From Oceans to Fields:

Socio-ecological Decision Making for the 21st Century

Carl Boettiger | UC Berkeley | @cboettig


Fisheries

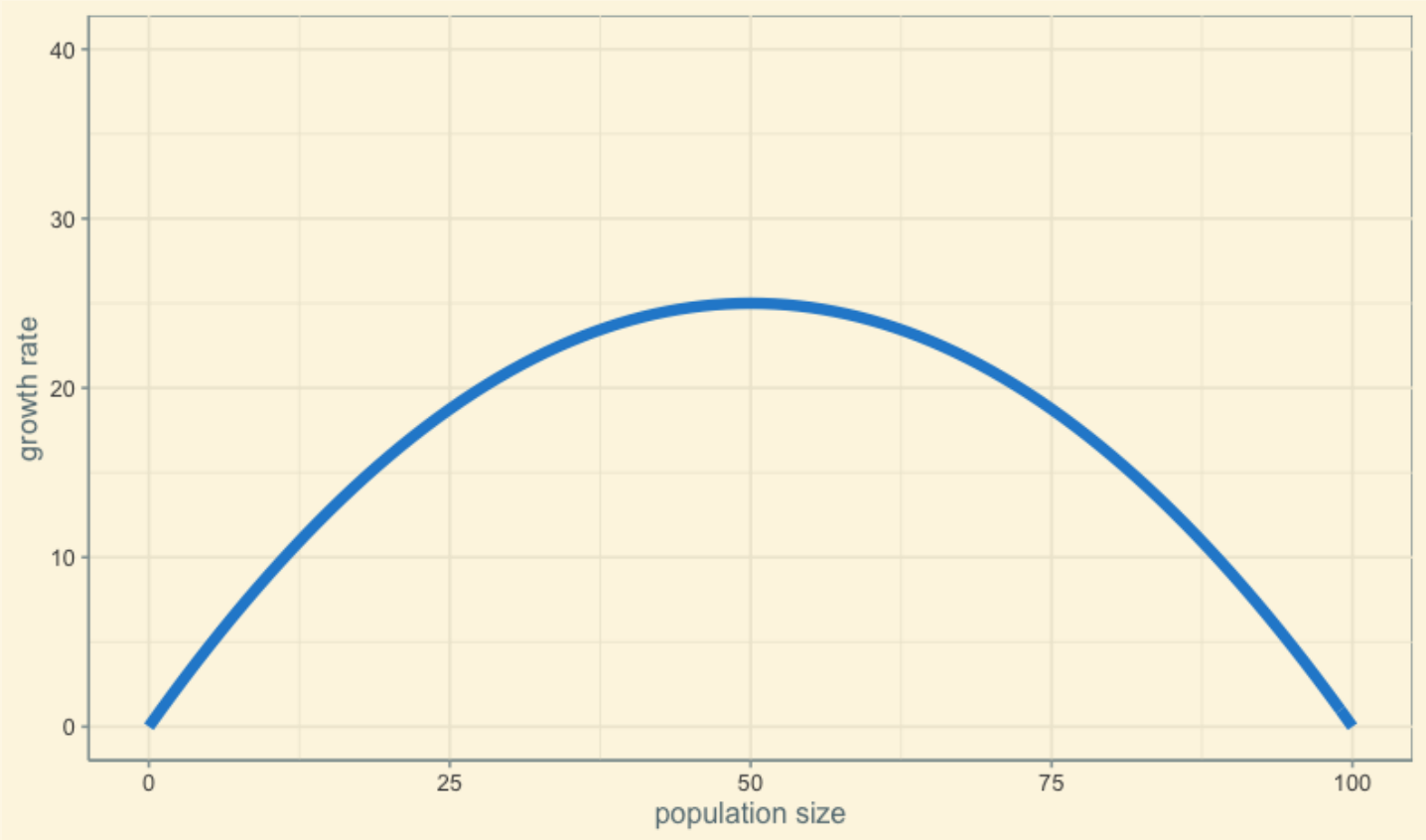

Farming

Fisheries Management

image: NOAA

Managing Fisheries Under Uncertainty: A History of Paradox

MSY (Schaefer 1954)



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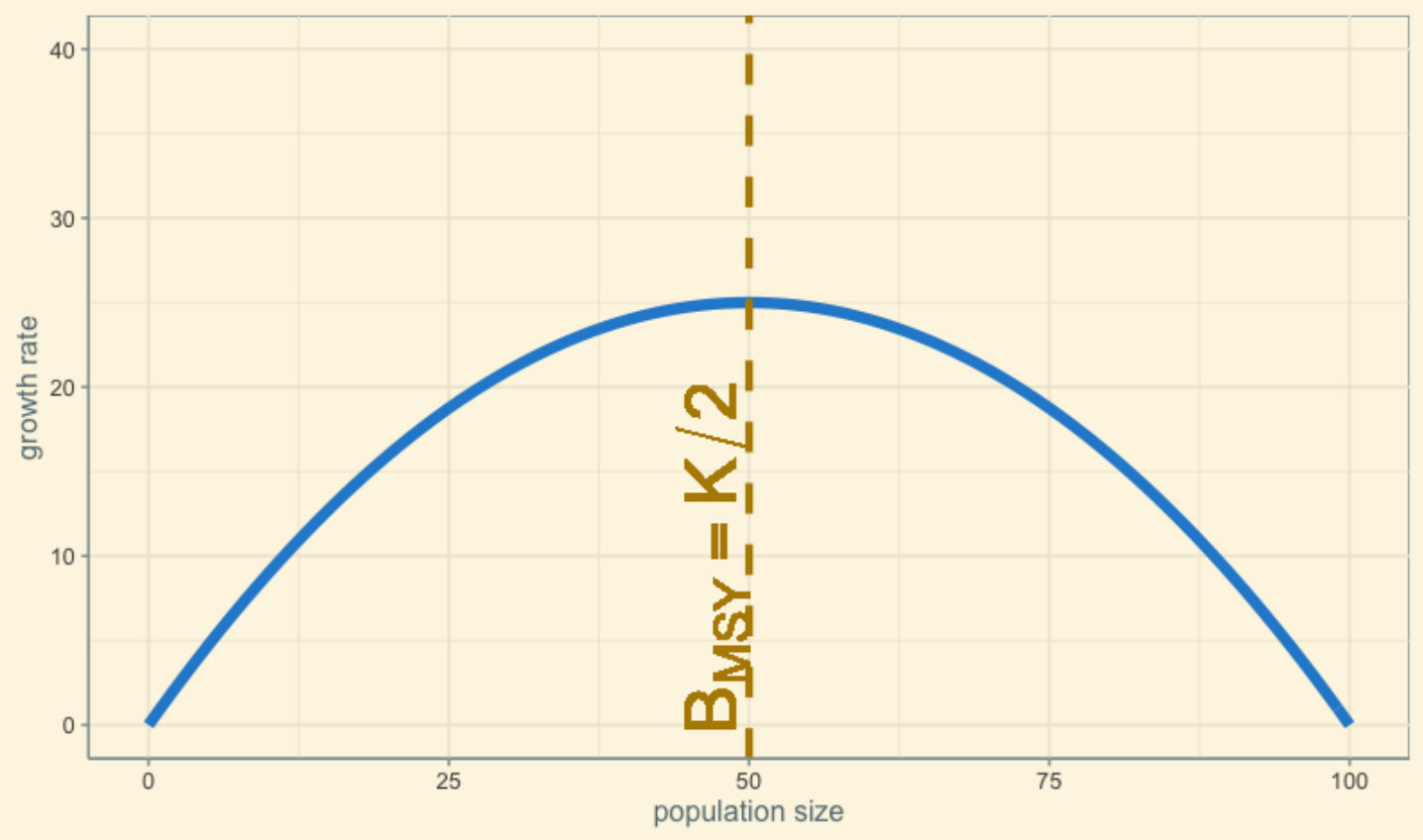

$$H = F \cdot B$$

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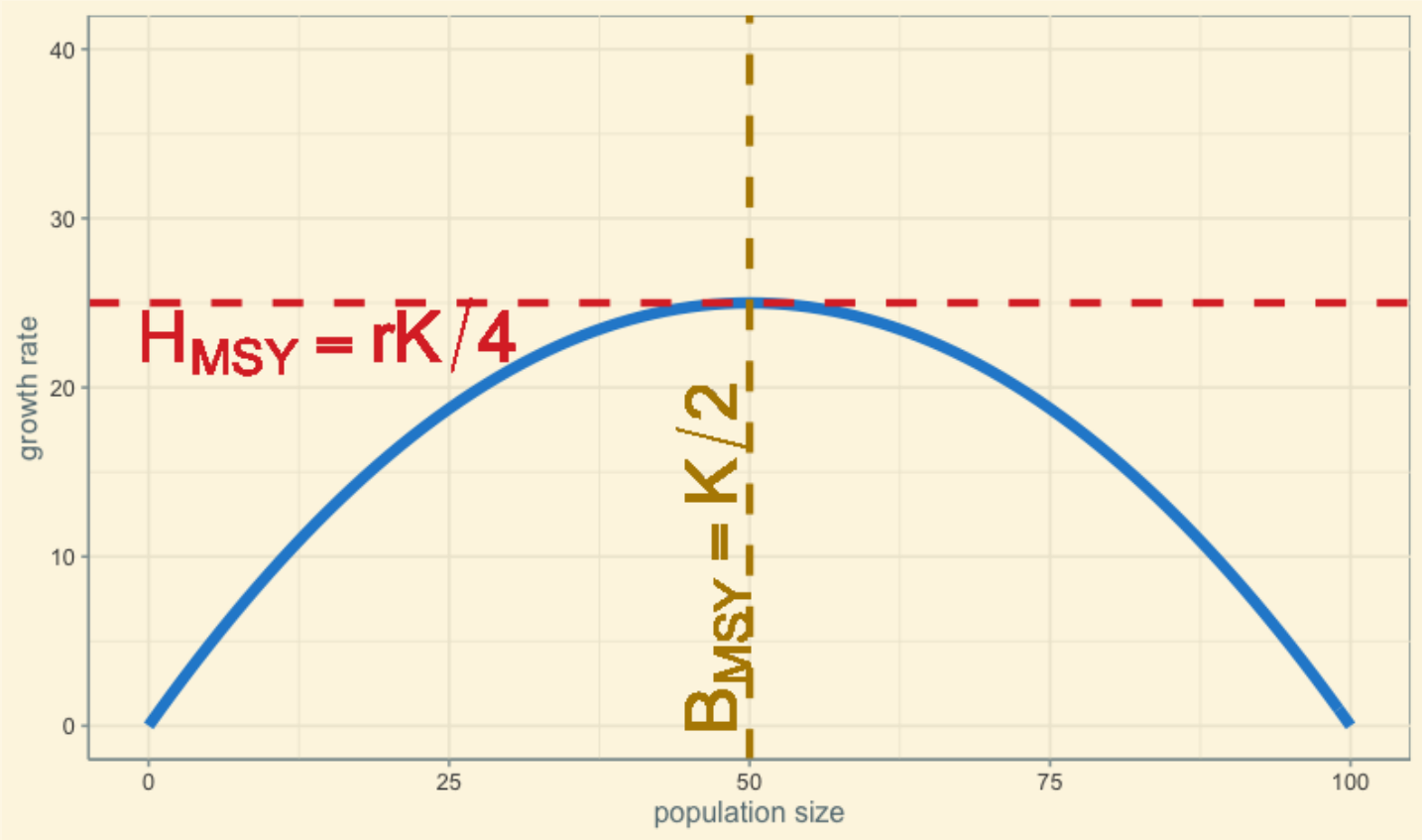

