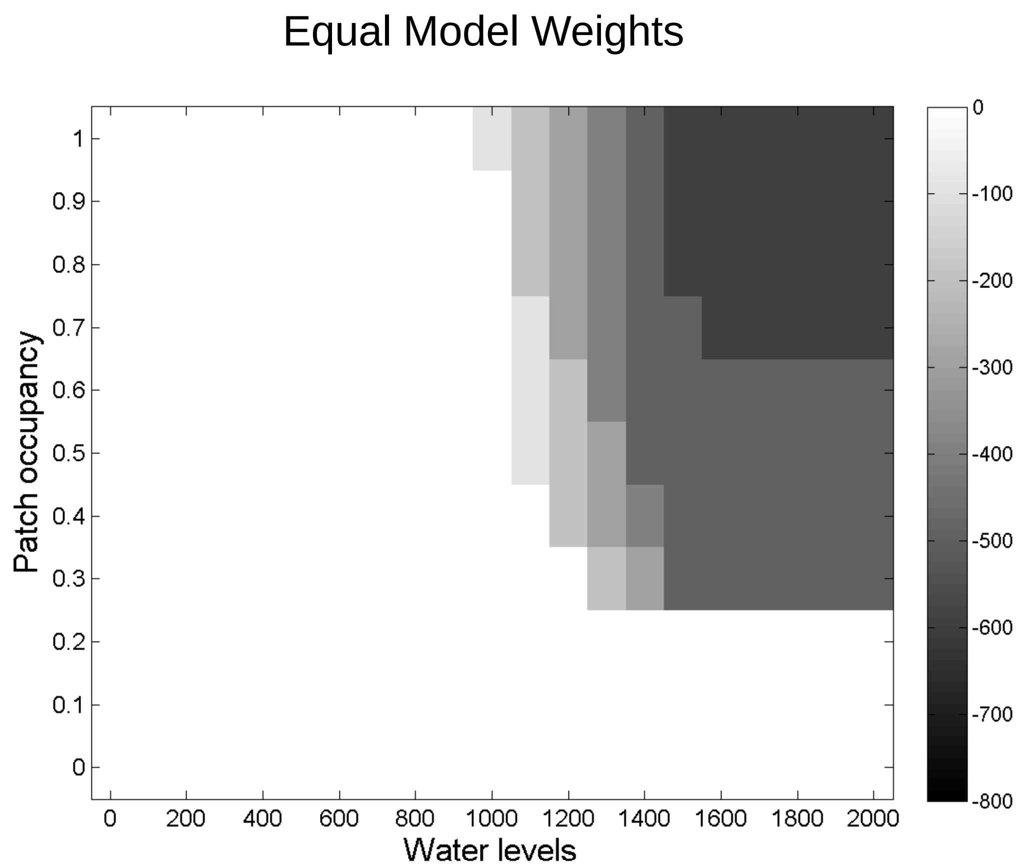


# Optimization

- As in SDM, the role of optimization is to find the action that best achieves the objectives, given the predictions from the model(s)

- For recurrent decisions, the optimization may need to be
  - Dynamic
  - Adaptive

# Dynamic optimization



# Adaptive optimization

- Actions have the potential to reduce uncertainty
  - Perhaps not equally

- Thus, we need to also anticipate how uncertainty will change over time, and how that will affect future decisions

