Adaptive Management: Concepts, Applications, & Challenges

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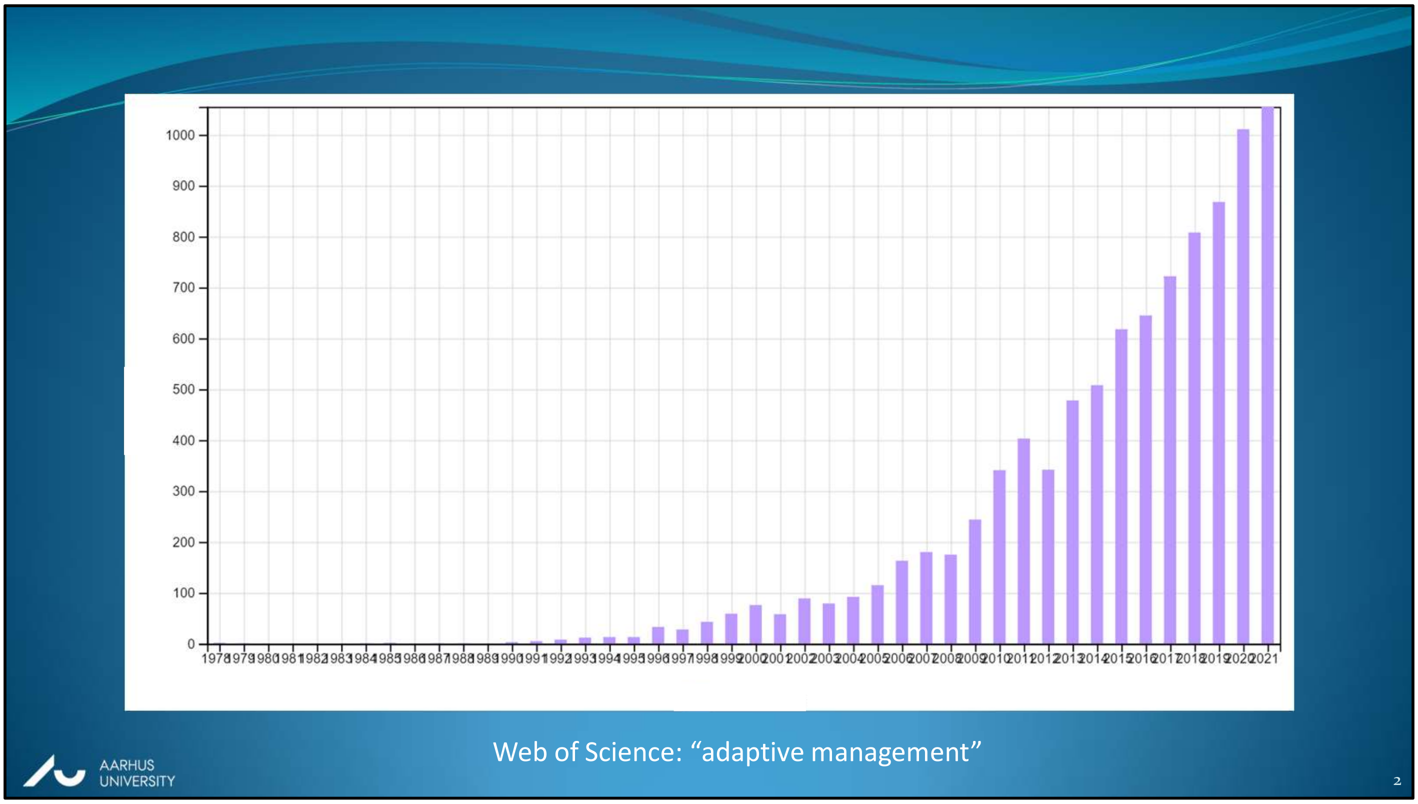

- A search of “adaptive management” among journal articles in the Web of Science reveals exponential growth since the advent of AM in the 1970’s
- Its core principles of managing to learn and learning to manage are so accepted that virtually all resource professionals today view adaptive management as a creed of sensible resource management.

“Adaptive management has been more influential, so far, as an idea than as a practical means of gaining insight into the behavior of ecosystems utilized and inhabited by people.”

Kai Lee 1999

- Yet documented success stories are rare, and touted examples often fail to meet one or more basic requirements of adaptive management.
- There are legitimate concerns that adaptive management is becoming little more than a slogan, regarded by cynics as devoid of any real meaning.
- A quote by political scientist Kai Lee is as true today as it was over 20 years ago.

Learning objectives

- What is decision analysis?
- What are dynamic decision problems?
- What makes a dynamic decision-making problem adaptive?
- How does learning occur in adaptive management?
- Why is managing adaptively so challenging?

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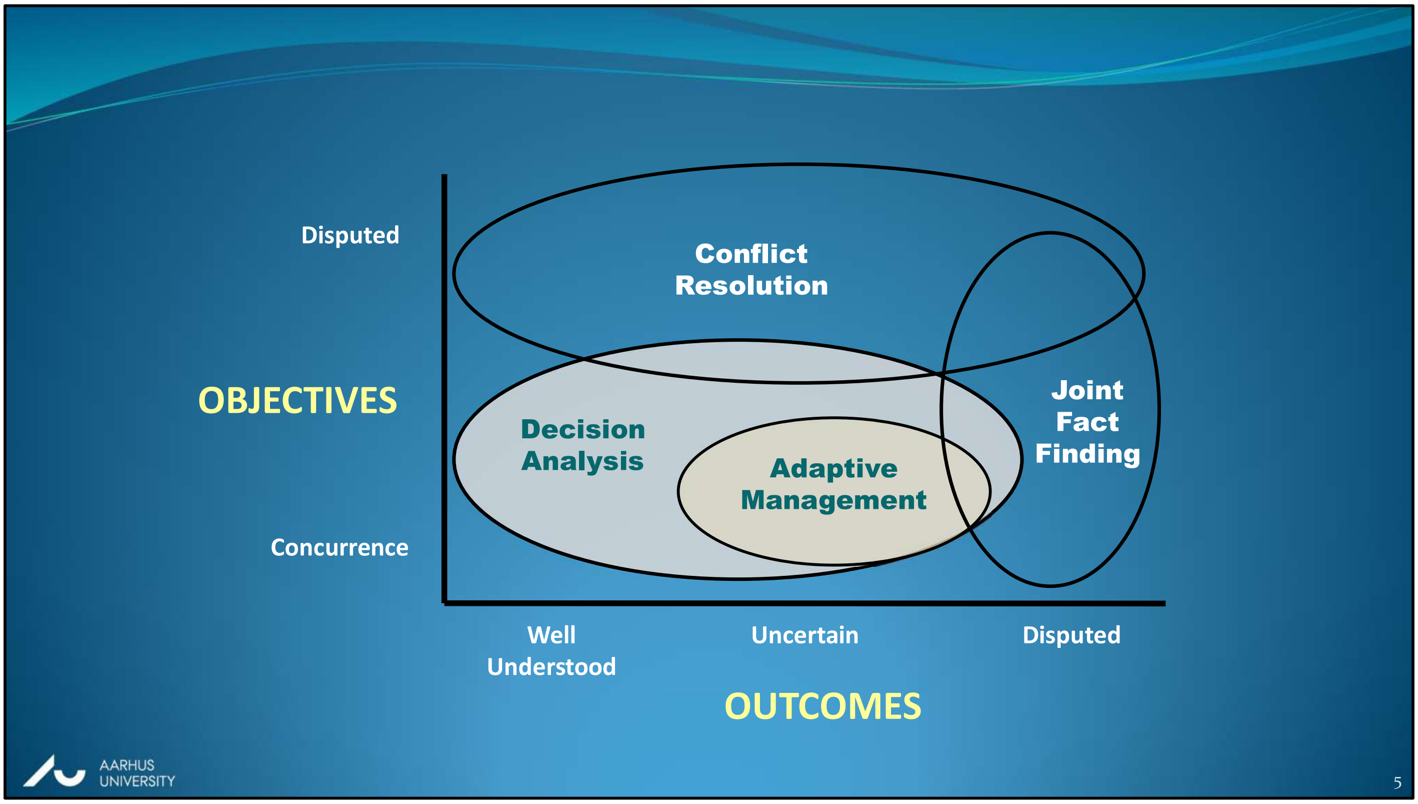
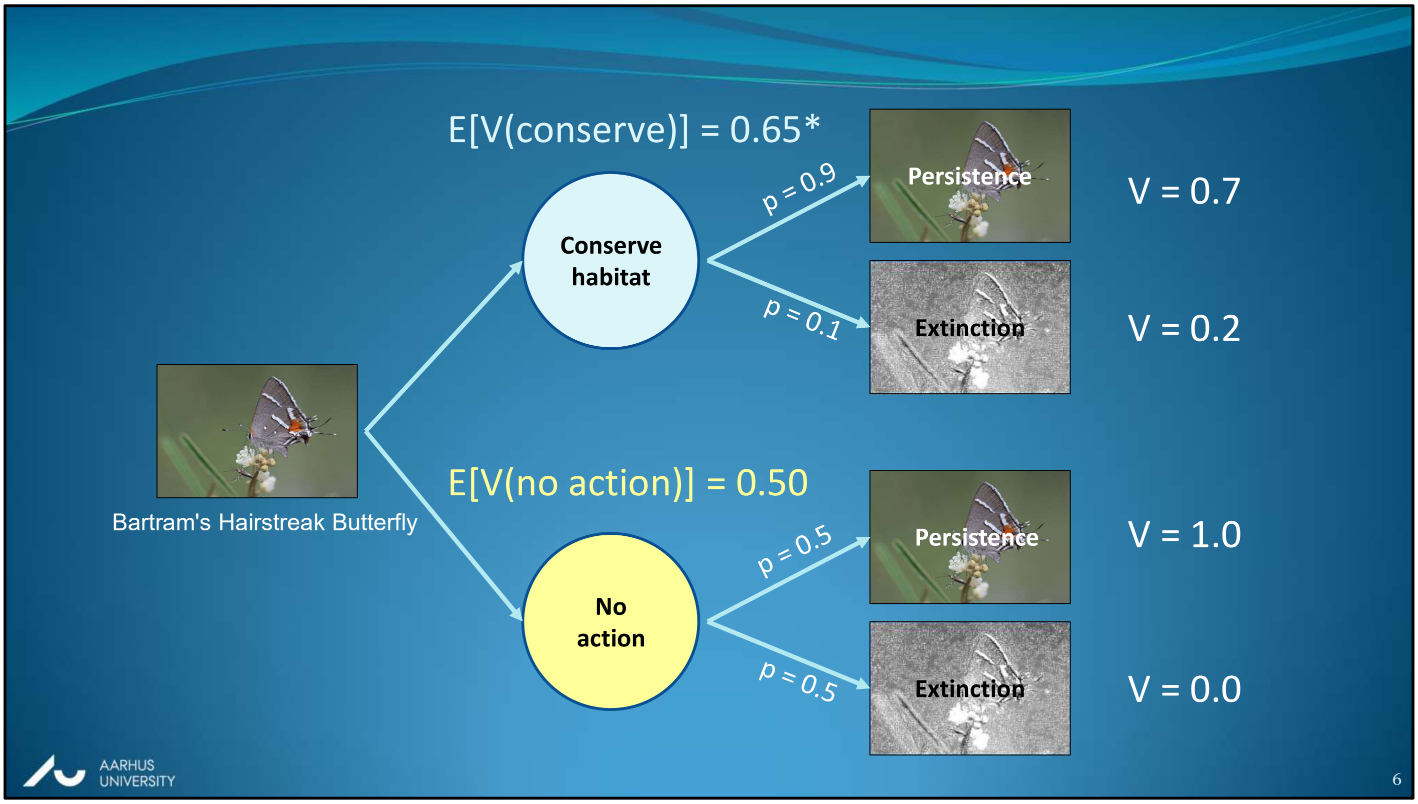
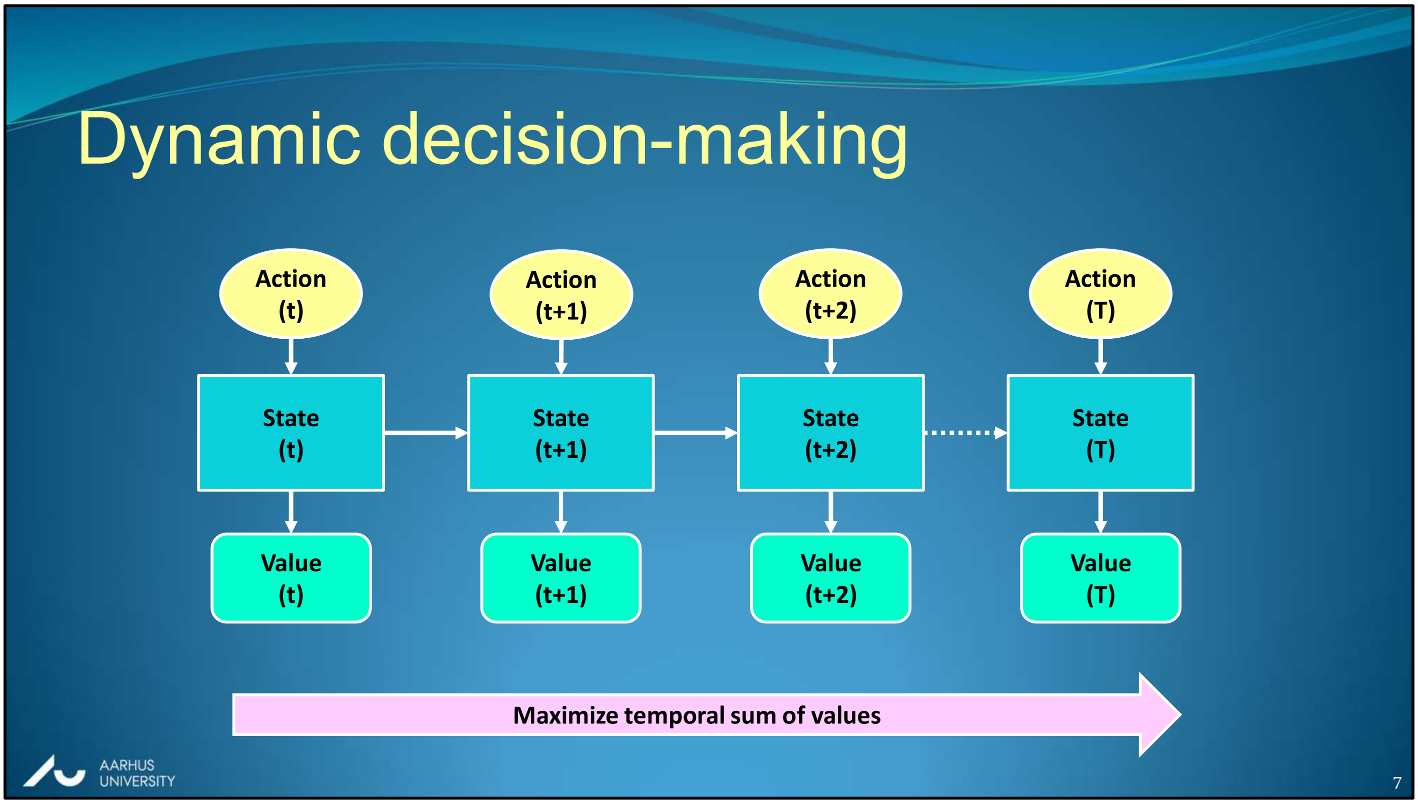
- Our goal today is to present a formal framework for adaptive management, provide illustrative examples, and discuss some of the challenges to successful implementation.
- Our coverage of the topic will be broad rather than deep in the hopes of conveying essential concepts.