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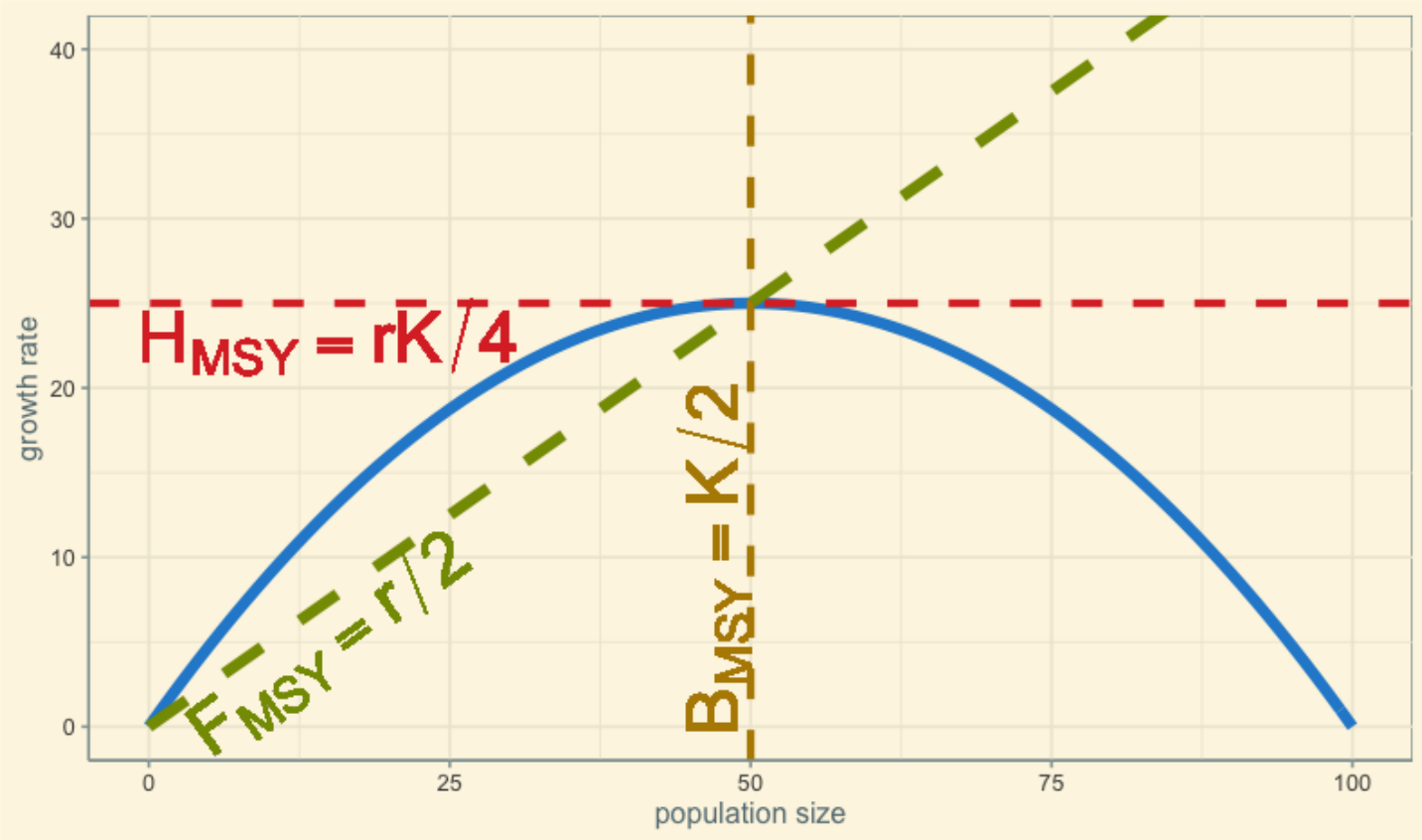
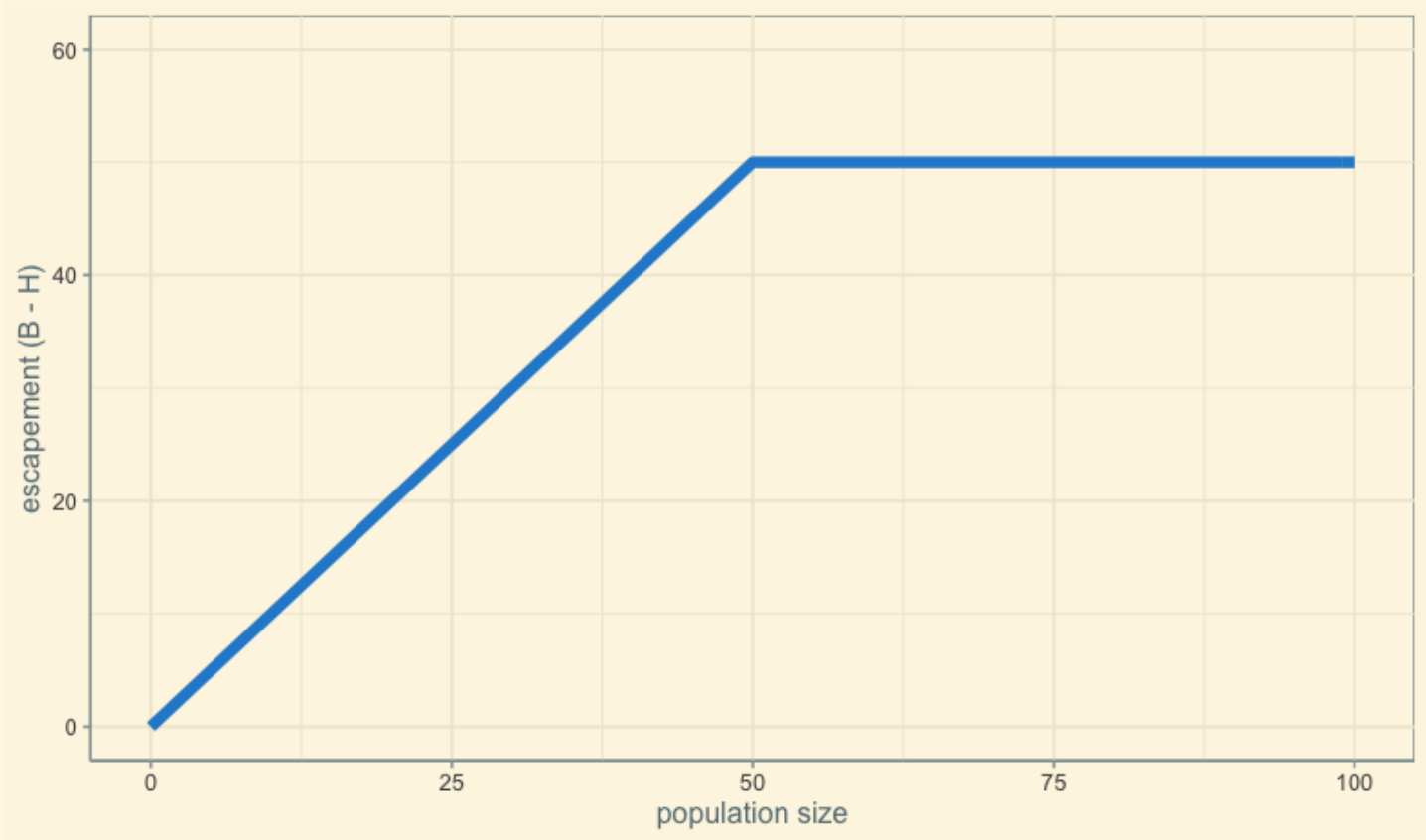


Constant Escapement (Clark 1973)



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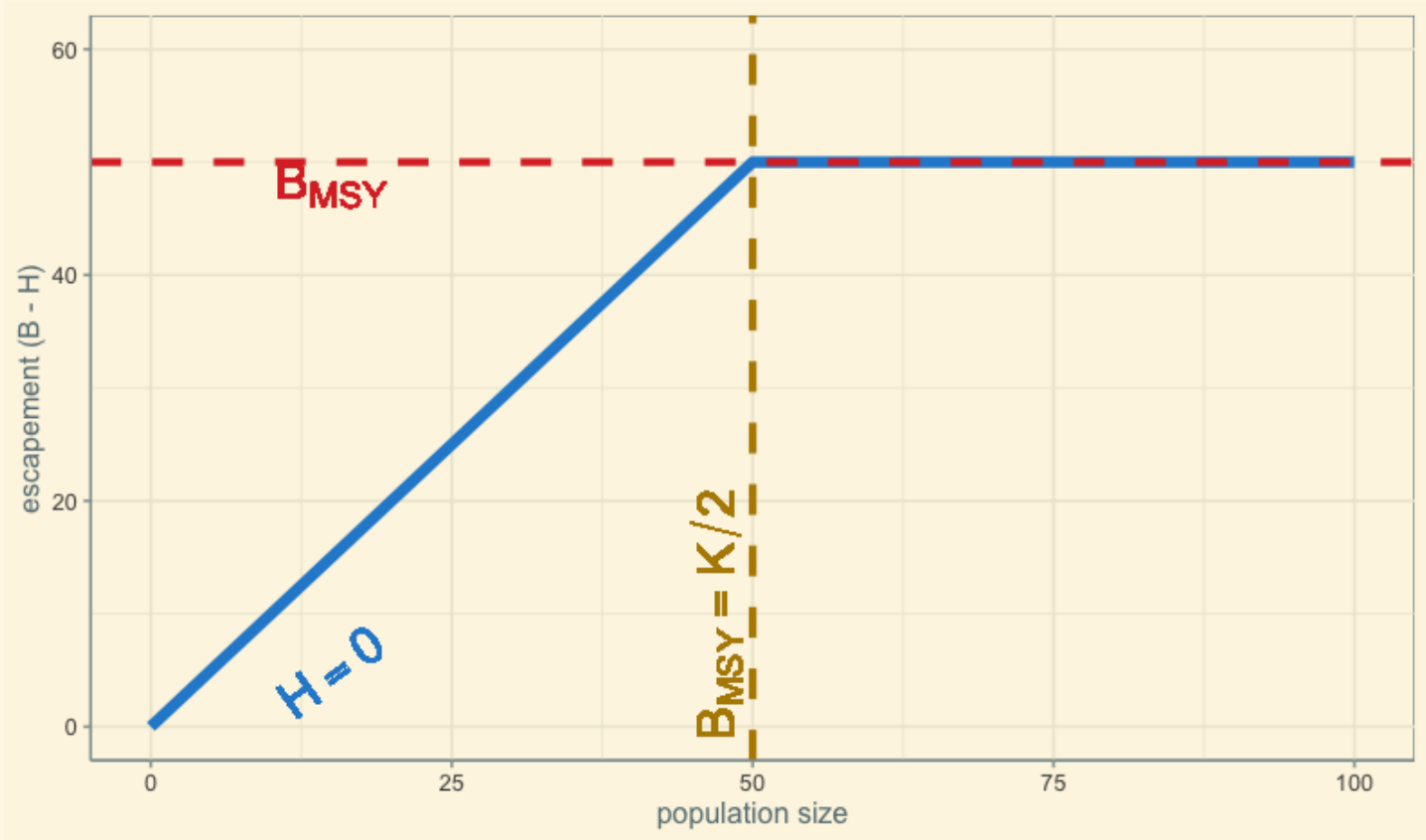

Stochastic growth (Reed 1979)

THEOREM 2. *Under the conditions of Theorem 1 if the level σ (at which the expected discounted annual growth in the immediate harvest value of the population is maximized) is self-sustaining then the optimal escapement is at σ (i.e., $S = \sigma$). If on the other hand σ is not self-sustaining then $S > \sigma$, (except in the trivial exceptional case when $S = \sigma = m$).*

Proof. In the case when σ is self-sustaining we proceed by induction and assume

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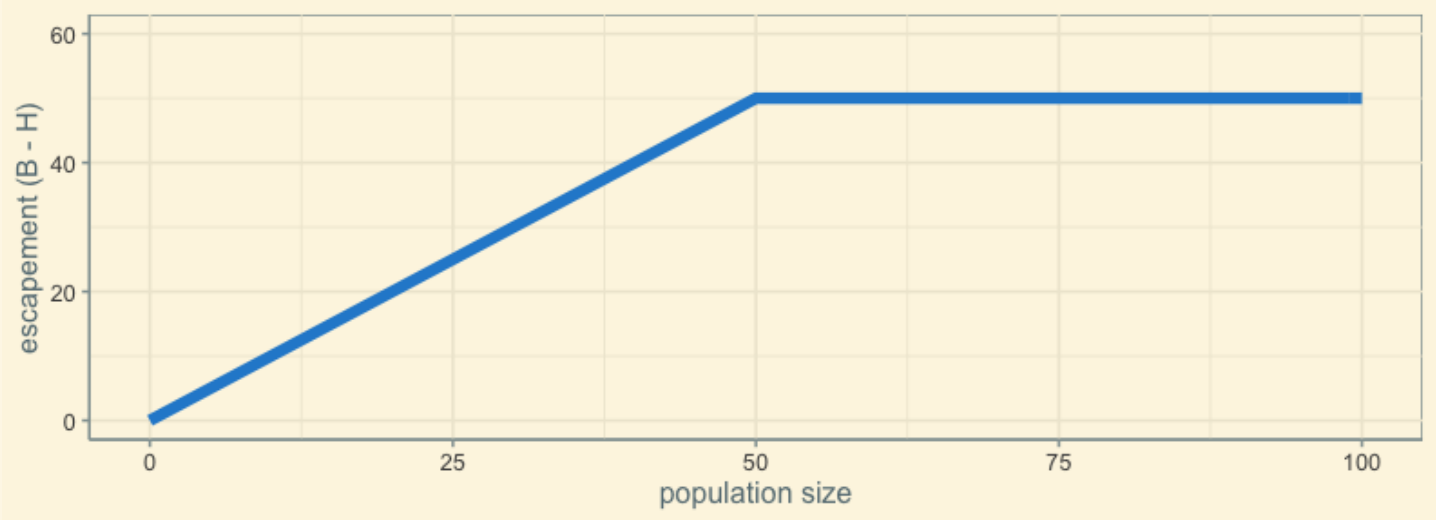

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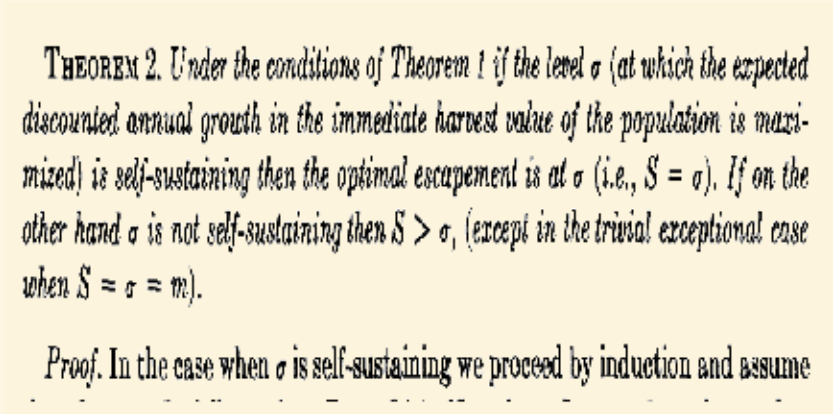