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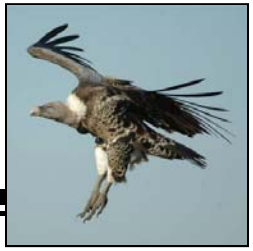
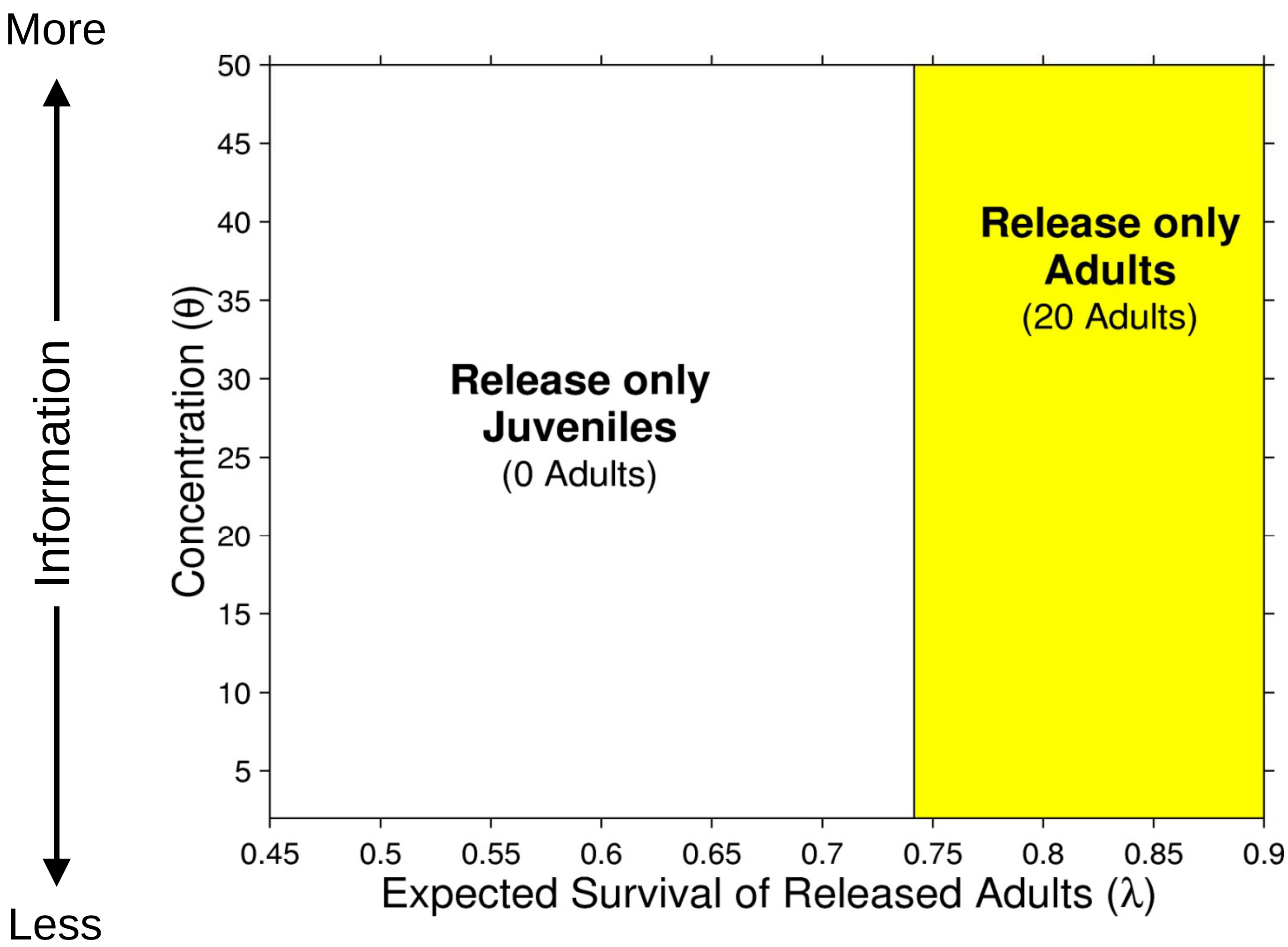
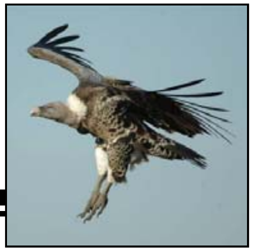
- Actions have the potential to reduce uncertainty, perhaps not equally
- Thus, we need to also anticipate how uncertainty will change over time, and how that will affect future decisions
- Adaptive optimization deals with the "dual-control problem", balancing
  - the short-term costs of learning, with the
  - long-term benefits of learning (are "probing" actions warranted?)
- Approaches to adaptive optimization:
  - Discrete model set: carry information state (vector of model weights) as a state variable
  - Models characterized by key parameter of general model: parameter value and variance are relevant