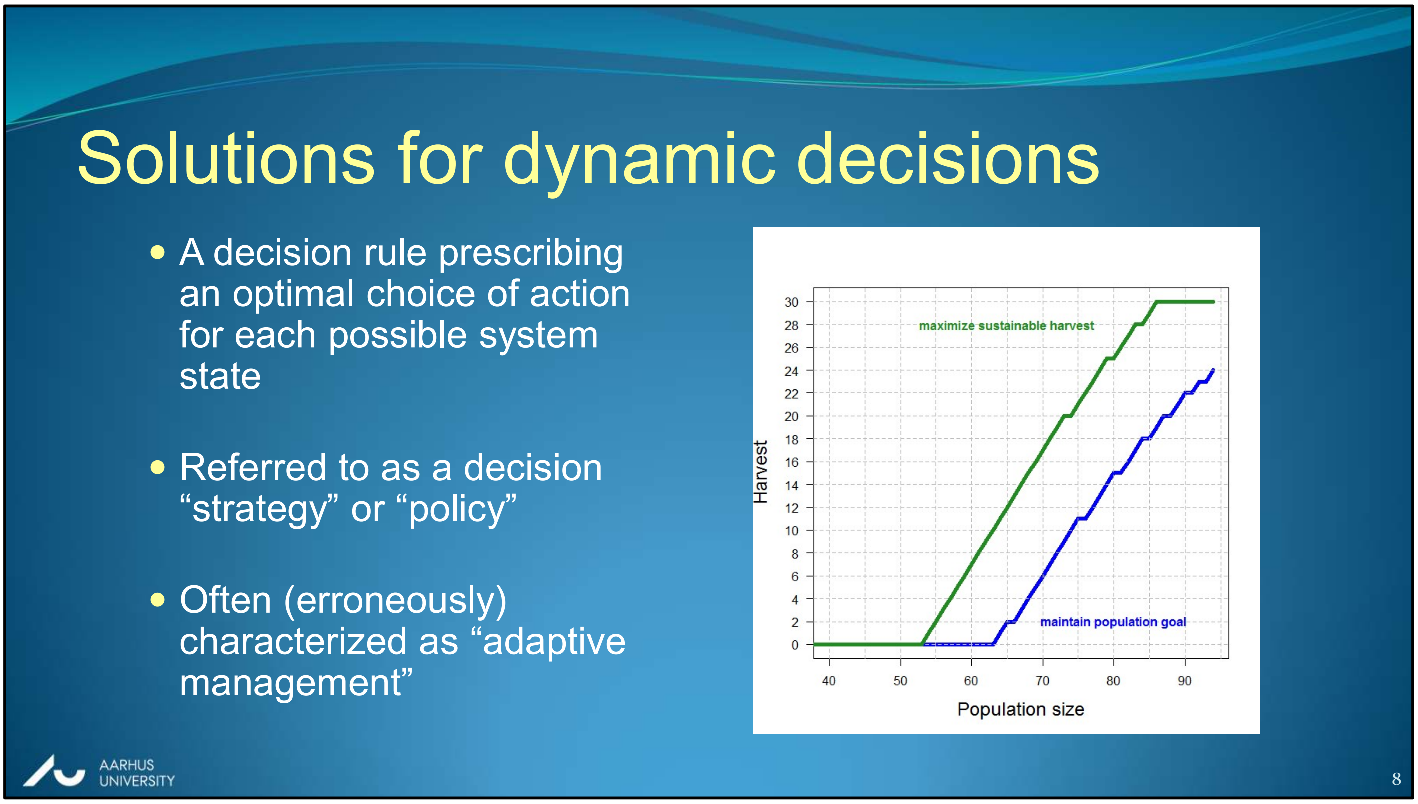
- All decisions involve two key components: the outcomes or consequences of alternative choices, and the objectives we wish to achieve in choosing an alternative. Difficult decisions typically involve ambiguity about one or both.
- Decision analysis has evolved as a means to identify the best choice in cases where the outcomes may be uncertain, but there is at least moderate concurrence on objectives.
- AM is a subset of decision analysis where outcomes may be highly uncertain.
- When objectives and/or outcomes are disputed, other forms of collective decision making are required.



- Let's examine what role outcomes and objectives play in making a decision.
- In this example, we must decide whether or not to conserve additional habitat for an endangered butterfly in the Florida Keys, with the objective being long-term persistence.
- If we take no action, we see that there is a 50:50 chance of the species persisting over the long term. These are outcomes based on the best available science.
- If the species persists, we assign the outcome a value of 1.0, which is the best possible outcome because we achieve our objective at no cost. Extinction is the worst possible outcome because we failed our objective and spent money.
- If we choose to conserve addition habitat, the probability of persistence is quite high. But the outcome is not the best possible because money was expended.
- If habitat is conserved and the outcome is extinction, the outcome is not the worst possible because we can assure the public that at least we tried.
- The best choice then is the expected value of each alternative (just a mean of values, weighted by the probabilities of their occurrence). The best choice is to conserve habitat.
- How might the best decision change?
- IMPORTANT: Decisions involve a science part (probabilities of outcomes) and a subjective part (values assigned to outcomes by the decision maker). Therefore, we cannot "let the science decide," as is so often heard in the conservation world.

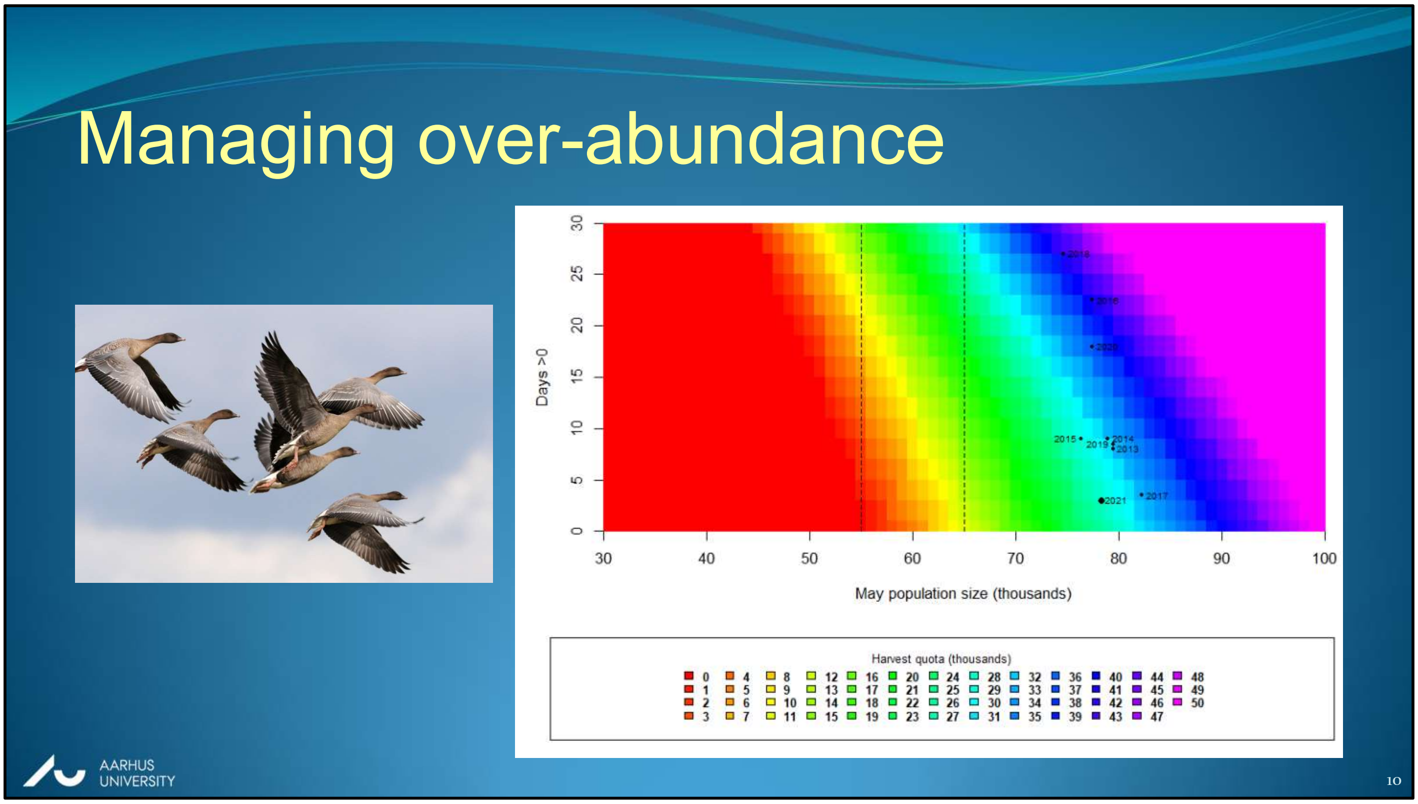


- Many decisions in conservation are dynamic, in the sense that the same type of decision must be made repeatedly over time.
- A key aspect of these problems is that we must assess the state of the resource of each decision epoch and possibly make a different decision than we did in previous epochs.
- Upon choosing an action, we derive some immediate value (benefits net of costs) and the managed system then evolves to a possibly different state, depending on the action we took and other uncontrolled environmental factors.
- The we must choose a new action, and so goes the process over time.
- The goal in a dynamic decision-making problem is to maximize the temporal sum of values over some time frame, which might be finite or infinite.