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Introducing uncertainty != more cautious harvesting

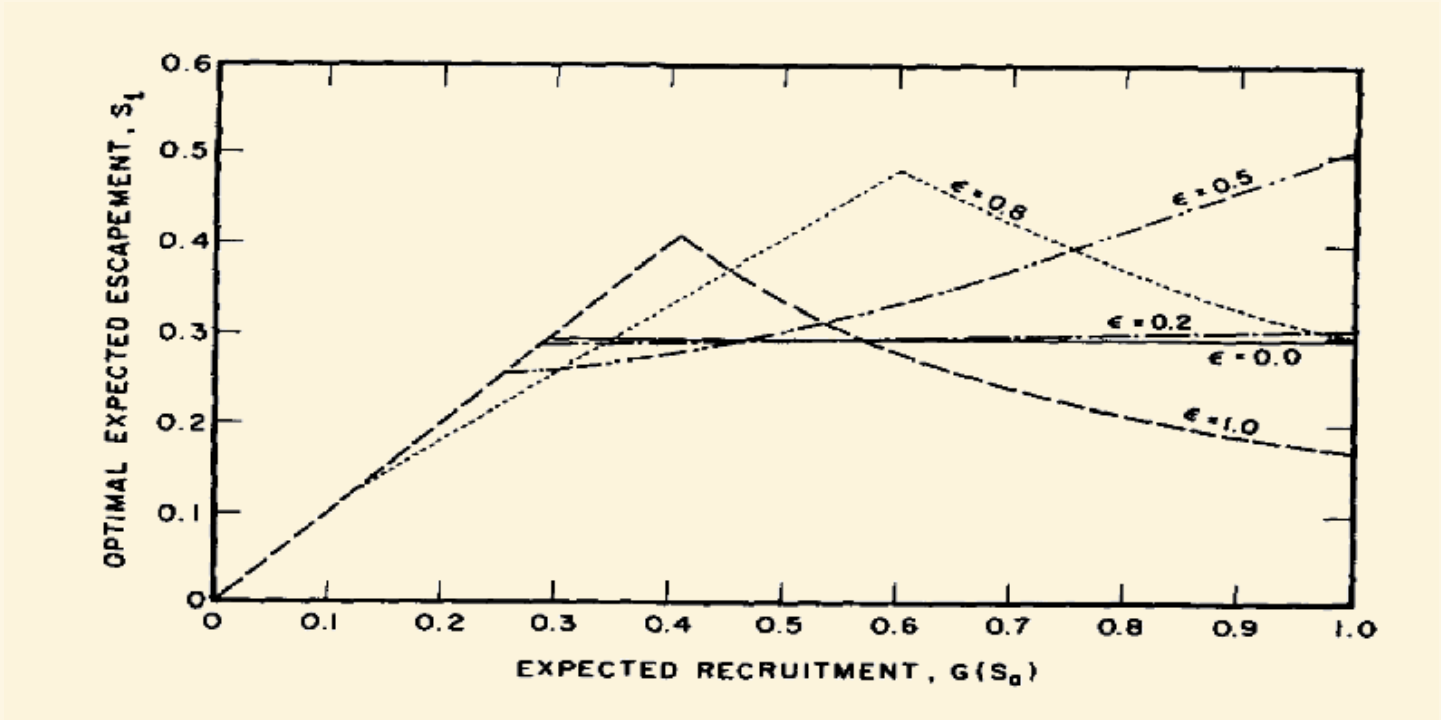
Is uncertainty truly negligible?

Adding more uncertainty (Clark & Kirkwood 1986)

> An important tacit assumption in Reed's analysis, as in the other works referred to above, is that the recruitment level X is known accurately prior to the harvest decision, [...] In the case of fishery resources, the stock level X is almost never known very accurately, owing to the difficulty of observing fish in their natural environment.
>
> -- *Clark & Kirkwood 1986*

In which tackling the first paradox...

... leads to another paradox paradox!



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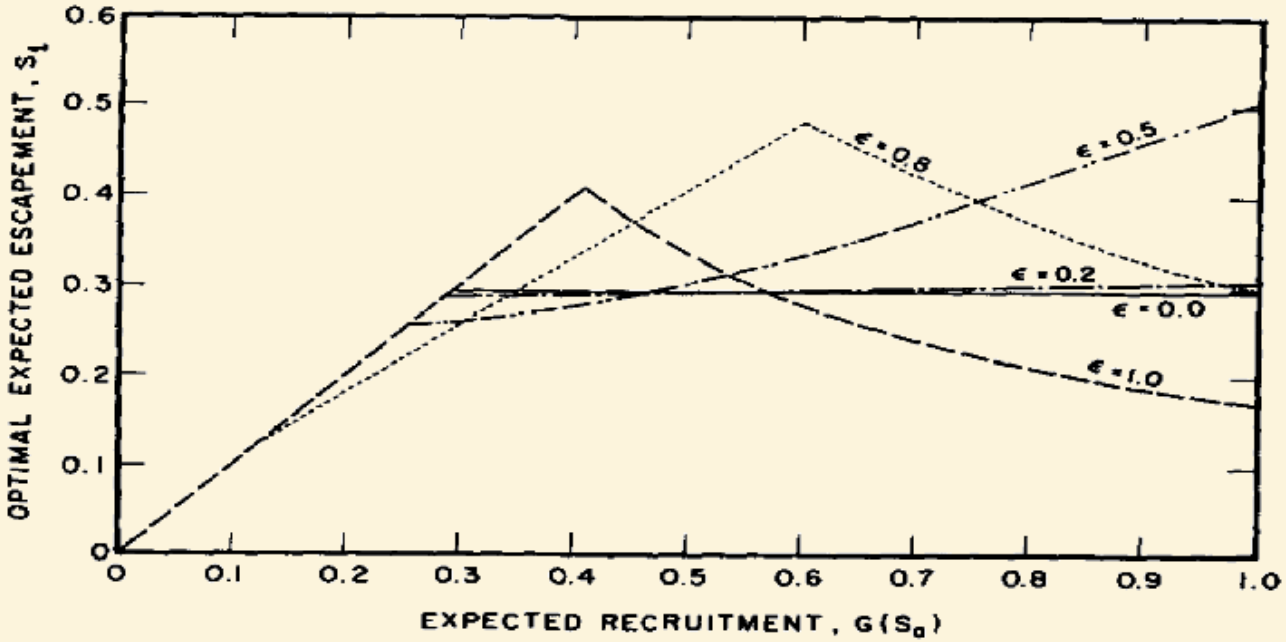


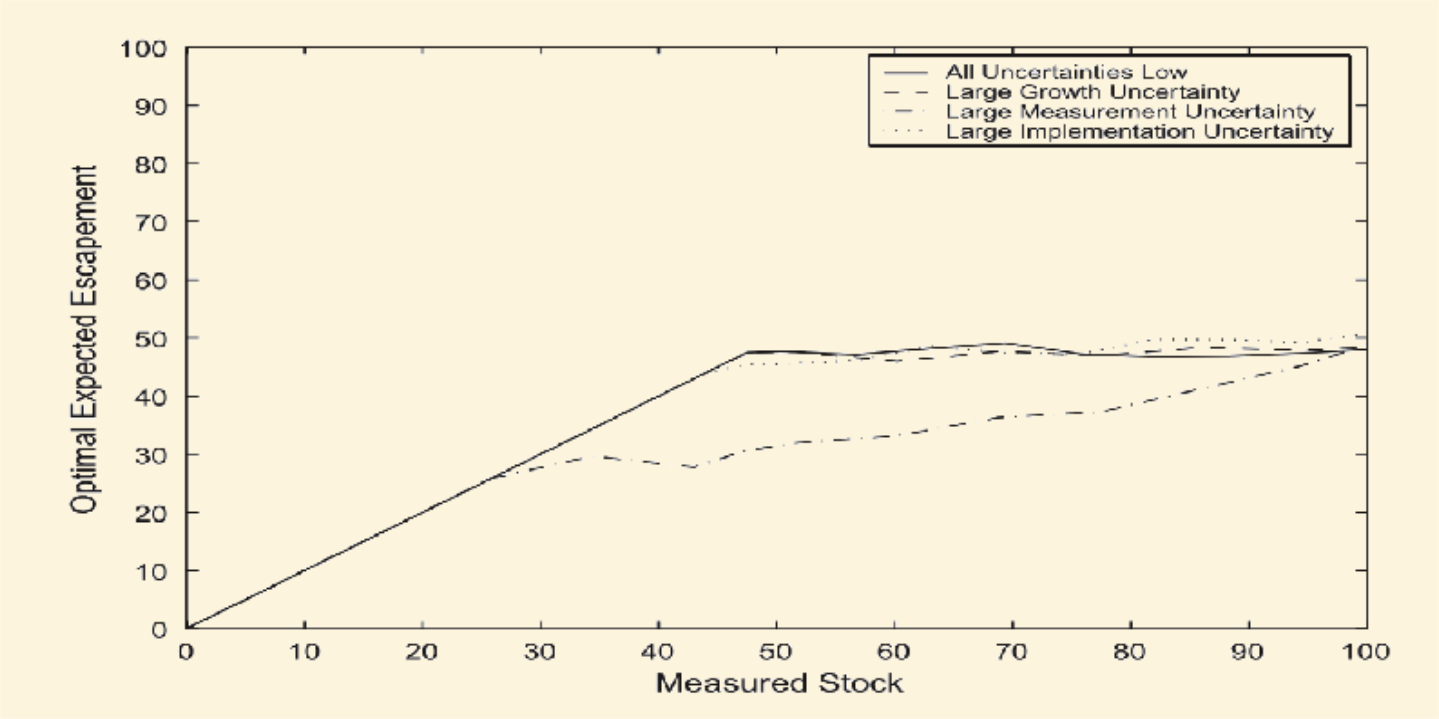
> The above results appear to **contradict the conventional wisdom** of renewable resource management, under which high uncertainty would call for increased caution in the setting of quotas.
>
> -- *Clark & Kirkwood 1986*

"Simplifying Assumptions"

How did we get here?

> For reasons of tractability, we shall adopt the simplifying assumption that the escapement level S is known exactly at the end of that period. (The mathematical difficulty of the problem increases markedly if this assumption is relaxed.)
>
> -- *Clark & Kirkwood 1986*

Complete Measurement Uncertainty



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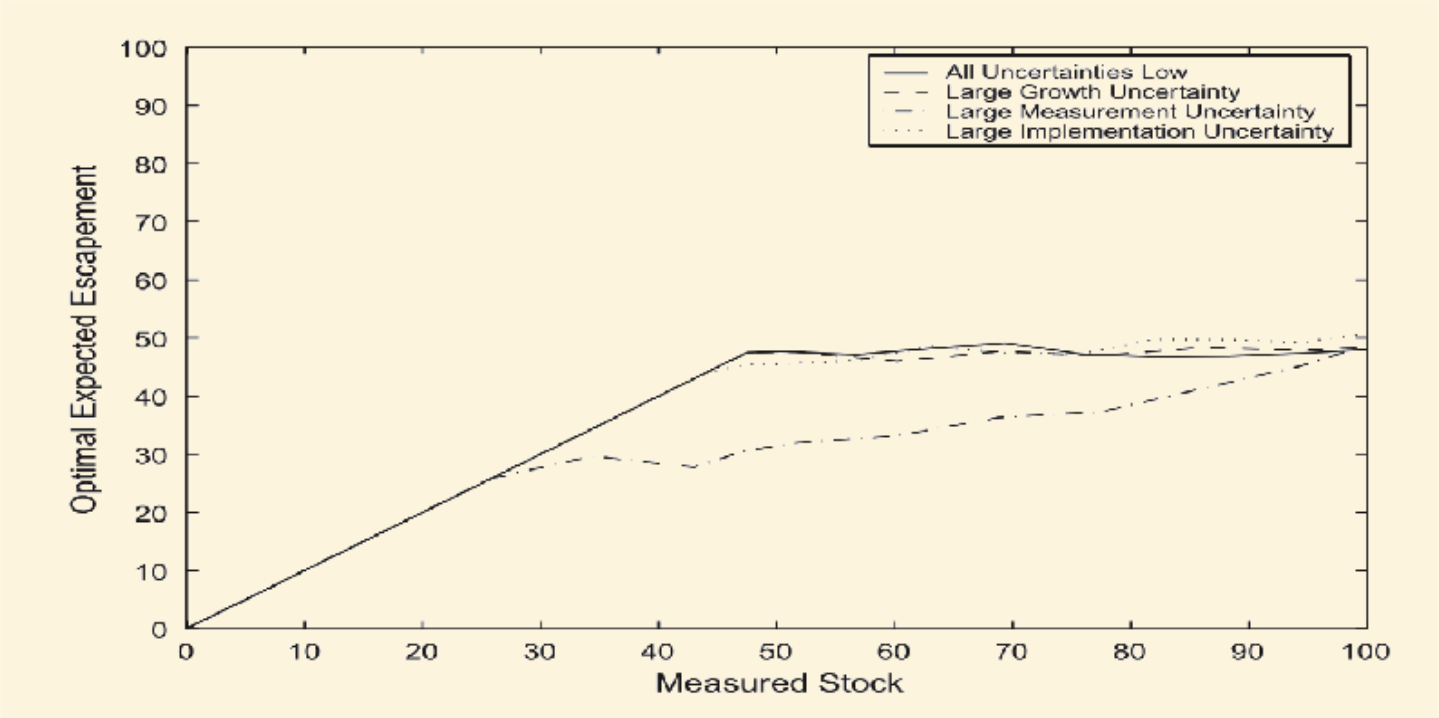

> It may seem counter-intuitive that a measurement error causes lower expected escapements below the deterministic fishery closure threshold.
>
> -- Sethi, Costello et al, 2005

How did we get here again?