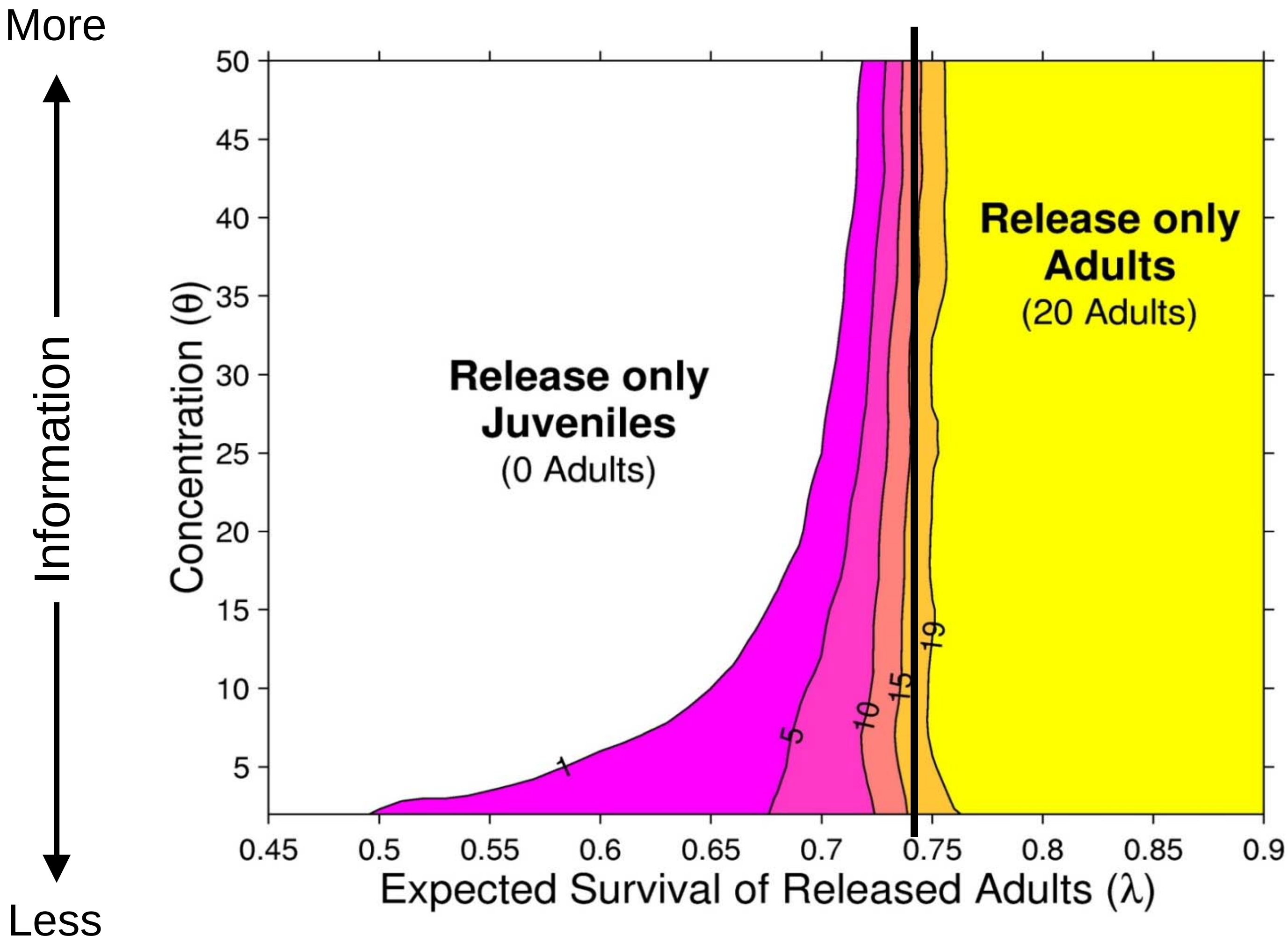
# Non-adaptive solution





# Adaptive solution





# Motivation for AM

- All management decisions are made without perfect knowledge
- This uncertainty is what makes decisions difficult
- Any management decision can potentially provide the chance to learn
- Iterated decisions can be adaptive

# Adaptive Management

- Seeks to optimize management decisions in the face of uncertainty,
- using learning at one stage to influence decisions at subsequent stages,
- while considering the anticipated learning in the optimization.