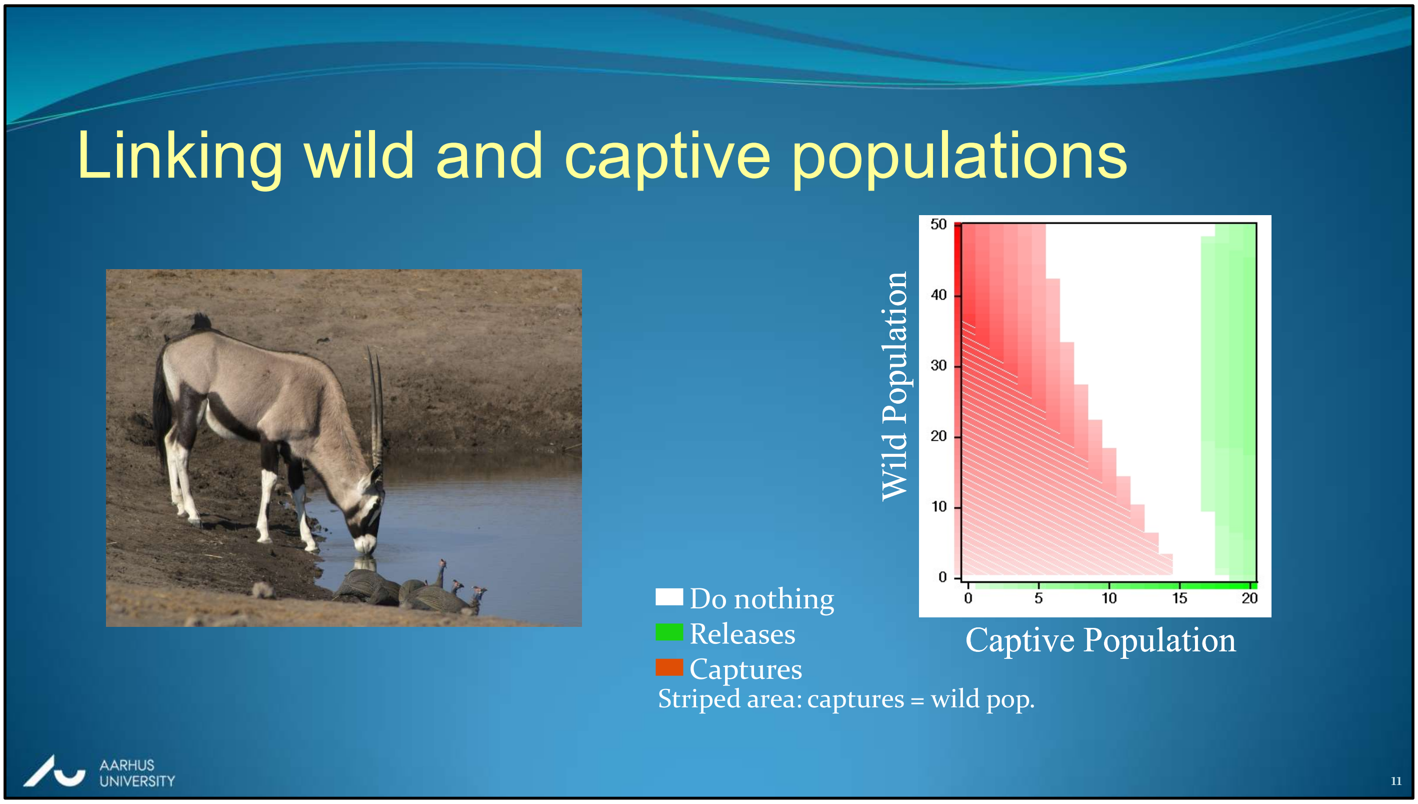


- Solutions to dynamic decision problems are much harder to calculate than we saw in the butterfly example because we have to account not only for the immediate consequences of our decision but it's future consequences as well.
- Think of it this way: a marathon runner must balance the need to run fast with the need to conserve energy in order to finish the race. This tradeoff between short and long-term consequences is a key feature of dynamic problems.
- Dynamic decisions can be solved using an algorithm called dynamic programming, which was developed during WWII for managing the inventory and distribution of military supplies.
- The solution is a decision rule prescribing the best action given the current state of the managed system. Here are two such decision rules for taiga bean geese: one in which the objective is to maximize the sustainable harvest and one in which the sole objective is to maintain a population size of 70k in spring.
- I emphasize that this is NOT adaptive management, although it is characterized in this way all too often.

- Dynamic decision problems are pervasive in conservation.
- We'll look at a few from the conservation literature.

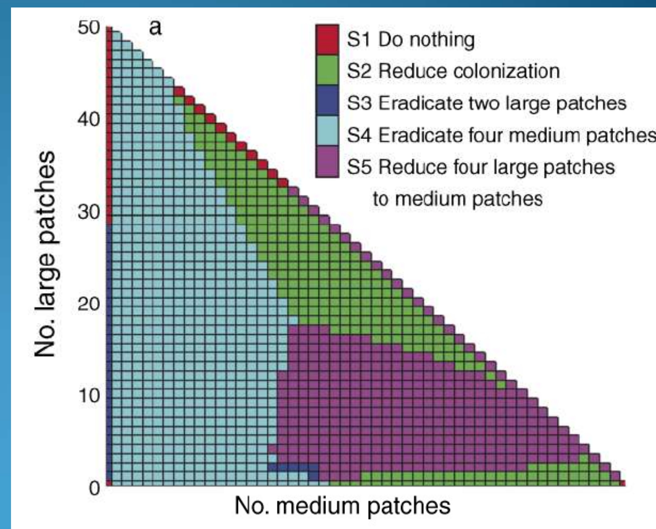


- Many goose populations in Europe have increased to the point that they are the source of social and economic conflict.
- Here is an example of a harvest strategy for pink-footed geese that is intended to maintain an acceptable population of about 60k birds (indicated by the vertical dashed lines).
- The fall harvest quota depends on the size of the population in spring each year and the number of days above freezing in May on the breeding grounds in Svalbard (which promotes reproductive success).
- https://egmp.aewa.info/sites/default/files/meeting_files/documents/egm_iwg_6_6_rev.4_population_status_report.pdf



- A decision rule for managing a captive breeding program for Arabian oryx, depicting when to release animals from captivity, when to bring wild oryx in the captive-breeding program, and when to do nothing based on the abundances of the wild and captive populations.
- Goal is to maximize the long-term probability of persistence in the wild.
- Tenhumberg, B., A. J. Tyre, K. Shea, and H. Possingham. 2004. Linking wild and captive populations to maximize species persistence: optimal translocation strategies. Conservation Biology 18:1304–1314.

Managing an invasive species



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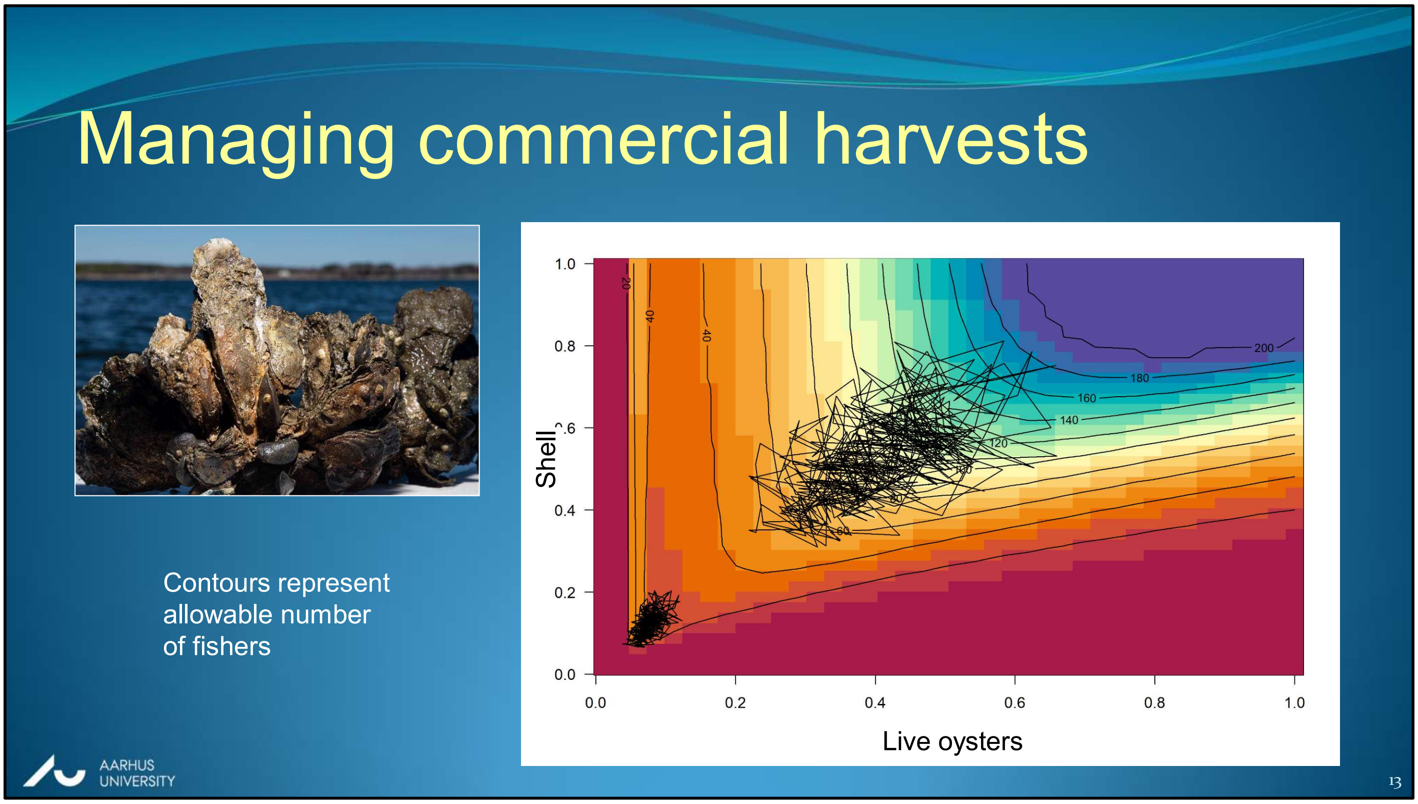
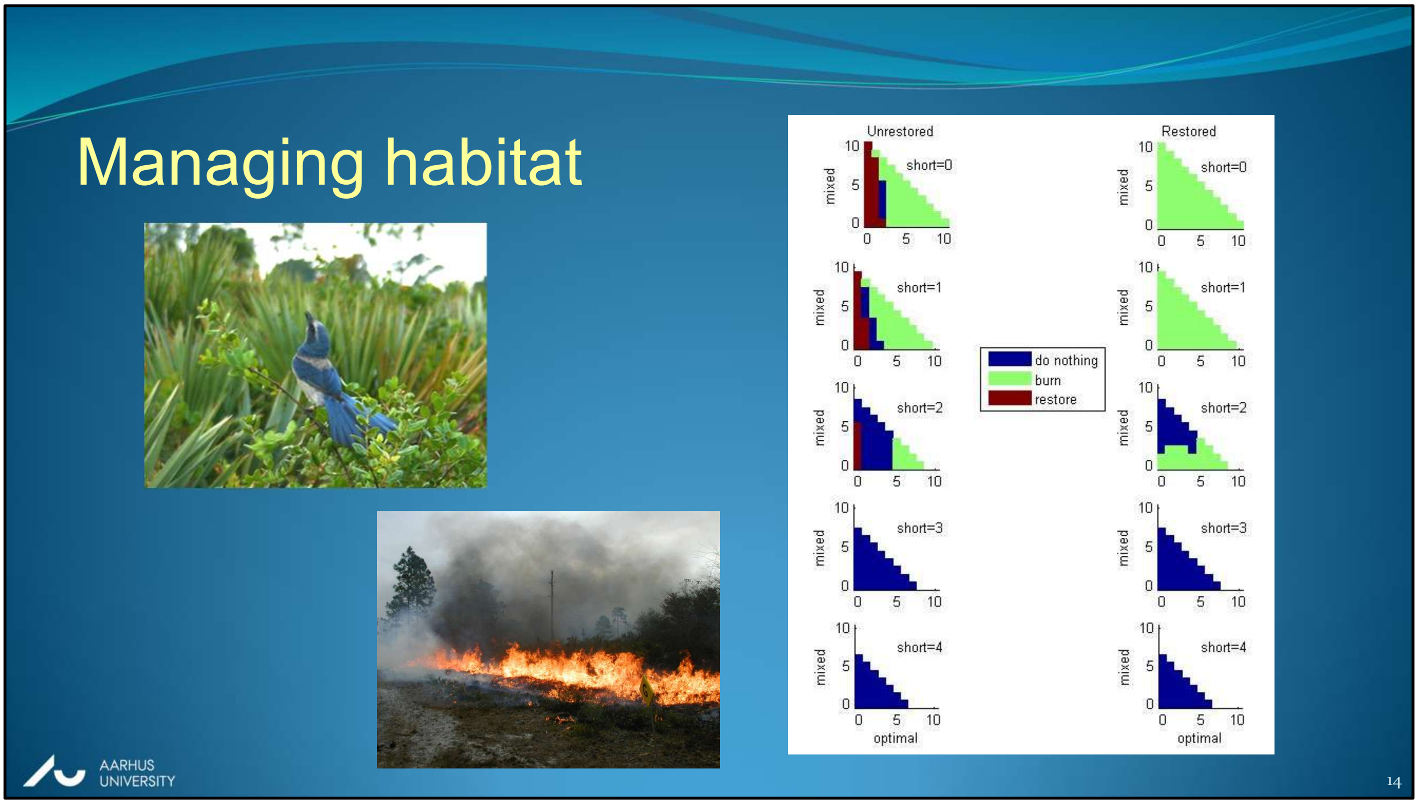
- In this example, the goal is maximize the number of landscape patches that are free of infestations of gypsy moths.
- The best course of action is dependent on the number of patches in the landscape that have medium or high infestations of moths.
- Bogich, T., and K. Shea. 2008. A state-dependent model for the optimal management of an invasive metapopulation. Ecological Applications 18:748–761.