> We should also note the somewhat misleading use of the term "optimal policy" in this context. Specifically, Assumption 3 states that the manager **uses only the current measurement when forming expectations**. This assumption implies that the current measurement is the only state variable for the manager's problem. Past measurements may contain some information about the current stock; a more sophisticated manager would use that information in forming expectations.

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So why did we do that?

> Second, the optimization problem for a manager who uses past measurements is very complicated...

Meanwhile...

The Optimal Control of Partially Observable Markov Processes over a Finite Horizon

Richard D. Smallwood

Stanford University, Stanford, California, and Xerox Palo Alto Research Center, Palo Alto, California

and

Edward J. Sondik

Stanford University, Stanford, California

(Received October 27, 1971)

This paper formulates the optimal control problem for a class of mathematical models in which the system to be controlled is characterized by a finite-state discrete-time Markov process. The states of this internal process are not directly observable by the controller; rather, he has available a set of observable outputs that are only probabilistically related to the internal state of the system. The formulation is illustrated by a simple machine-maintenance example, and other specific application areas are also discussed. The paper demonstrates that, if there are only a finite number of control intervals remaining, then the optimal payoff function is a piecewise-linear, convex function of the current state probabilities of the internal Markov process. In addition, an algorithm for utilizing this property to calculate the optimal control policy and payoff

20 years later...

Thrun 1992

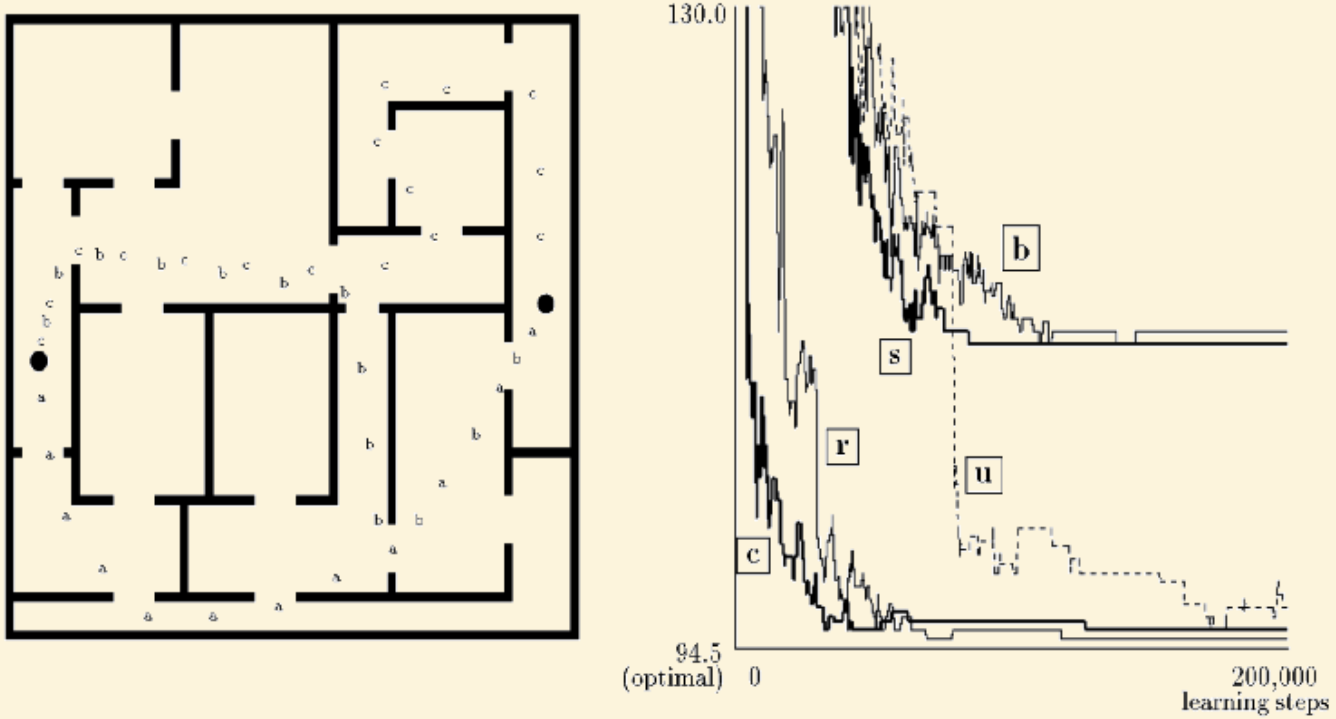


Figure 6: (a) Task: The task is to navigate the robot (left circle) to its destination (right circle) on the shortest possible

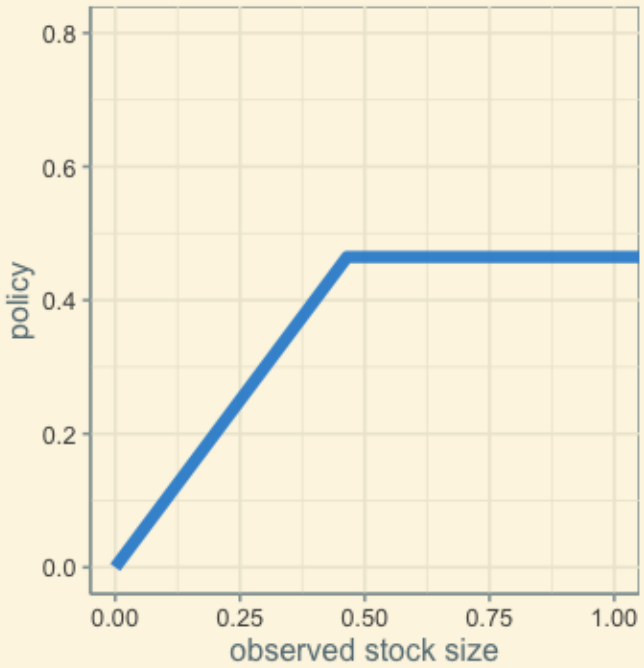
DARPA 2005 Autonomous Vehicle Challenge

"Stanely," Stanford Racing Team led by Sebastian Thrun PUBLIC DOMAIN

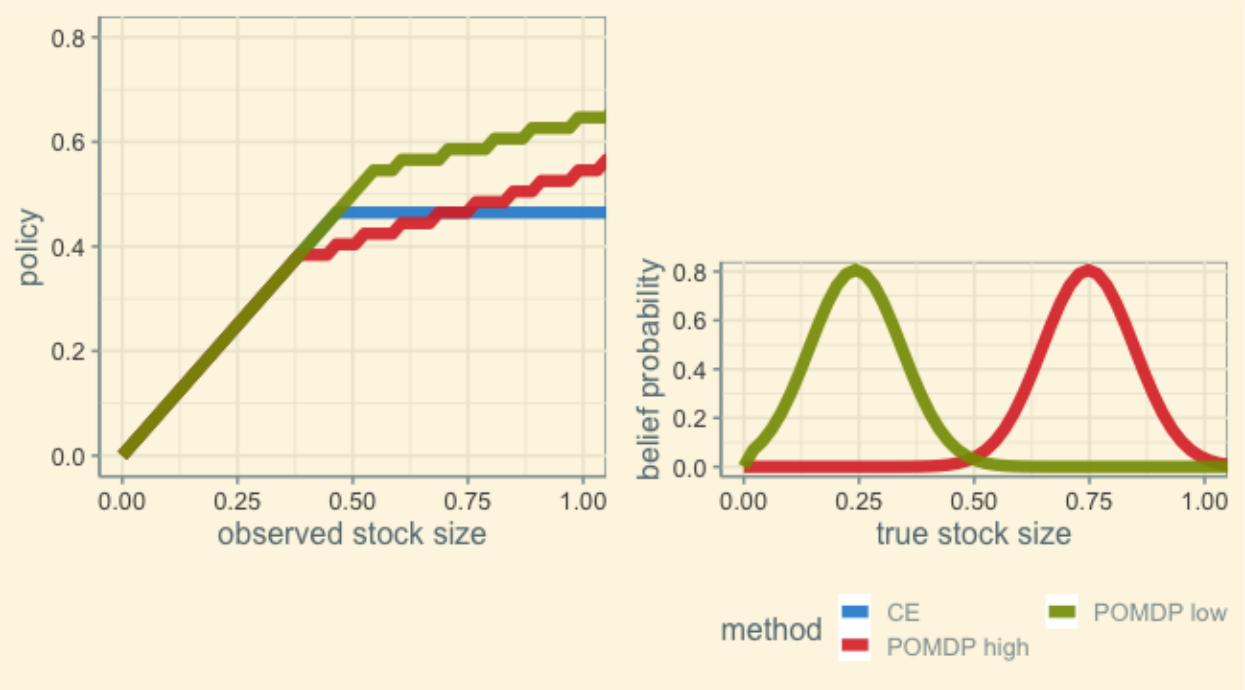
So back to fisheries...


SPEED
LIMIT
40

Damn the complexity, full speed ahead!

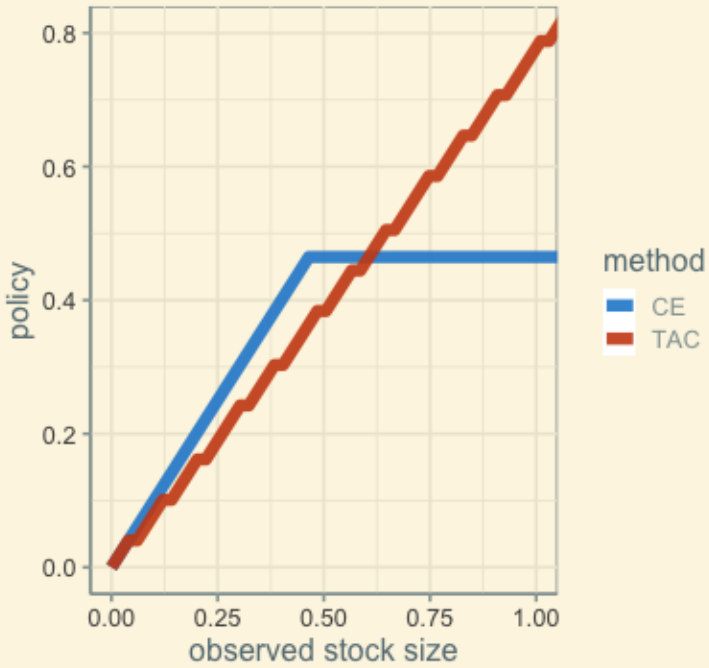


A resolution to the paradox!