# AM or SDM?

- Is the decision recurrent?
- Is there structural uncertainty that matters in terms of management decisions? (do we need to learn?)
- Is there a monitoring program that is sufficiently focused and precise to discriminate among alternative hypotheses / models? (can we learn?)
- Is there an ability to change management strategy in response to what is learned? (can we adapt?)
- If “yes” to all, then AM

# Adaptive Management: process

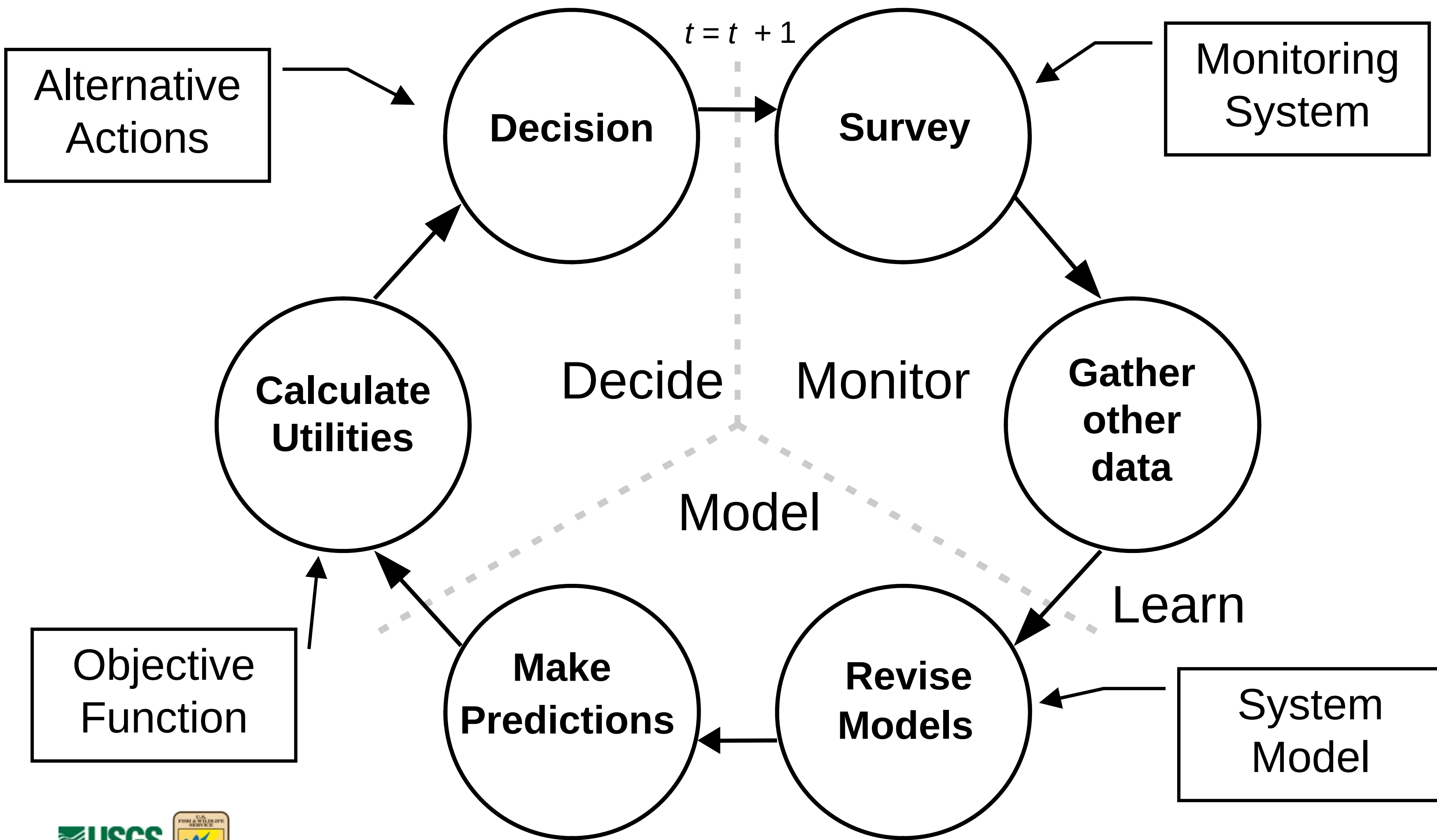
- Use dynamic optimization to select management action based on:
  - (1) objectives
  - (2) available management actions
  - (3) estimated state of system
  - (4) models and their measures of credibility