- This example concerns the management of commercial oyster harvests in the eastern U.S.
- The goal is to maximize the sustainable harvest and the possible actions are the number of fisheries permitted each year.
- The optimal number of permits (shown as contours) is a function of both the abundance of live oysters and the abundance of oyster shell, which provides settlement habitat for oyster larvae.
- The simulated system trajectories depict two basins of attraction: one on the lower left in which system collapse is a result of a MSY policy and the other in which the number of fishing permits is state dependent and can change from year to year.
- Johnson, F., W. E. Pine, and E. V Camp. 2022. A Cautionary Tale: Management Implications of Critical Transitions in Oyster Fisheries. Canadian Journal of Fisheries and Aquatic Sciences.



- Finally, we examine a policy for managing the fire-dependent habitat of the imperiled Florida scrub-jay, demonstrating that dynamic decision problems can be quite complex.
- The goal of the dynamic decision-making process is to maximize the growth rate of the scrub-jay population.
- The system state is characterized by the number of sites that are classified by successional stage and whether a site has been previously mechanically treated.
- The decision rule prescribes a decision to do nothing, to conduct a prescribed burn, or to mechanically restore a site depending on the number of sites in each system state.
- Doing nothing is only optimal if there are a lot of optimal scrub sites and “short” sites that soon will become optimal.
- Fackler, P. L. 2012. Category count models for resource management. Methods in Ecology and Evolution 3:555–563.

Is dynamic decision making adaptive?

- ***Only*** in the sense that actions can change depending on the state of the system
- Dynamic decision making is a necessary, *but not a sufficient*, condition for adaptive management
- What's missing?
  - An explicit recognition of uncertain effects of actions on system transitions
  - A process for reducing uncertainty and improving future decisions

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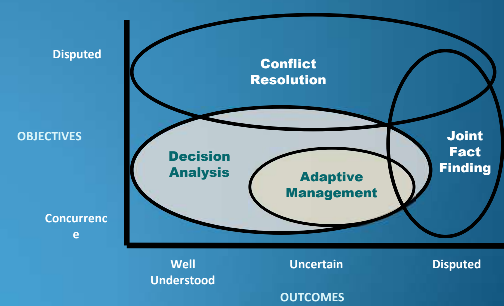
- Not all dynamic decision problems are adaptive.
- All adaptive management problems are dynamic.

Adaptive management is…

- Management in the face of uncertainty, with a focus on its reduction
- A systematic approach for improving resource management by learning from management outcomes
- *NOT* trial & error management
- *NOT* simply dynamic decision making



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- Adaptive management is dynamic decision-making in which the outcomes of management actions are uncertain
- And where observations of outcomes can reduce that uncertainty

Types of uncertainty

- Environmental variation
  - E.g., timing of spring thaw in the Arctic
- Partial controllability: outcomes deviate from management prescriptions
  - E.g., harvest affected by more than length of hunting season
- Partial observability: system features are monitored imperfectly
  - E.g., sampling variance of population size
- **Structural uncertainty**: incomplete knowledge of system dynamics
  - E.g., density-dependent vs. density-independent mortality
  - The key focus of adaptive management