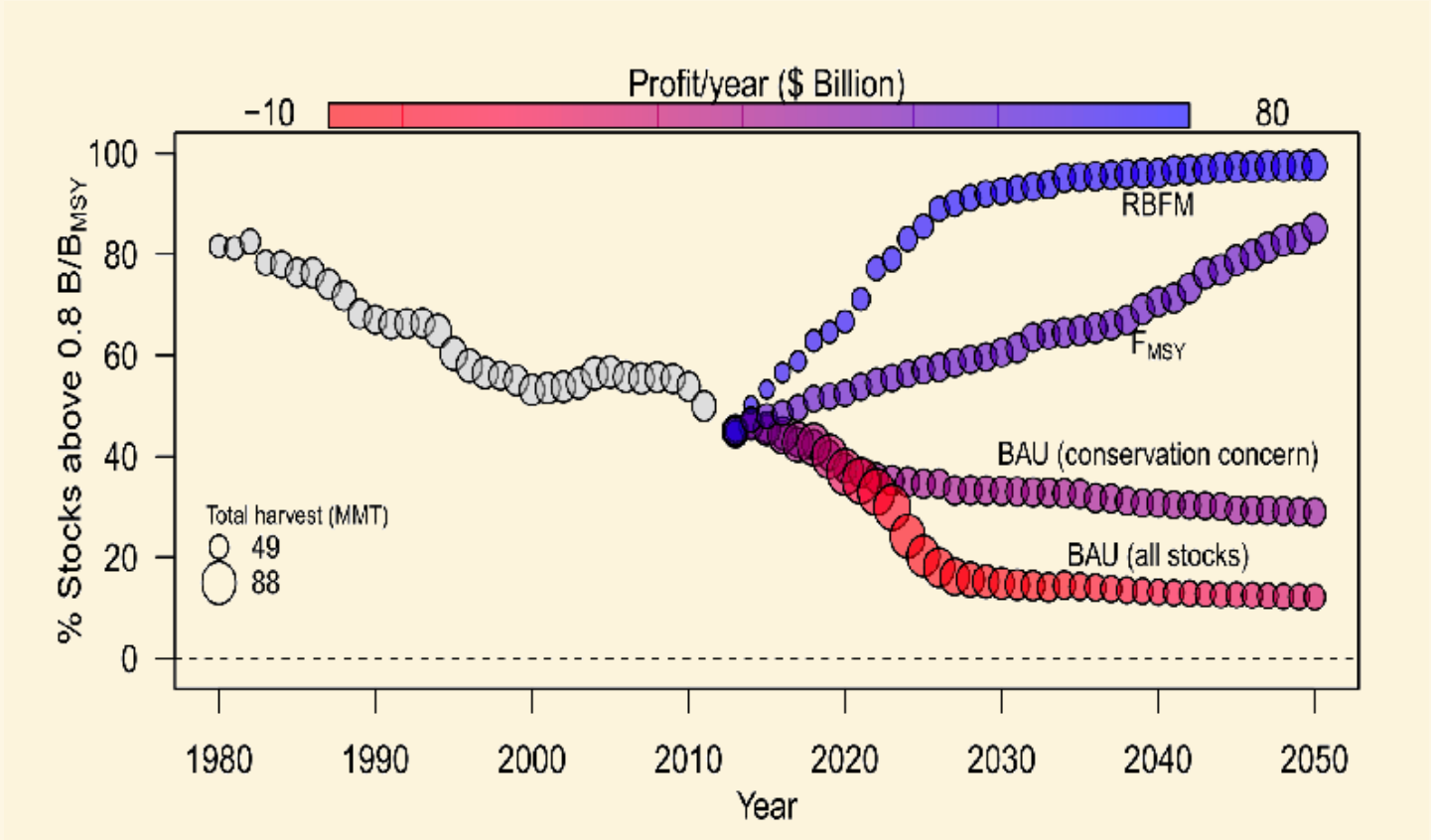


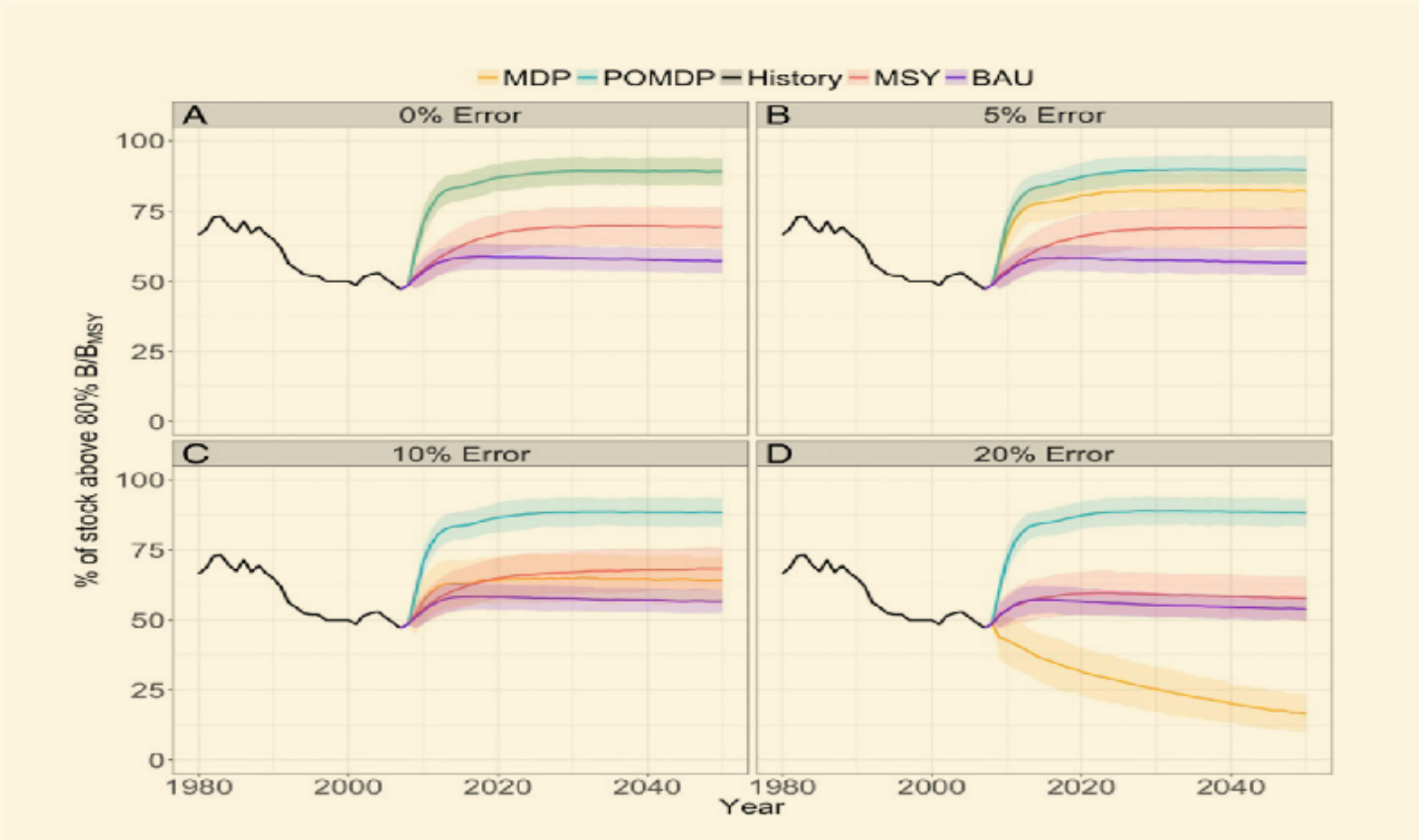
Memarzadeh & Boettiger (2019)

Comparison to "constant mortality" rule



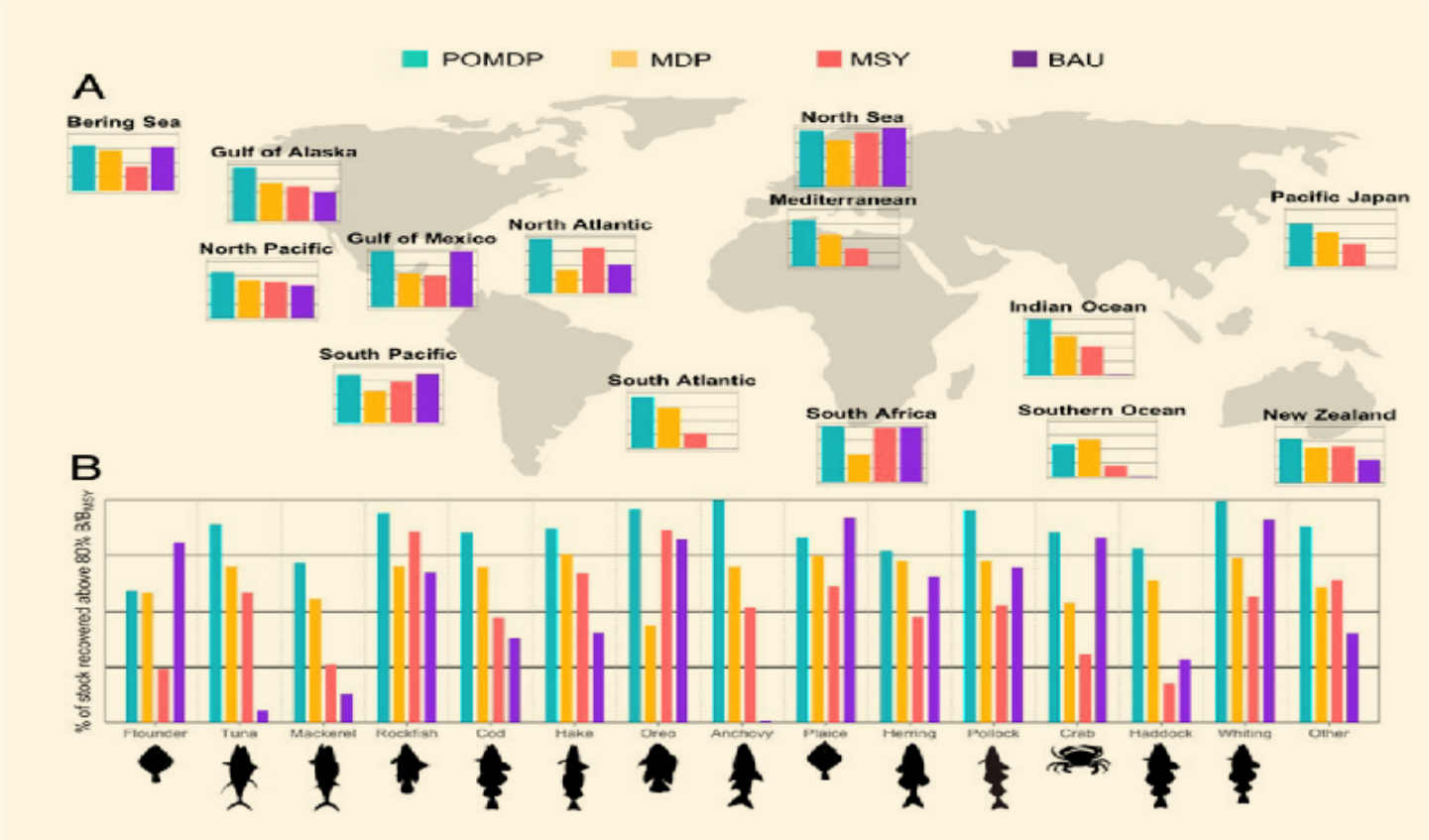
Future of Fish





Memarzadeh et al, 2019 *PNAS*

Forecast outcomes by location and taxon



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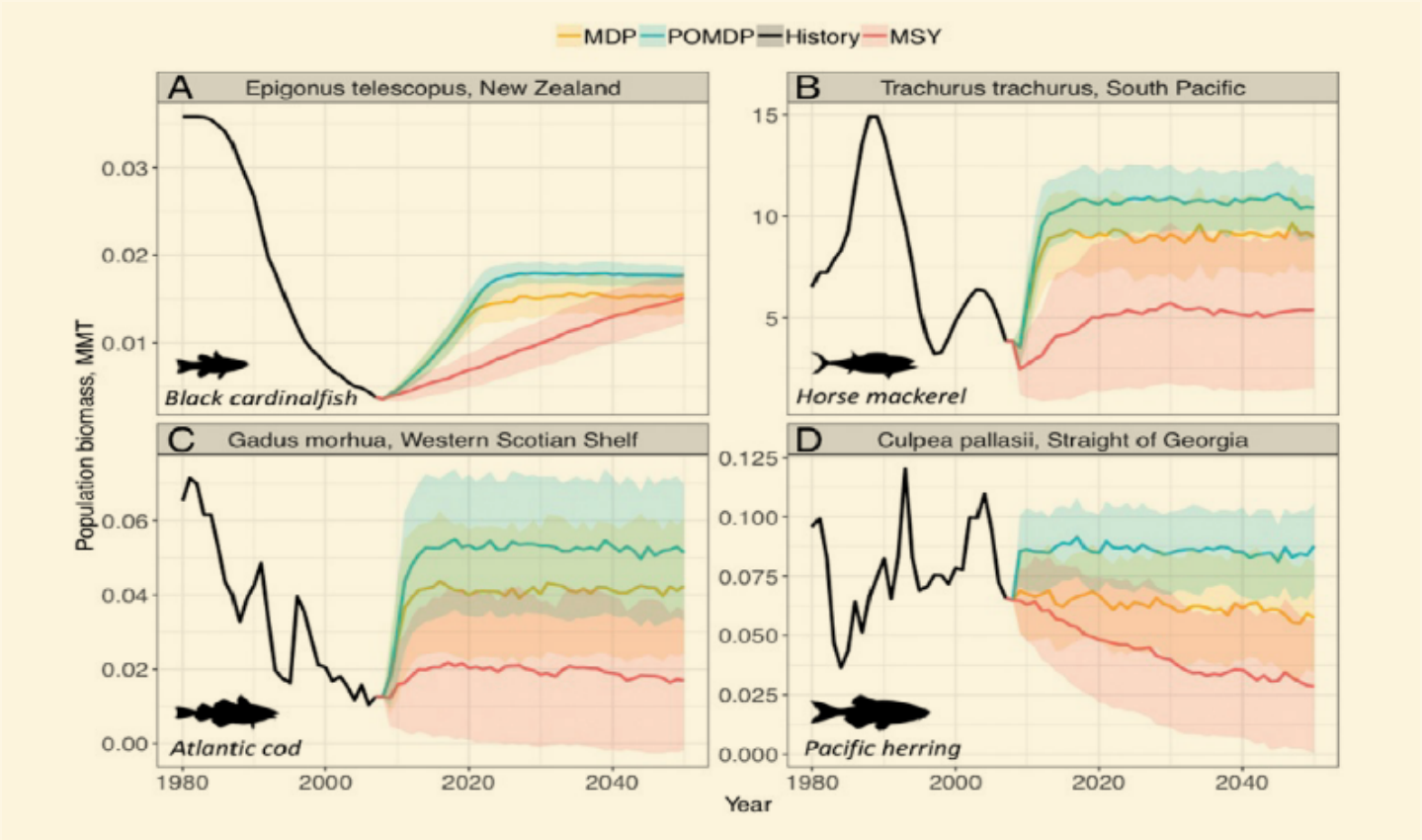
Life history and environmental sensitivity influence impact



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Does this really contradict Costello et al?