- Action drives system to new state, identified via monitoring program

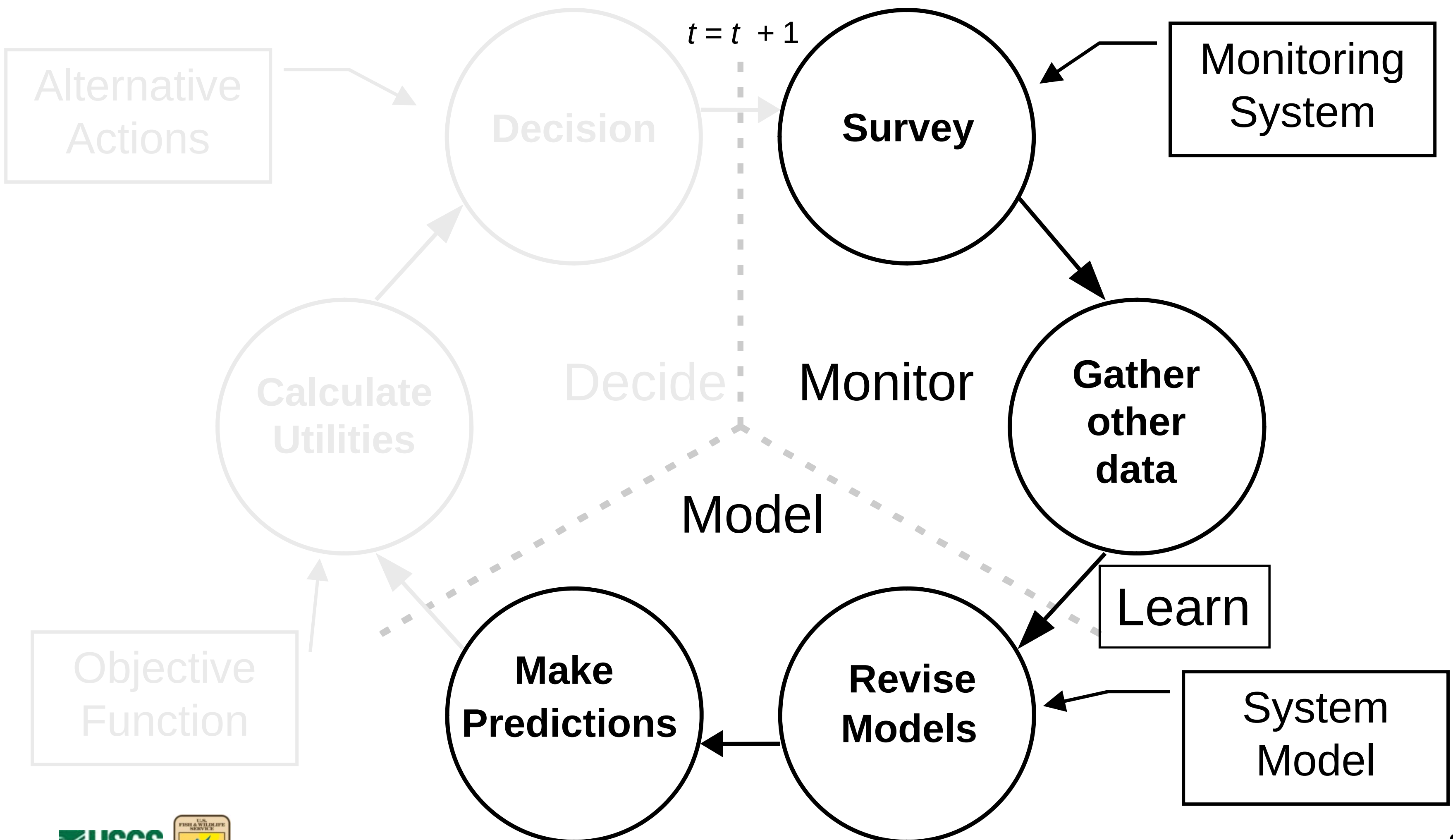
- Compare estimated and predicted system state to update measures of model credibility