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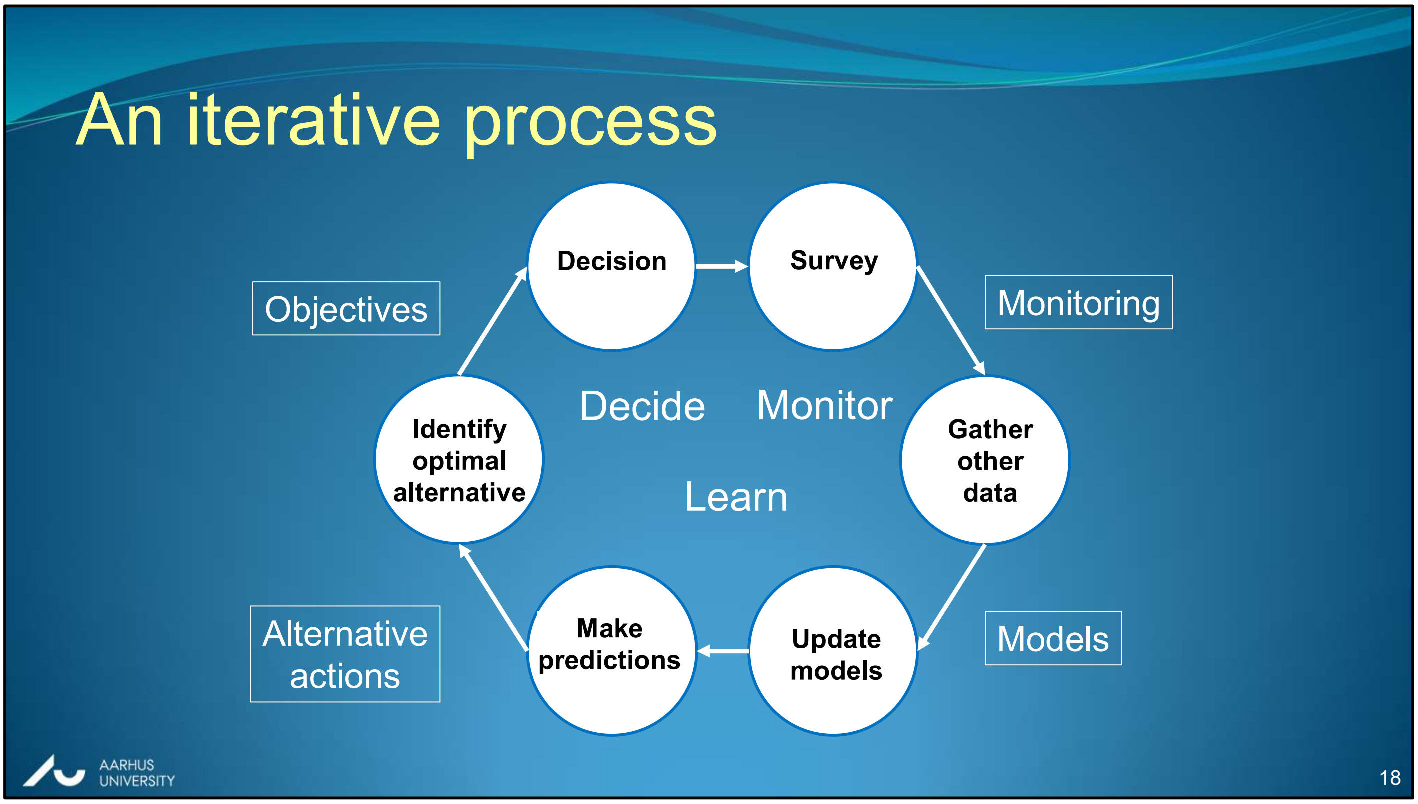
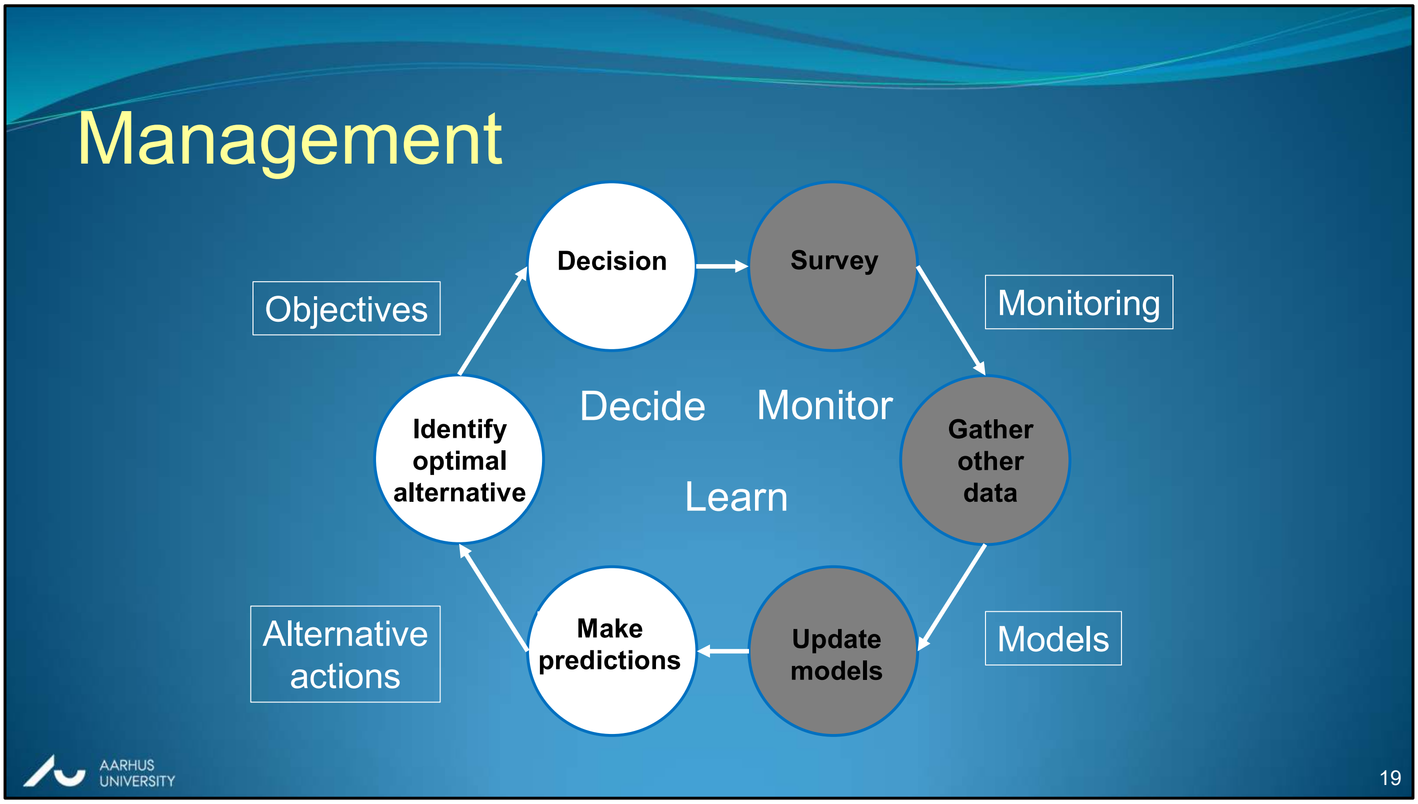
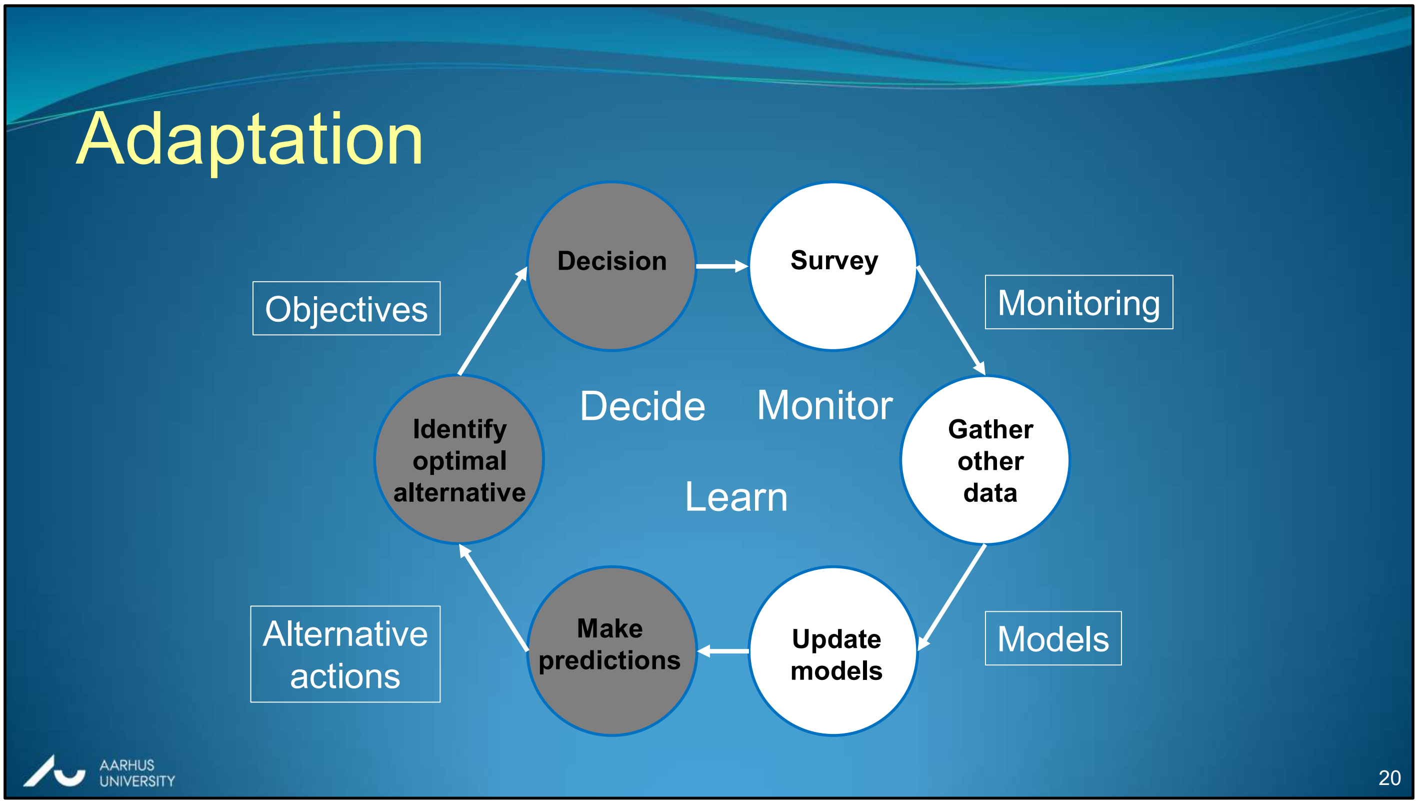
- Uncertainty is a pervasive problem in conservation. We can generally think of four types.
- To these we could add demographic uncertainty, which is important in very small populations (e.g., a binomial survival probability can only produce an integer-based number of survivors).
- Environmental variation, partial controllability, partial observability, and demographic uncertainty can all be accommodated in dynamic decision problems.
- Adaptive management additionally focuses on structural uncertainty that can be reduced through an iterative process of making decisions and observing outcomes.



- Like dynamic decision-making, adaptive management involves making decisions based on the state of the managed system and observing the outcomes.
- Unlike simple dynamic decision-making, however, the observed outcomes are used to update the models we use to make predictions of outcomes.

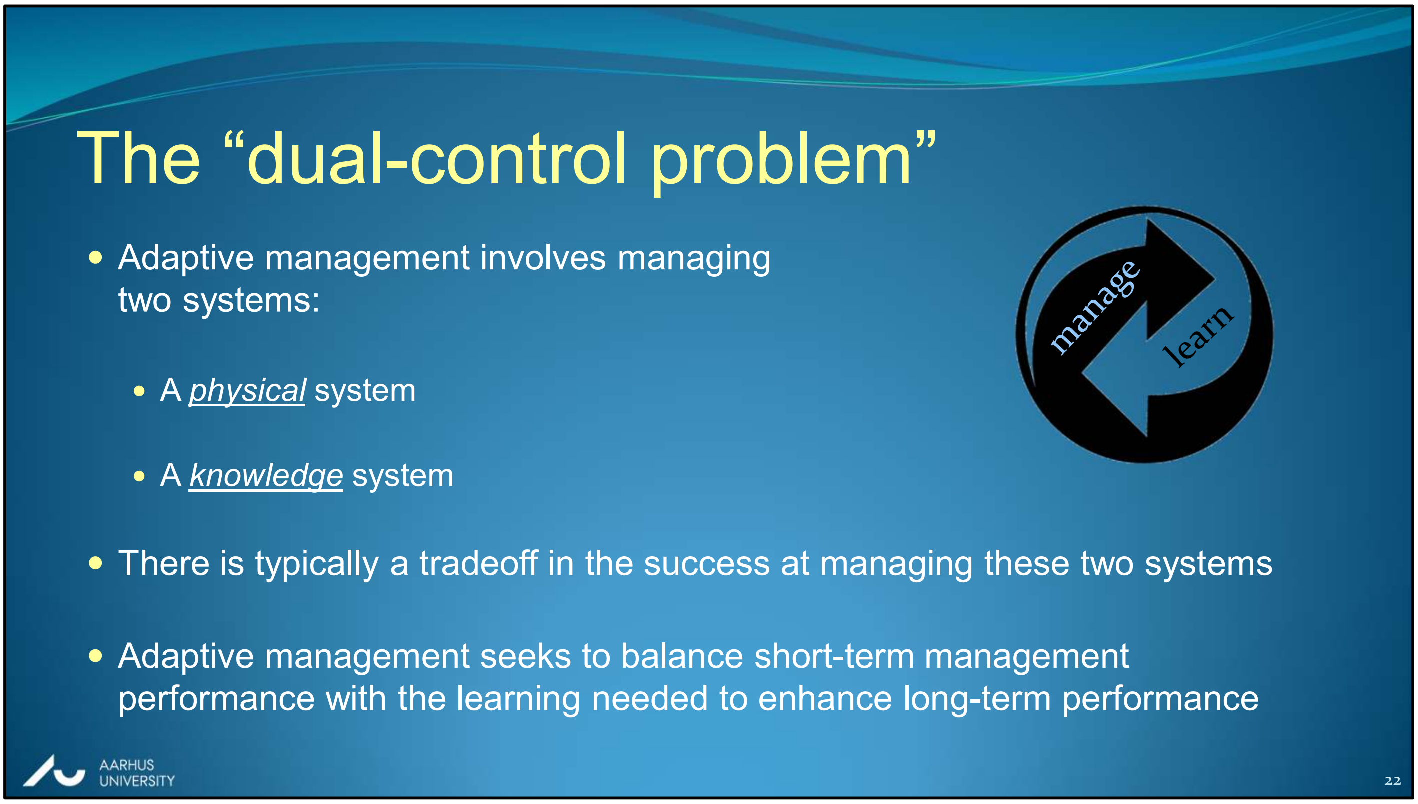


- Thus, there is a management component involving predictions of outcomes from alternative actions, identifying the optimal decision based on our objectives, and then implementing the preferred alternative.

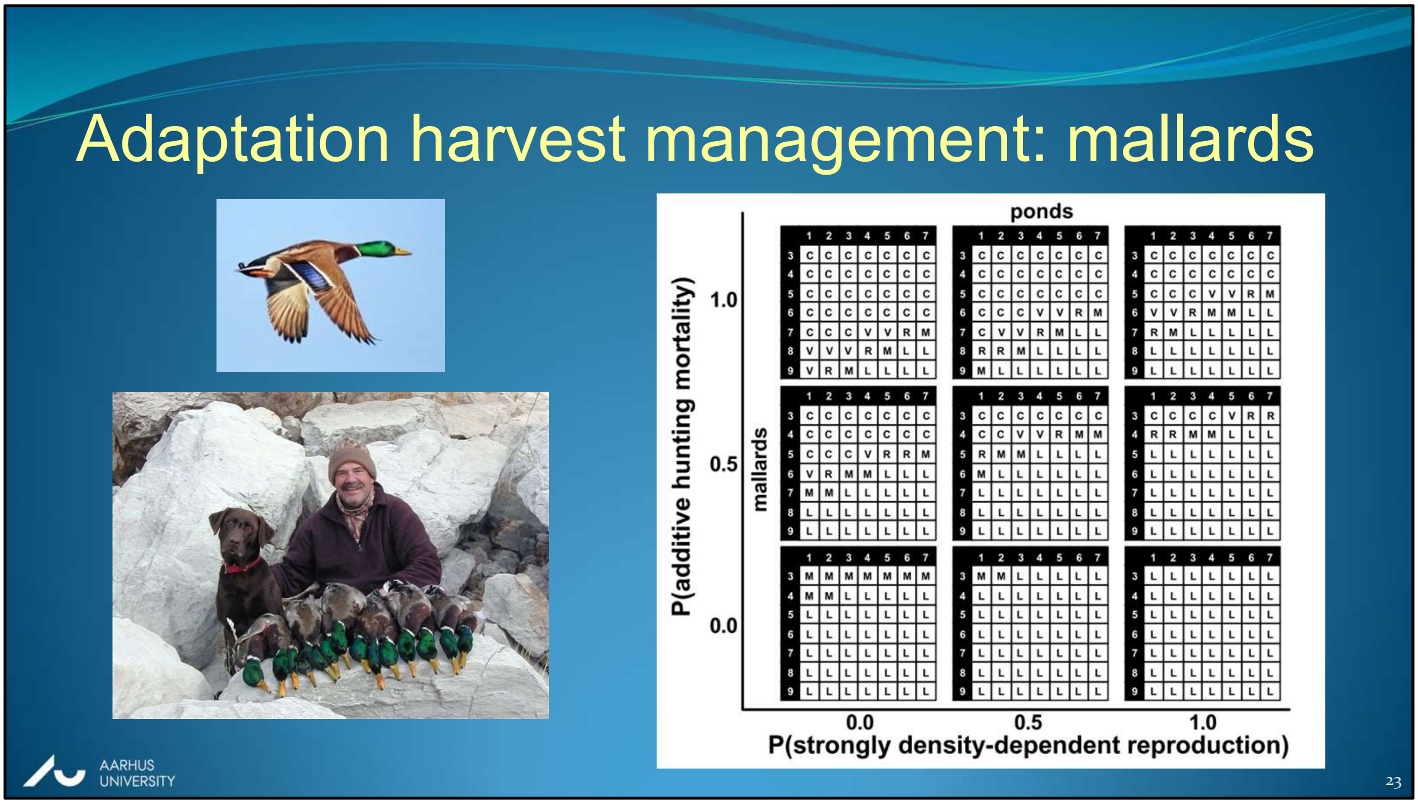


- Then there is an adaptive component, where we monitor the resulting state of the system, possibly gather other relevant data, and then compare our predicted outcomes with those actually observed.
- The comparison of predictions with observations is used to update our models of how the system works prior to making a new management decision.