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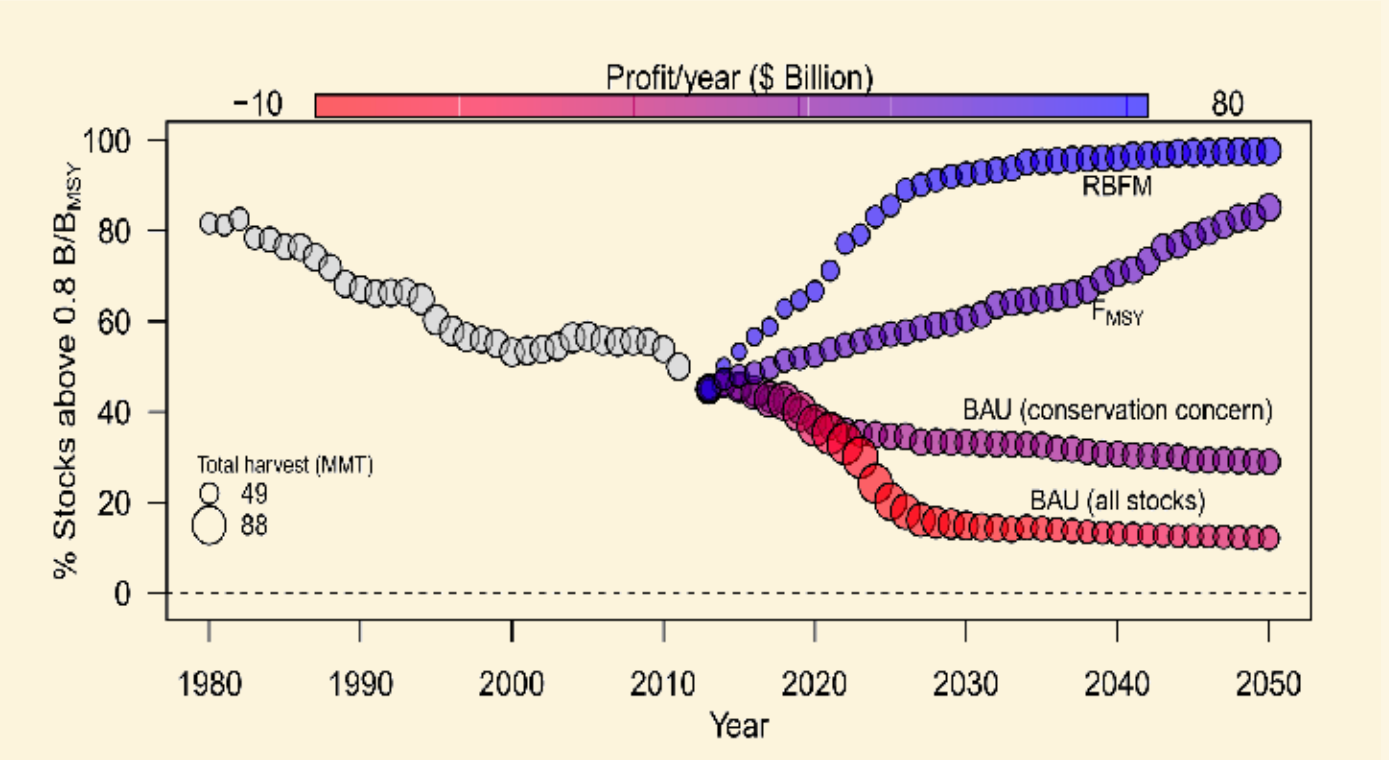

Rights-Based Fisheries Management

Setting Total Allowable Catch (TAC)

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Rights-Based Fisheries Management

> the optimal TAC at each point of time corresponds to the maximization of the quota share price, provided, of course, that the Individual Transferable Quota (ITQ) property rights are of sufficiently high quality.

Setting Total Allowable Catch (TAC)

Rights-Based Fisheries Management

> the optimal TAC at each point of time corresponds to the maximization of the quota share price, provided, of course, that the Individual Transferable Quota (ITQ) property rights are of sufficiently high quality.
>
> This implies that the TAC-setting authority does not have to engage in extensive data collection and calculations to set the best possible TAC. It only needs to adjust the TAC until the share quota price is maximized.
>
> -- Arnason 2012

Decision-Making in Fisheries Management: Reflections

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Dangers of certain simplifying assumptions

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Theoretical, algorithmic, and computational advances in other fields can improve ecological decisions

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Do these decisions really come from technology or human behavior?

Decision-Making in Fisheries Management: Reflections

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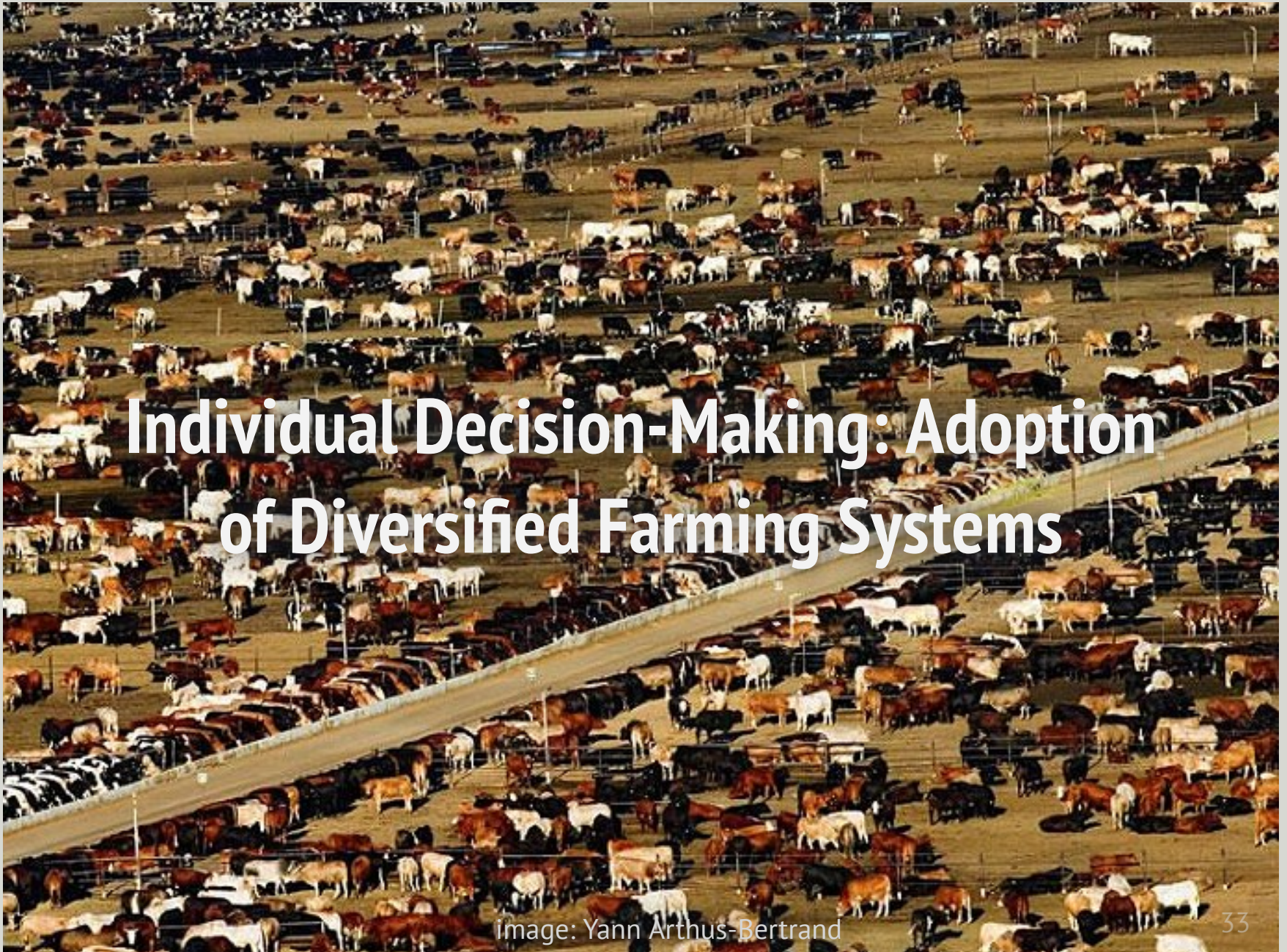
Do these decisions really come from technology or human behavior?

POMDP solution is qualitatively far more intuitive!



Individual Decision-Making: Adoption of Diversified Farming Systems

image: Yann Arthus-Bertrand

Adoption in Diversified Farming Systems

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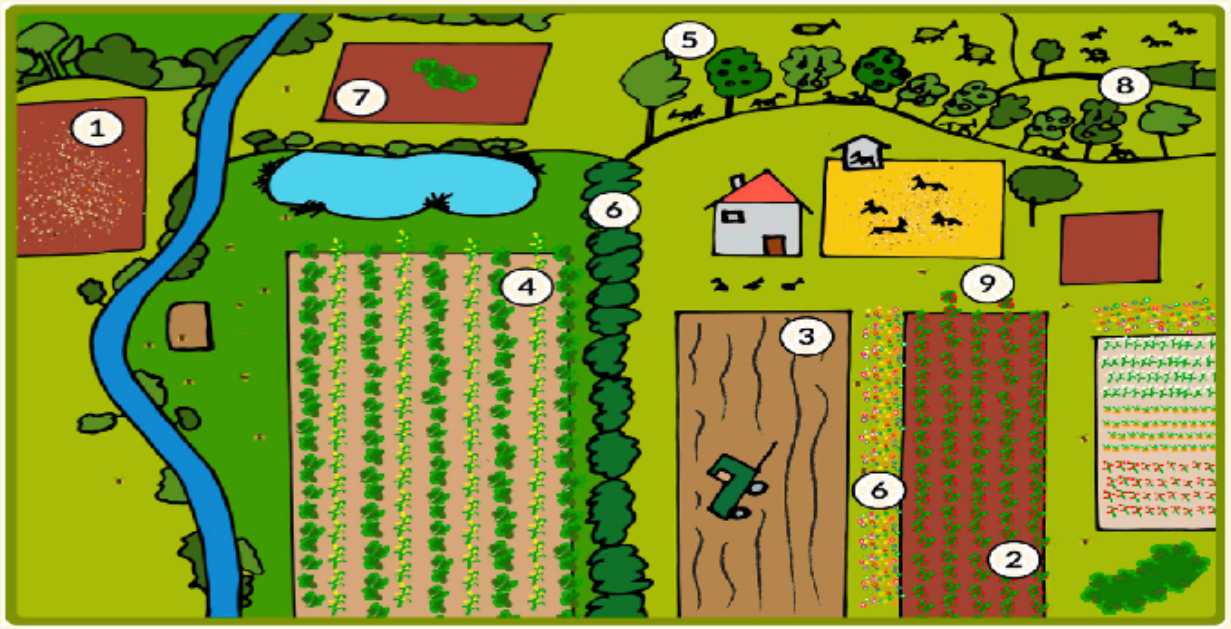
Diversified Farming Systems



Single measures

1. Cover crop & green manure
2. Diversified crop rotation
3. Reduced tillage
4. Intercropping
5. Agroforestry
6. Structural elements

Combined practices

7. Conservation agriculture
8. Mixed crop-livestock
9. Organic agriculture

Rosa Schleich et al (2019), Ecological Economics

What factors most influence the adoption of Diversified Practices?

Diversified Farming Practices

- Cover crops
- Crop rotation
- reduced tillage
- Agroforestry
- Hedge rows
- Mixed crop-livestock
- Organic agriculture
- Conservation agriculture

...