- Return to first step

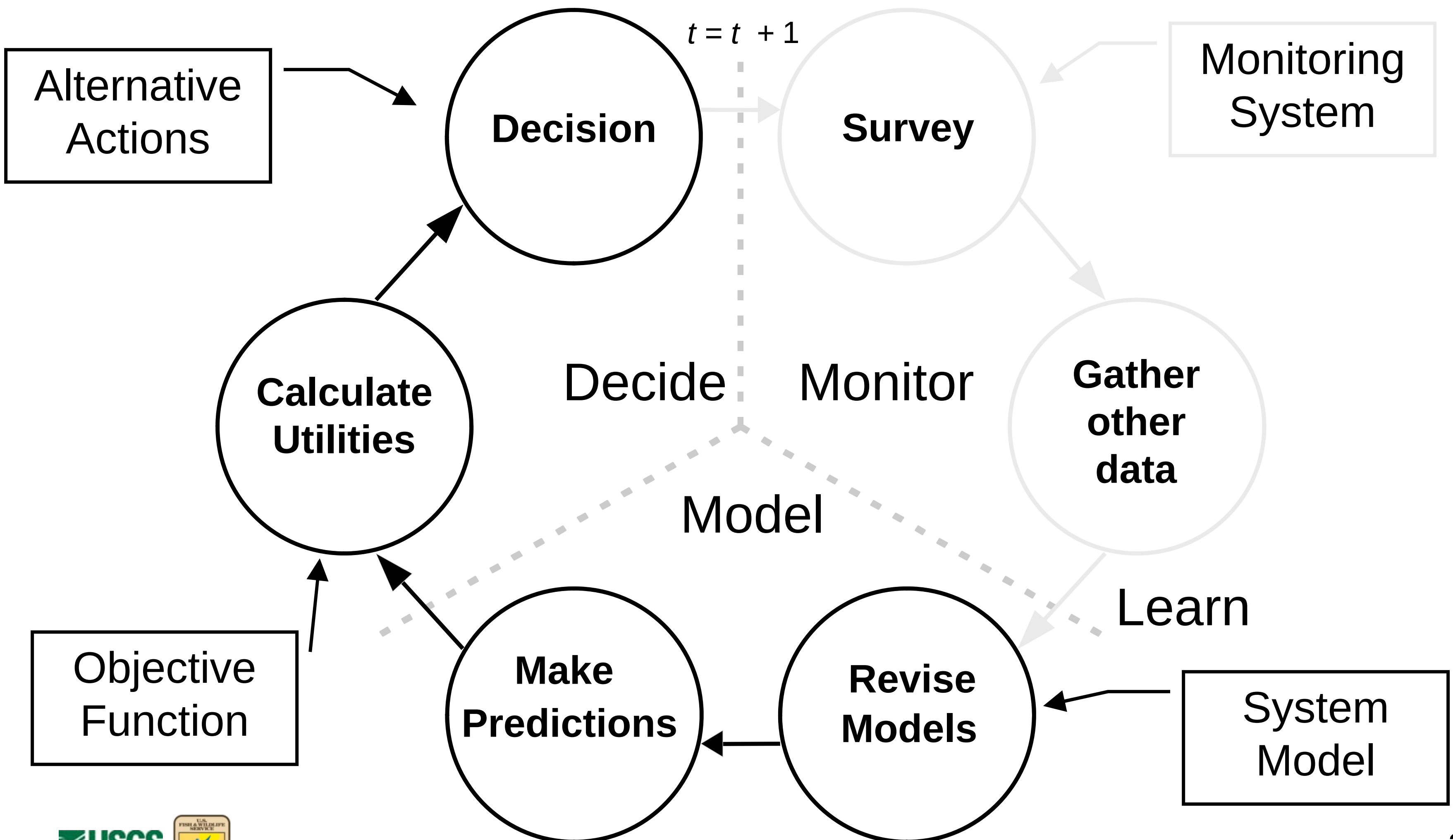
# Adaptive Management



# Learning ("Adaptive")



# Optimization ("Management")



# Institutional Stuff

# Public decisions

- Many natural resource management decisions involve public agencies

- So, many ARM applications need to involve the public in
  - Problem framing
  - Objectives setting
  - Joint fact finding
  - Implementation

- This calls for participatory, deliberative processes in which communication is paramount

# Framing the problem

- That is, recognizing the core elements of the decision and how they fit together

- This is one of the hardest parts

# How to frame ARM problems?

- Ask what the decision is

- Identify the elements of the decision
  - Objectives, actions, models, etc.

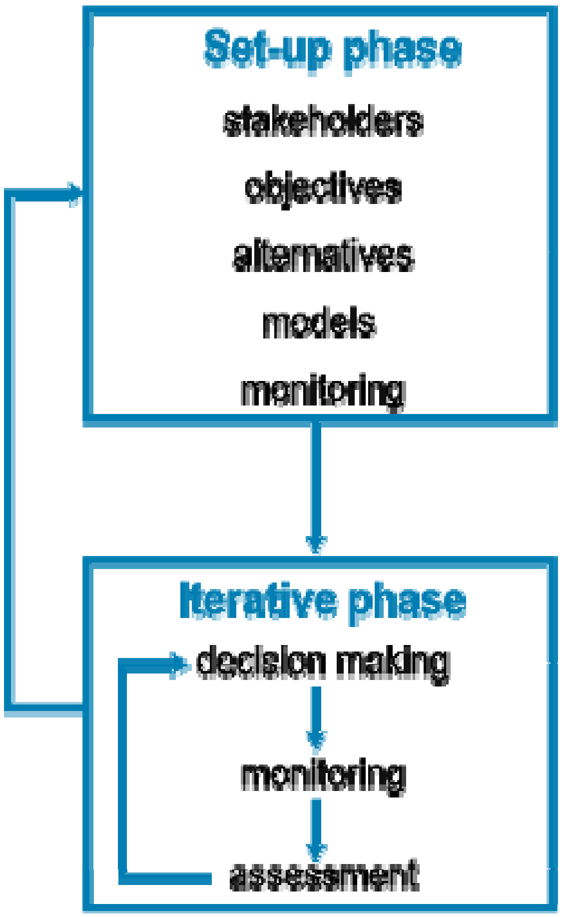
- Ask what impedes the decision
  - What uncertainty makes the decision difficult?
  - This is the motivation for ARM

# Iterative problem framing

- Often, problem framing is iterative
  - Start with a prototype structure
  - Perform some initial analysis
  - Revise the prototype
  - Implement & gain experience
  - Revise the structure…

- It is sometimes difficult to understand the core issues of a problem until you've implemented a prototype structured approach

# Double-loop learning



# Summary

- AM involves recurrent decisions in which predicted outcomes are uncertain
- Of the 4 flavors of uncertainty, the focus in AM is on structural uncertainty
- Learning in AM might be passive or active
- In practice, AM faces many obstacles (as does any informed approach); requires persistence and openess to double-loop learning