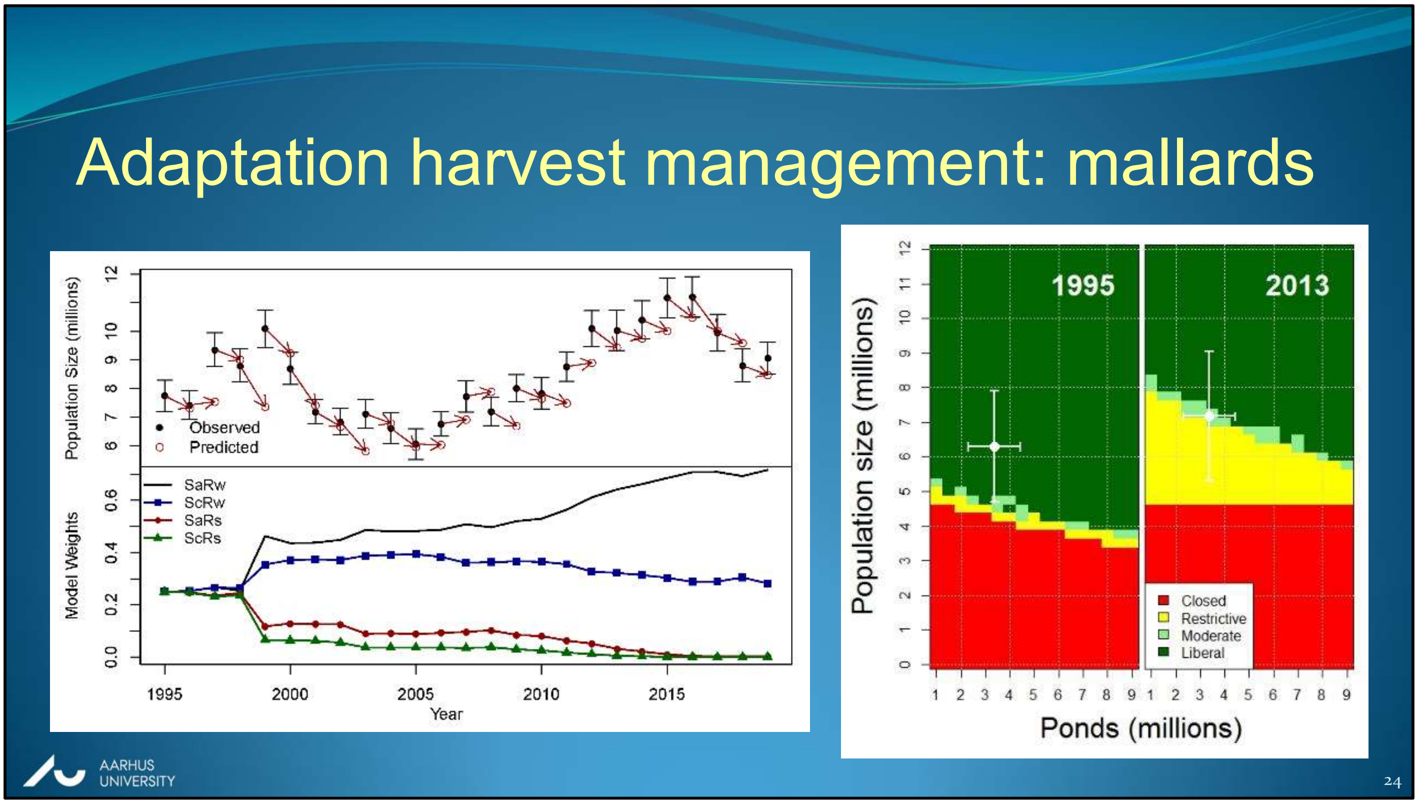
Intermission



- Adaptive management has often been characterized as a problem of dual control.
- As in dynamic problems, we are concerned with managing a physical system; e.g., population size, habitat conditions
- But we must also be concerned with managing a knowledge system – our understanding of the physical system and the outcomes of our management actions
- But there is typically a tradeoff in the success at managing these two systems; large perturbations of the system can contribute greatly to my understanding of system dynamics, yet negatively affect the achievement of my objectives; conversely, a precautionary approach to management might suffice for meeting my objectives, but sacrifice knowledge that could be used to improve future decisions
- (smart) Adaptive management seeks to balance this tradeoff
- A key point to remember, however, is that adaptive management recognizes the importance of learning ONLY to the extent that it helps improve future outcomes. In that sense, learning is valued only indirectly. It is not about experimenting with managed systems solely for the sake of understanding them better. It is, after all, adaptive *management*, not adaptive *research*.



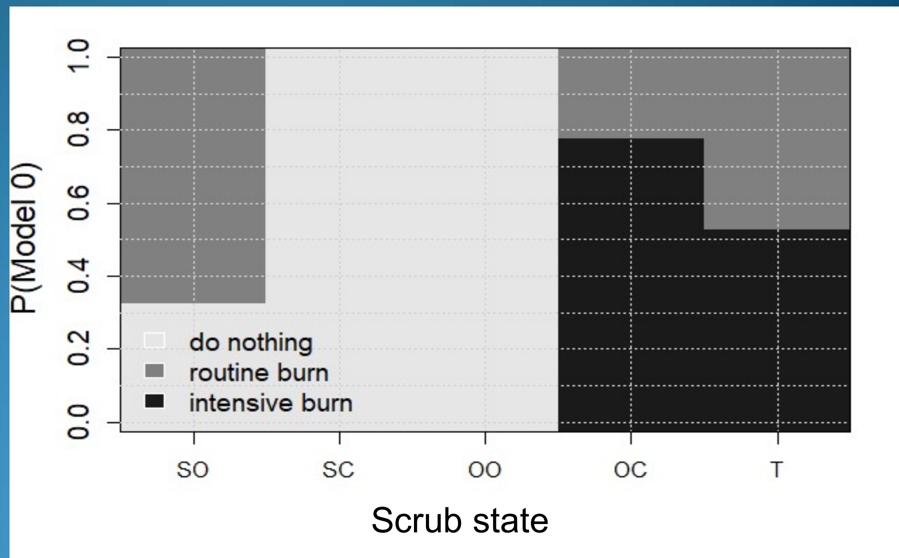
- One of the largest scale and longest running examples of adaptive management concerns the sport harvest of mallards in the U.S.
- Begun in 1995, it seeks to maximize sustainable harvest, while maintaining the population near a continental goal.
- The decision concerns the level of hunting regulations from a closed season to a very liberal season, and is based on population size and the number of wetlands in their breeding range.
- The knowledge system focuses on uncertainty about whether reproduction is strongly or weakly density dependent and whether harvest mortality is additive to sources of natural mortality.
- Thus, the optimal hunting regulation in a given year is based on the status of mallards and ponds, AND on the probability that reproduction is strongly density dependent and on the probability the hunting mortality is additive.
- Based on the hunting seasons chosen, the status of both the physical and knowledge systems will change over time.
- Johnson, F. A., G. S. Boomer, B. K. Williams, J. D. Nichols, and D. J. Case. 2015. Multilevel learning in the adaptive management of waterfowl harvests: 20 years and counting. Wildlife Society Bulletin 39:9–19.



- The left panel depicts (top) the predicted and observed population size each year as a function of a weighted average of four separate models describing the hypotheses about the reproductive and survival processes. The bottom panel depicts how the confidence in those four models has changed over time. The models hypothesizing strongly density dependent reproduction have essentially no credibility, while the model hypothesizing weakly density dependent reproduction and additive hunting mortality has the highest credibility.
- This change in our knowledge system over time has resulted in a decision rule that has become more conservative over time, with many fewer resource conditions allowing for liberal hunting regulations.

Adaptive habitat management: scrub-jays

- Two competing models of scrub response to fire
- Vertical axis is prob(Model 0)