Ecosystem Services

- higher biodiversity
- improved pest control
- weed control & soil health
- reduced soil erosion
- improved nutrient management
- carbon sequestration
- increased resilience
- yield improvement
- reduced fertilizer input
- $ higher profitability and less risk

Rosa Schleich et al (2019), Ecological Economics

Markov Decision Process Model

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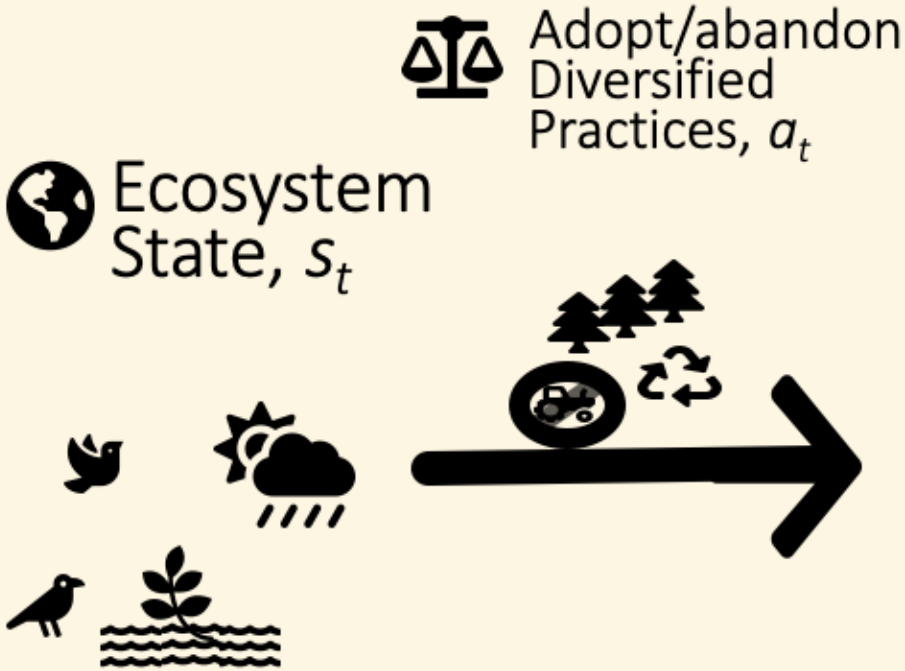

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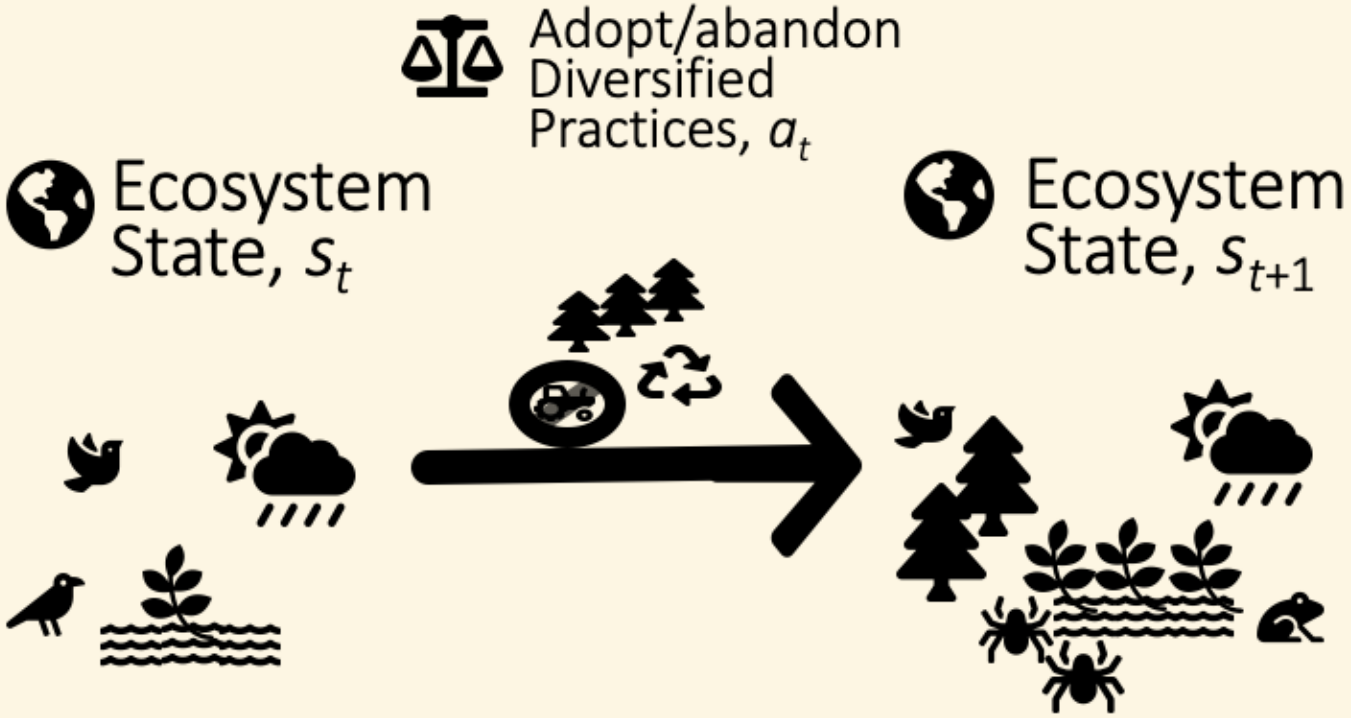

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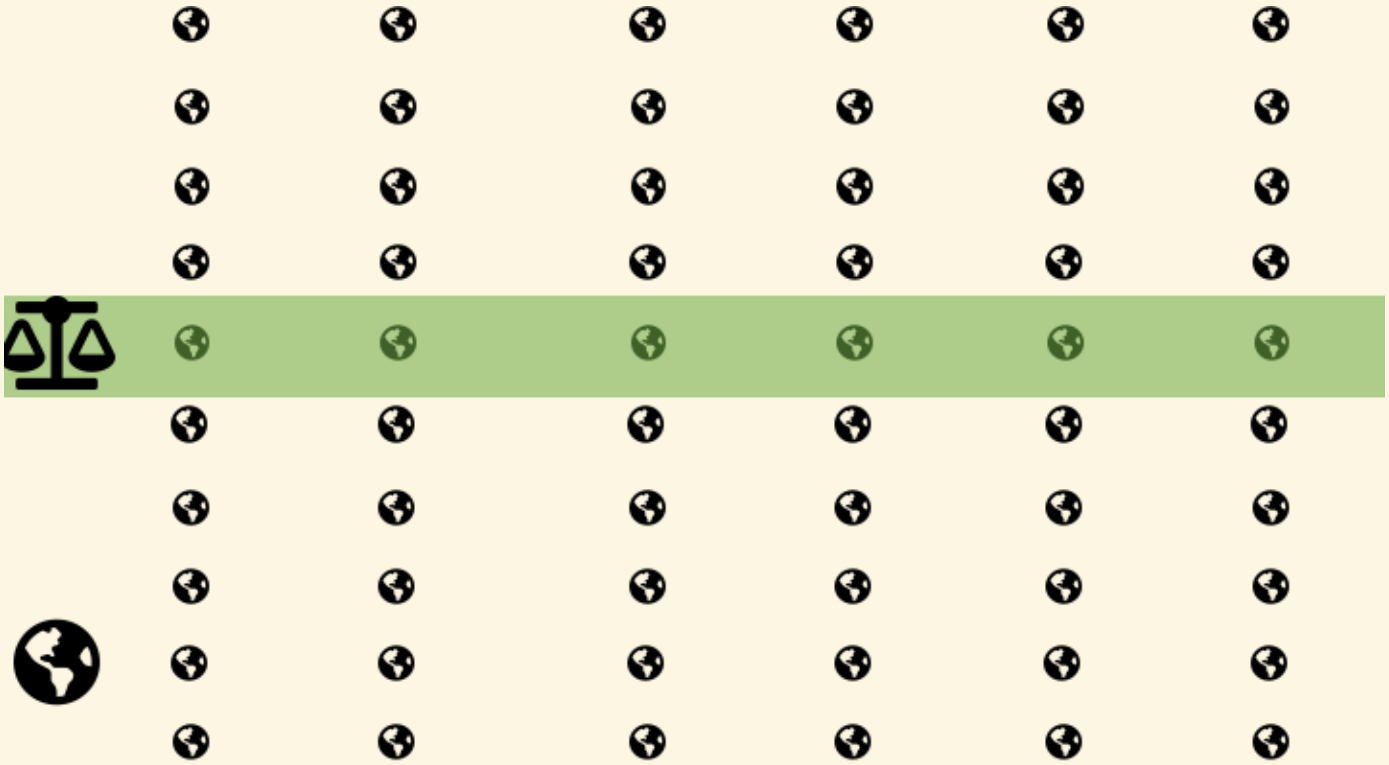

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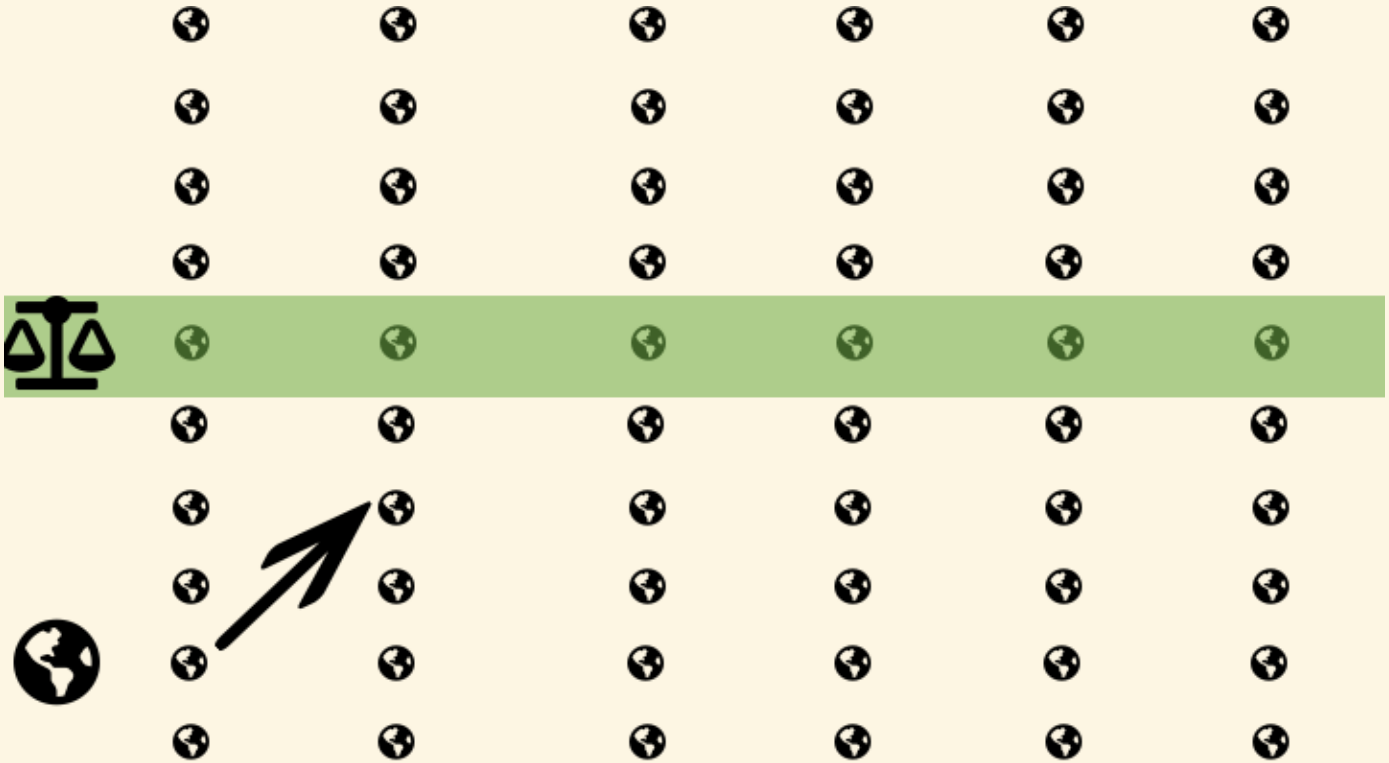

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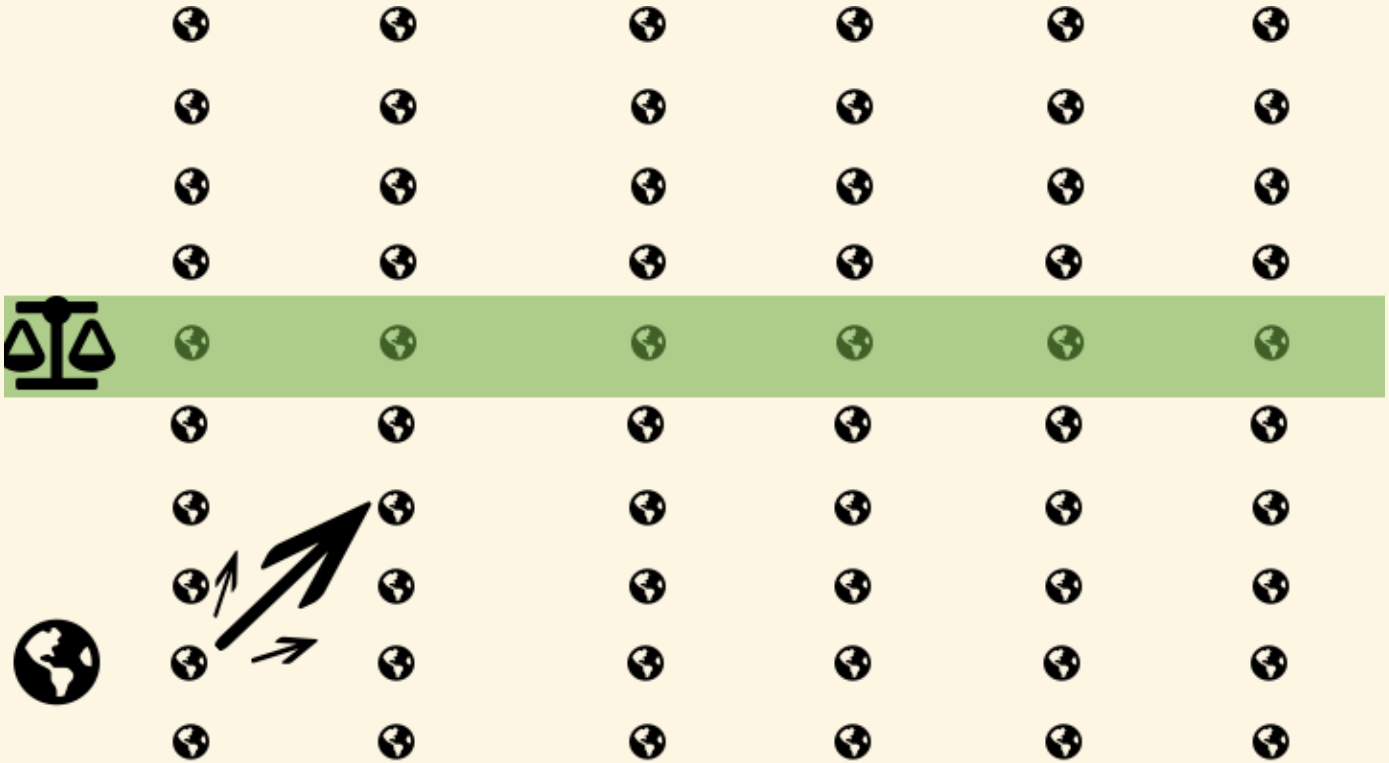