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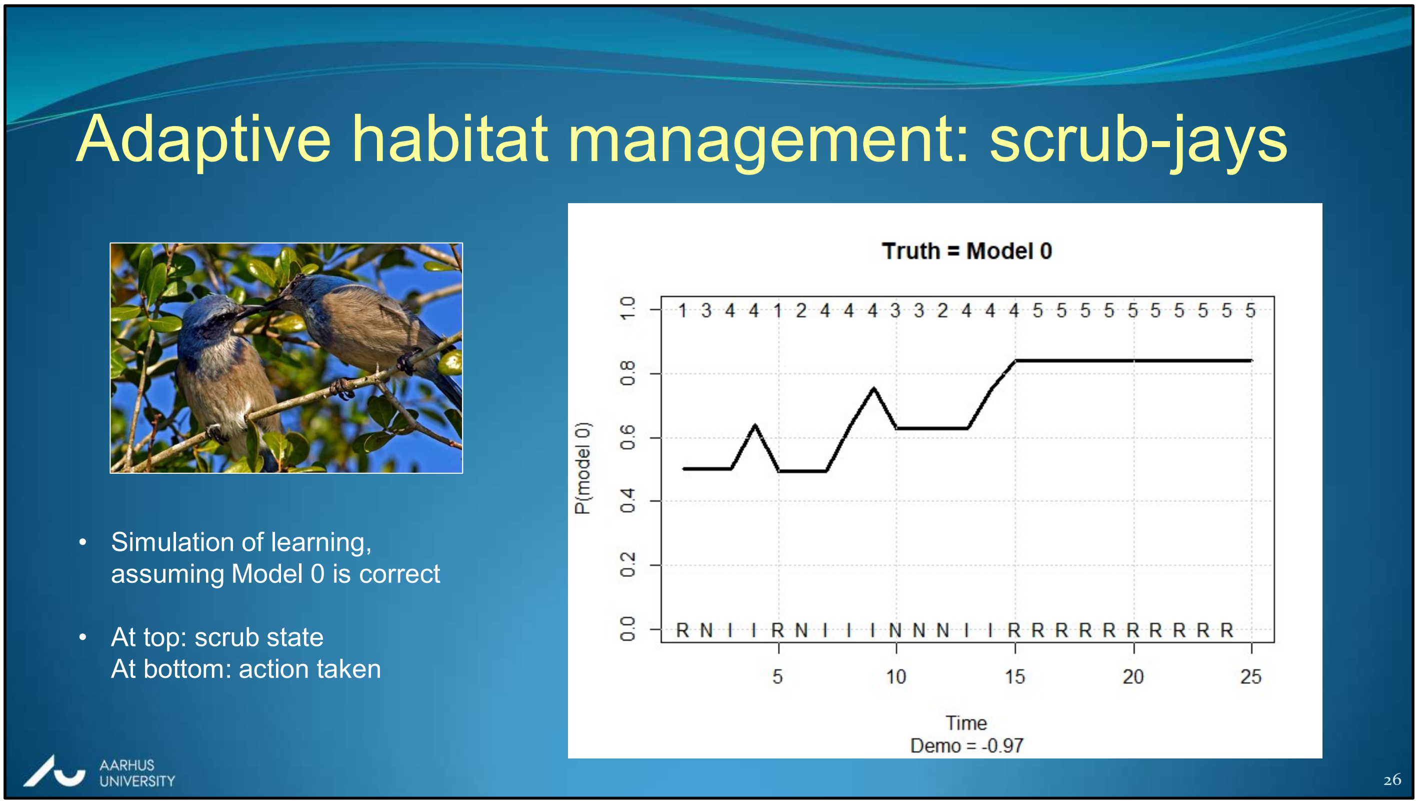
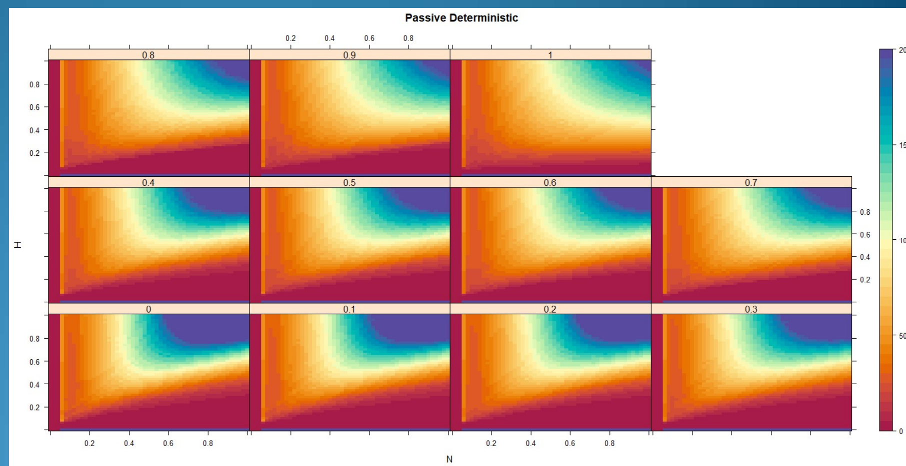
- We return to an example with Florida scrub-jays.
- Here we are concerned with a single site, where the decision again depends on the successional state of the habitat. In this case optimal-height, open scrub is the best habitat.
- But the decision also depends on our knowledge system: in this case uncertainty about whether a very intensive, hot burn is better than a routine, cool burn at setting back succession.
- Model(0) is our null model, stating that routine burns and intensive burns produce similar outcomes. Thus, when the credibility of the null model is high, it is never optimal to do an intensive burn due to the extra cost and risk to public safety.
- Williams, B. K., and F. A. Johnson. 2018. Value of sample information in dynamic, structurally uncertain resource systems. PLOS ONE 13:e0199326.



- If our null model in fact were “true,” we can simulate how the evolving understanding of the system could affect our actions and the system (and thus our ability to meet our management objective of promoting growth in the scrub-jay population).
- If we begin with complete model uncertainty (P(Model 0) = 0.5), we can see that our confidence in the null model increases over time. As a result, we stop using intensive burns (I, lower sequence) and apply only routine burns (which are ultimately ineffective at setting back succession (upper sequence where state 5 is the highest successional state).
- What would one do if faced with these results on the ground? Managers should look for other actions to set back succession than a routine burn. This is referred to as double-loop learning. Single-loop learning concerns the iterative decision-making process and the change in model credibility. Double-loop learning results as a recognition that even optimal decisions may not produce the desired outcome.

Adaptive commercial fisheries: oysters



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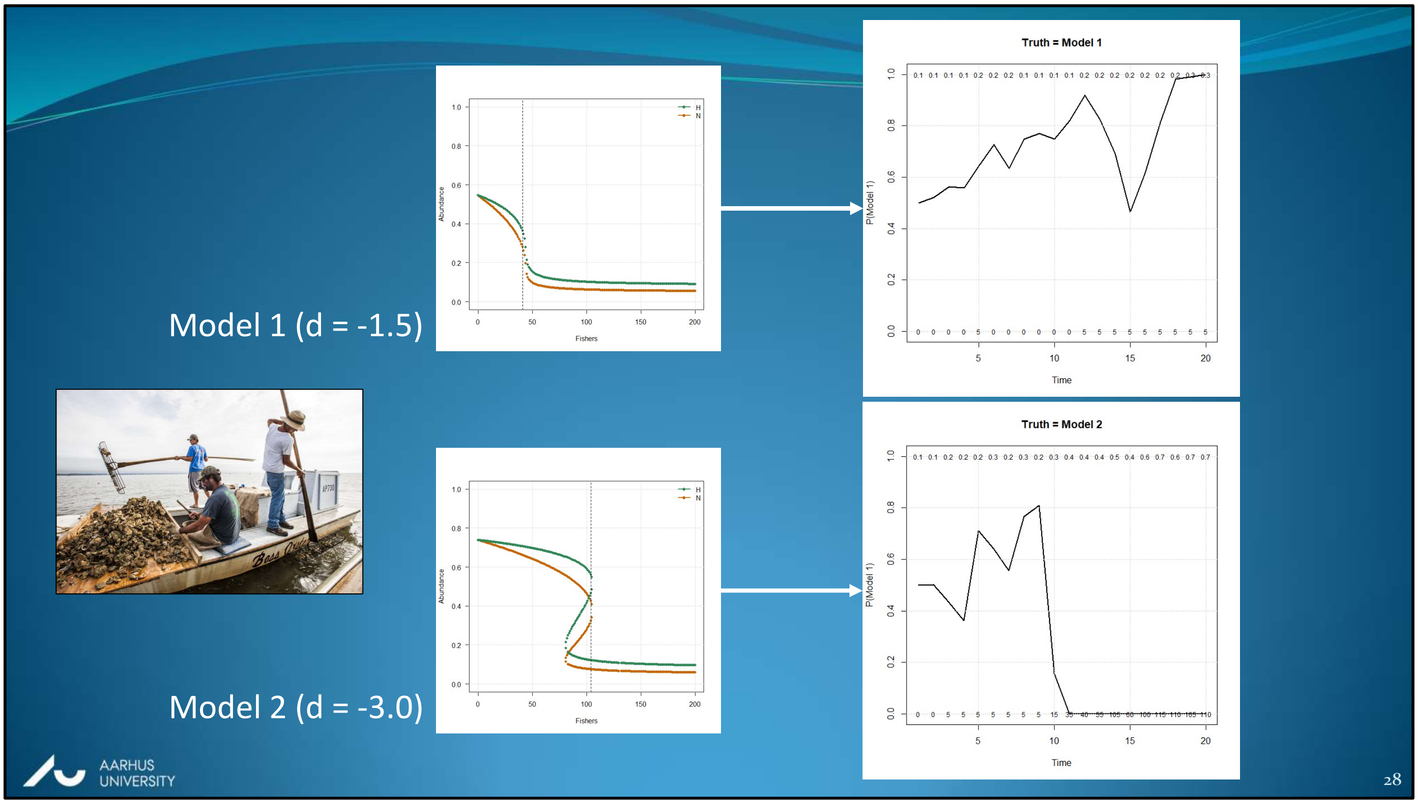
- As a last example, we return to the commercial harvests of oysters.
- In this example, we are concerned with two competing models of oyster dynamics. The first model posits convex density dependence, in which the strongest effect of density is a small population sizes. The second model posits a concave form of density dependence, in which density effects are strongest at high population sizes.
- Here is the adaptive management policy where again the number of fishers to permit is based on the status of live oysters and shell (with number of permits in color contours).
- In the bottom left, we have complete confidence in the model with concave density dependence, and this supports the highest number of fishers overall.
- At the top right, we have the policy for the convex form of density dependence and this model permits far fewer fishers in most circumstances.
- The other policies are intermediate between those extremes, depending on the credibility of convex density dependence.



- What might learning look like in this example?
- Here we simulate decisions over time, first under a model with convex density dependence and then under a model with concave density dependence.
- For Model 1 with concave density dependence, the graph on the left depicts oyster (orange) and shell (green) equilibriums for varying numbers of fishers.
- If this model is “correct” we could expect to learn so in a little under twenty years and that the system will be relatively unproductive (bottom sequence is number of fishers, top sequence is abundance of oysters as a proportion of the maximum possible abundance).
- For Model 2 with concave density dependence, we see it can generally support more fishers (the vertical, dashed line) and also that, for an intermediate number of fishers, the system can exist in multiple stable states (a subject of great interest in the fisheries world).
- Learning is potentially much more rapid in this case, with the credibility of the convex model essentially zero after about 10 years. The abundance of oysters and the permitted number of fishers is very much large than with the convex for of density dependence.

- A couple of more concepts before moving on to some of the challenges of implementing adaptive management.
- You may have heard of a distinction between passive and active adaptive management.
- The classic definition of passive AM comes from Carl Walters (a fisheries biologist in British Columbia) in the 1970s. The idea was to use the model that seemed the best of the alternatives and then change to a different model if the original model performed badly (made predictions that didn't correspond very well with observed outcomes)
- The modern definition allows for the consideration of multiple models in the decision process, with their influence on decisions a function of their credibility
- But there is no consideration of how decisions today might affect knowledge tomorrow.
- In contrast, active AM seeks to understand how decisions today might influence the learning need to improve future decisions

Motivating adaptive management

- As ecologists, we have a strong tendency to ask for more information.
- But will the new information significantly improve the performance of management / conservation?
- If so, is the new information worth its cost?
- the **Value of Information** addressed this problem

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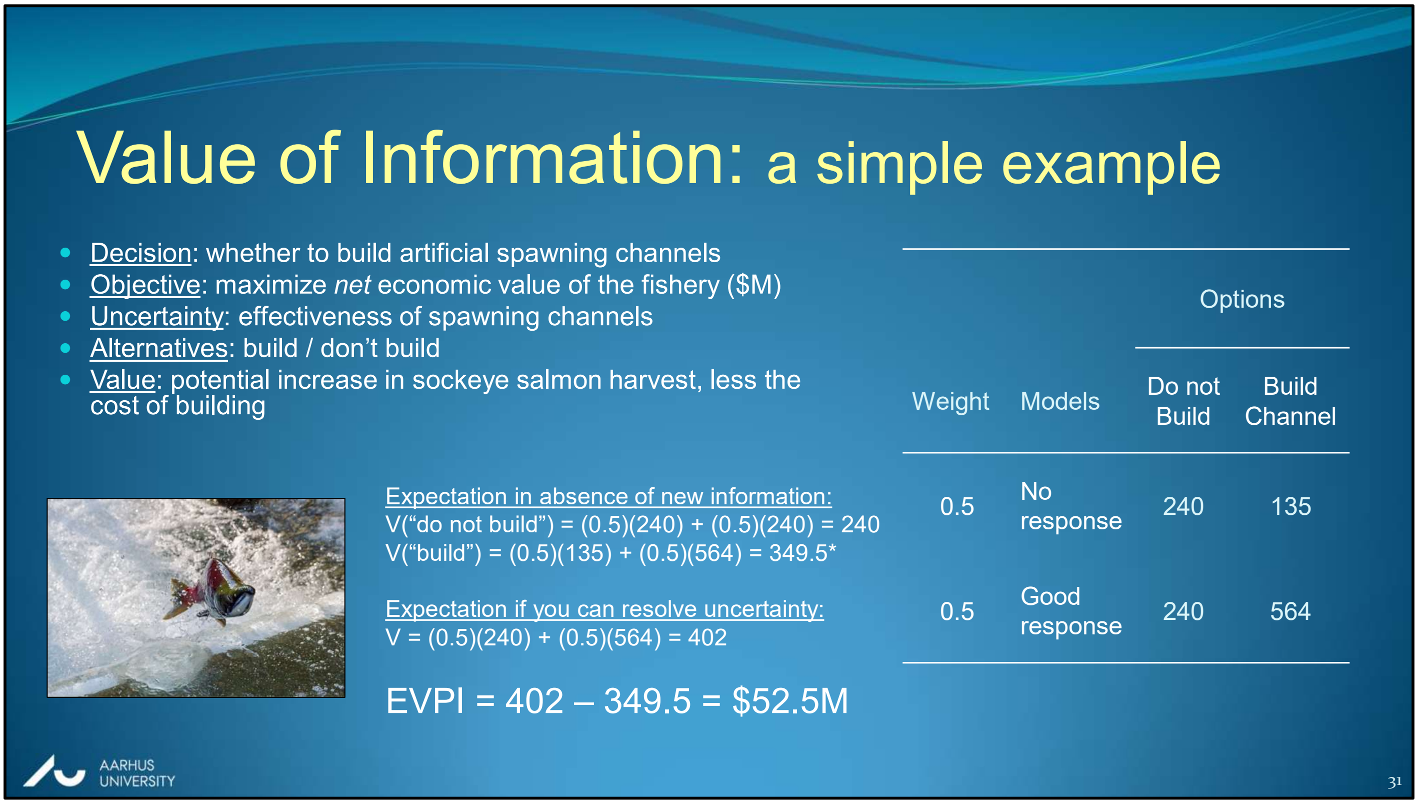
- Before launching into an AM program, how might it be motivated in some formal way? After all, AM can be expensive and time consuming and decision makers deserve to know whether their investment is likely to be rewarded.
- If you were to ask any ecologist what they were uncertain about in any particular system, you better have a long time to hear the answer. After all, (honest) ecologists profess to be certain about virtually nothing.
- But do all uncertainties matter in terms of making good conservation decisions? Is the investment in learning in AM likely to significantly improve management performance.
- A concept known as the Value of Information expresses the value of investing in learning versus the value of making decisions in the continued face of uncertainty



- A simple example to demonstrate the basic concept: the decision involves whether to build spawning channels around dams in British Columbia. The structural uncertainty is whether they will be effective.
- Here is a "consequence table" for the decision. Notice we are completely uncertain about our alternative models/hypotheses.
- If we choose not to build the channels, the value of the fishery will remain as it is now ($240m).
- The value of the fishery is only different between the two models if we decide to build. If we build and get no response, then the value is decreased by the amount spent to build the channels ($135m).
- If we get a good response, the value of the fishery will more than double, even after accounting for the cost of the channels ($564m).
- What is the best decision in the face on continuing uncertainty? We simply take a weighted average of the two possible outcomes for each decision choice. The decision to build has a higher expected value ($349.5m).
- What is the expected value if you could resolve the uncertainty? It's simply an average of the best you could do if you knew the no-response model was correct and the best you could do if the good-response model were correct = $402m.
- The expected value of information is thus the best you could expect if you could resolve the uncertainty minus the best you could expect if uncertainty persists: EVPI = $52.5m. This is powerful incentive to conduct research or implement an AM program to resolve the uncertainty.
- Walters, C. J. 1986. Adaptive Management of Renewable Resources. MacMillan Publishing Co., New York, NY.

- If AM offers so much promise, why are there so few examples some 40 years after its introduction?

Hitting the wall

- AM often becomes a perpetual planning exercise because:
  - Reluctance to accept accountability or share decision-making
  - Modeling becomes central focus
    - Driven by notion that more detailed analyses can eliminate uncertainties that were motivation for AM in the first place
    - Unlikely to be productive: reliance on retrospective analyses, confounding of environmental drivers, lack of sufficient contrasts in extant data, scaling issues, emergent processes

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- A common problem involves planning for, but not ever implementing, an AM program.
- Often this stems from a reluctance on the part of decision makers to be completely transparent or to engage in participatory decision-making processes.
- The burden is then shifted to scientists to eliminate the uncertainty in decision making through ever more complex models that are often understood only by those building them and rarely are successful at eliminating the key uncertainties.

Hitting the wall

- Unrealistic expectations
  - Costs can be absorbed within traditional operating budgets
  - Managers exercise efficient control over system responses and behaviors
  - Learning can occur fast and without significant system perturbations
- Lack of follow-through
  - Monitoring, learning, adapting
  - Continuing communication with, and feedback to, stakeholders

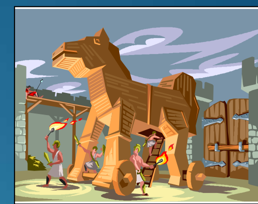
- In addition, there are often unrealistic expectations going into an AM program.
- As well as a lack of commitment for maintaining the program over the time scales needed for successful learning.

Hitting the wall

- More often than not, perpetual planning, unrealistic expectations, and lack of follow-through…
- result is loss of enthusiasm for AM and, thus, for its implementation and sustainability;
- inaction (status quo) often seen as rational choice until more is "known"

- Thus, the failure to widely implement AM is mostly a failure of governing institutions, rather than any problems with AM concepts of principles.

Laying siege



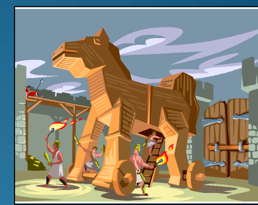
1. *Infiltrate the ranks of bureaucrats married to the status quo*

   - Top-down efforts often involve less transparency and acknowledgement of uncertainty/risk; resisted by the rank-and-file; higher public profile invites controversy

   - Bottom-up efforts are usually easier to manage: smaller scope and number of players; more flexibility in exploring alternatives, values, and outcomes; more ownership

- The most successful AM efforts I’ve encountered do not arise from the top of governing institutions, but from the bottom.

Laying siege



2. *Use a "skunk works"*

- Assemble a core development team of <15 participants
- Ensure all stakeholder interests are represented
- Ensure all skill sets are represented
  - Resource managers
  - Ecological scientists
  - Social scientists
  - Human-dimension / communication specialists

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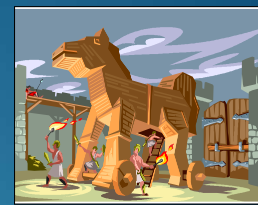
- A small development team is more effective than the large groups typically involved in AM planning.

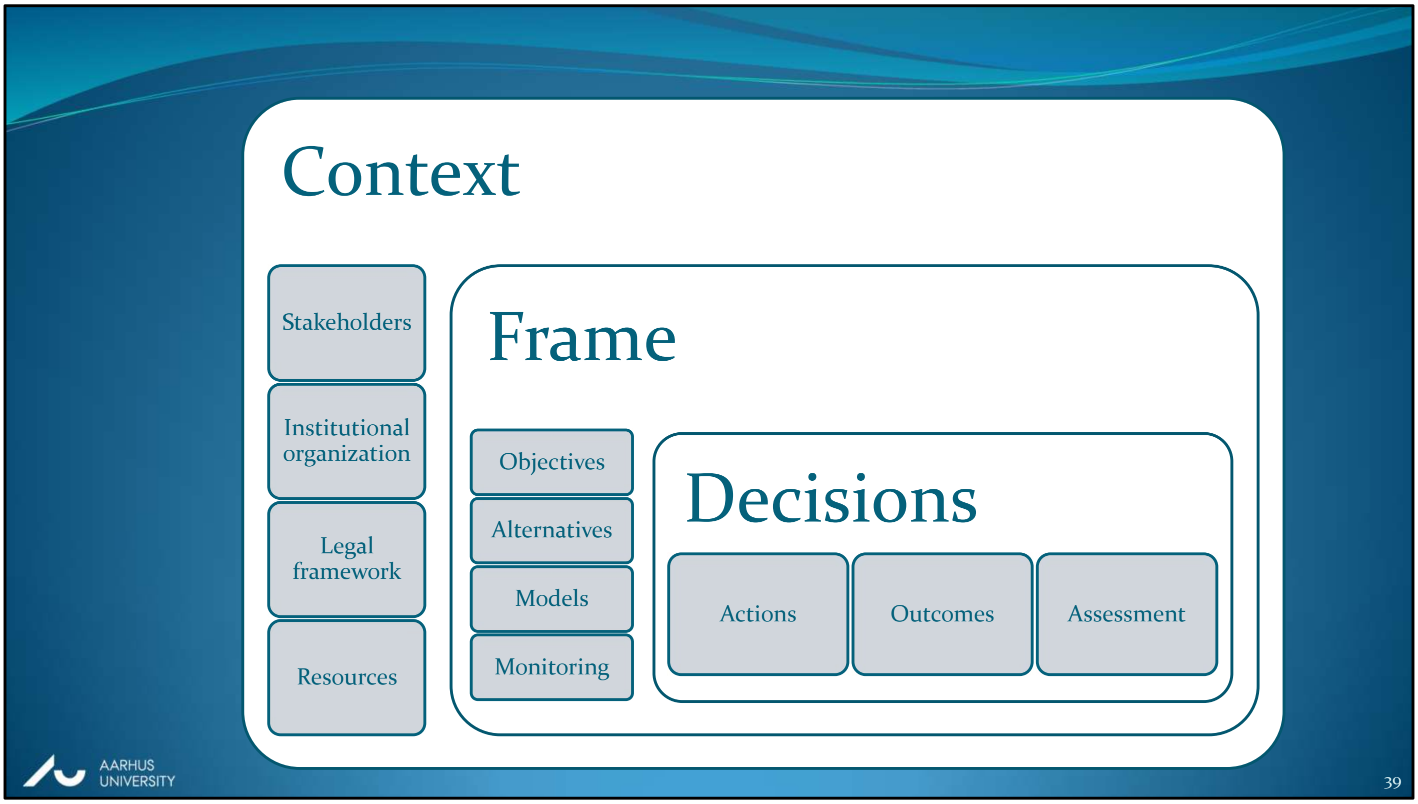
Laying siege



3. Find a champion who...

- has sufficient time to devote
- has sufficient expertise in both management and research
- has infectious enthusiasm and great communication skills
- can be trusted to be impartial ("honest broker")
- *is persistent as hell!*

- Virtually every successful AM program has had a champion, an individual with sufficient leadership skills who helped guide and maintain the effort when it might have otherwise faltered.



- Finally, it's worth emphasizing that an effective institutional process for AM involves three frames of reference.
- There is the iterative process of decision making and comparing outcomes with predictions.
- This iterative process is embedded in a problem frame, in which objectives and decision alternatives must be agreed upon, and system models and monitoring programs developed.
- Lastly, the framing of the problem is embedded in a contextual process of identifying and including stakeholders, defining the governance structure, subscribing to legal mandates, and providing the resources necessary to develop and sustain the process.
- And it is important to recognize that learning in any of these frames of reference can effect change in other frames.
- E.g., the failure of any models to make reliable predictions might motivate the development of new models. Or the failure to achieve objectives might motivate the need to amend or change rules or laws limiting the effectiveness of management.

What to remember

- **Adaptive management is useful:**
  - For dynamic problems
  - With uncertainty that is *important to management decisions*
  - Where alternative actions can be informative of underlying system dynamics
  - When monitoring can be used to guide decisions and then learn from the outcomes

- **Adaptive management involves the management of two systems:**
  - The *physical system* of interest
  - A *knowledge system*
  - There is usually a tradeoff in managing these two systems; a balance is needed for good long-term performance

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More to remember

- Institutional structure for decision making must be clear, with well-defined roles & responsibilities for all
- Even so, decision-making can be over-whelmed by bureaucracy – a proliferation of rules and procedures that produce rigidity & inertia in decision making
- Can be overcome by:
  - Active & ongoing stakeholder engagement
  - Acknowledgement and acceptance of uncertainty & risk
  - Transparency in operations (effective communication)
  - *Strong leadership* (presence of a champion to serve as an honest broker)

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