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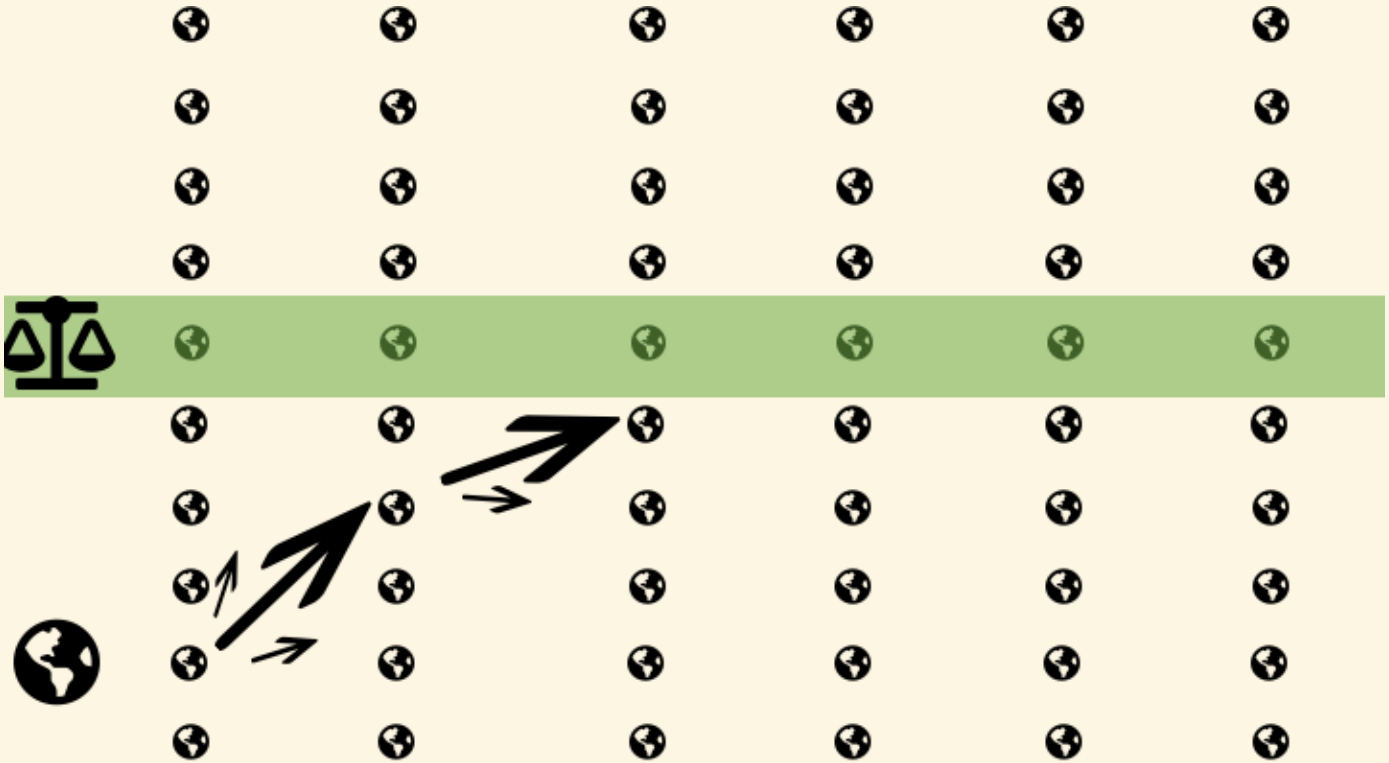

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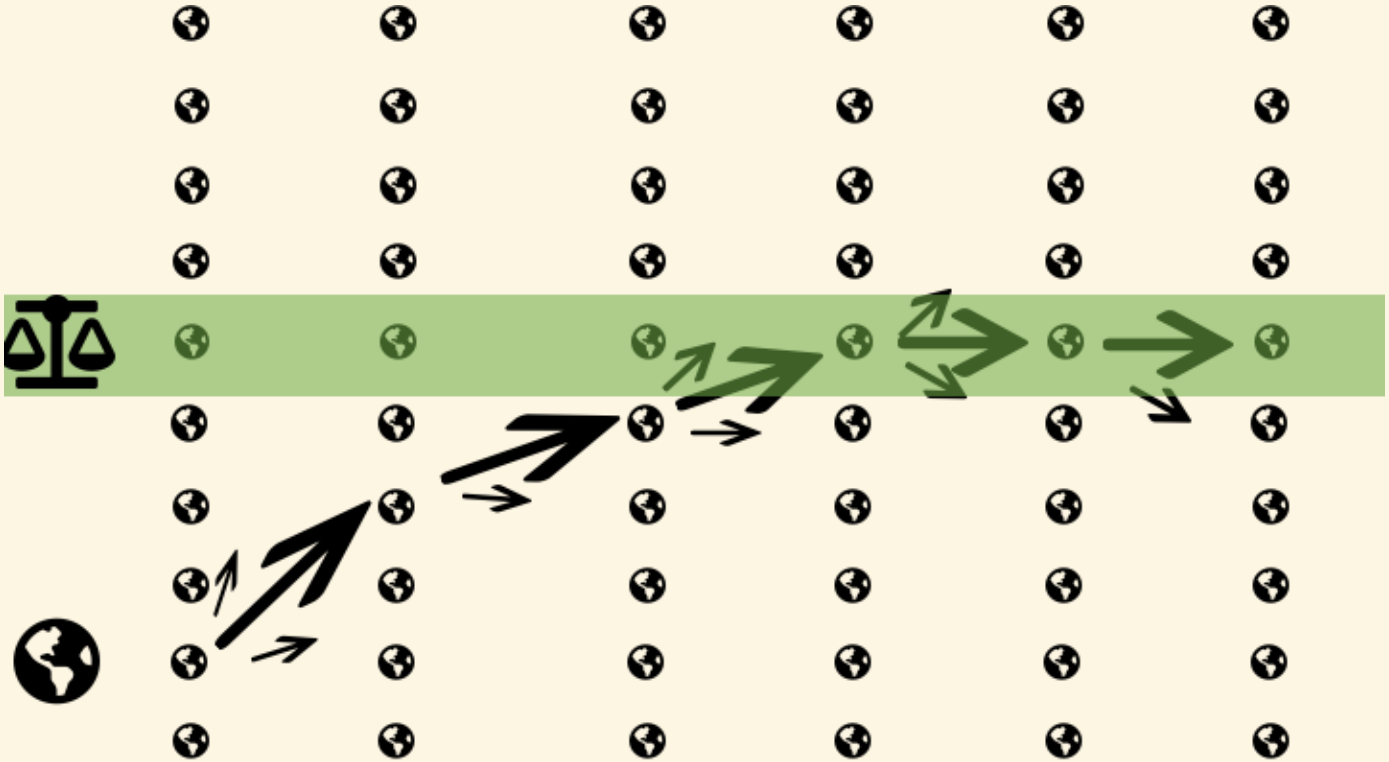
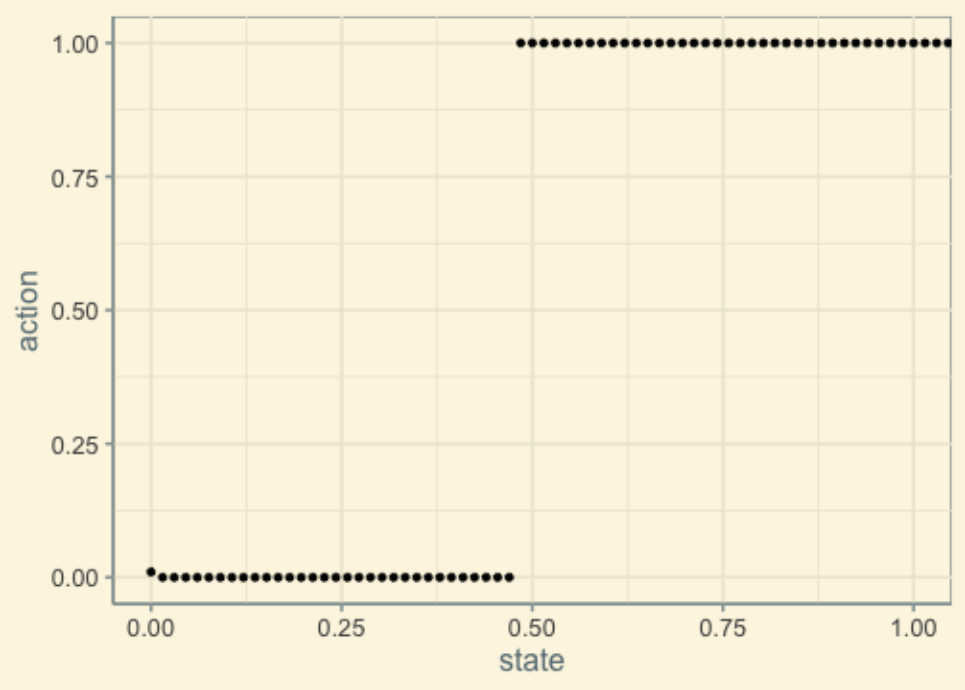
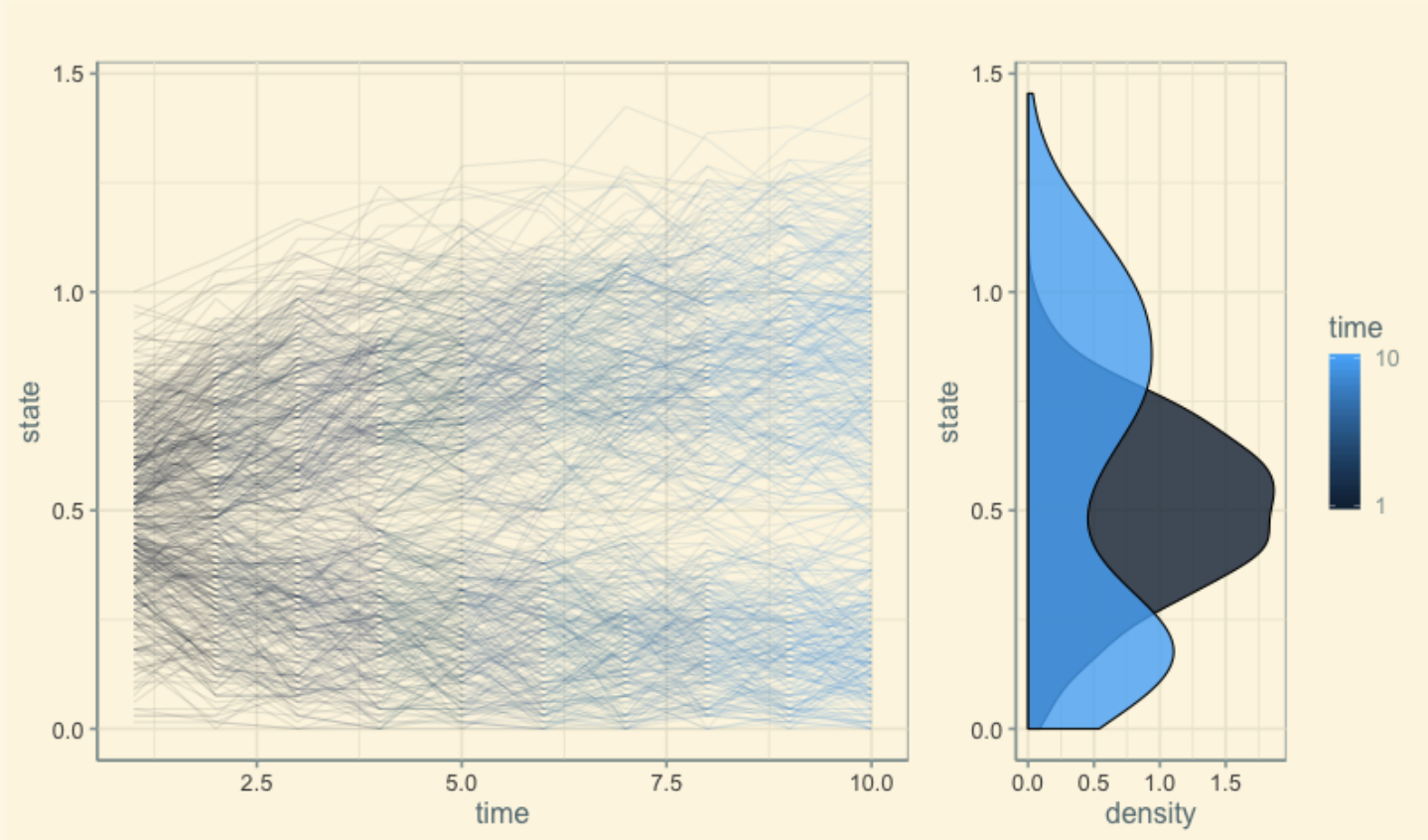


A simple decision rule emerges:

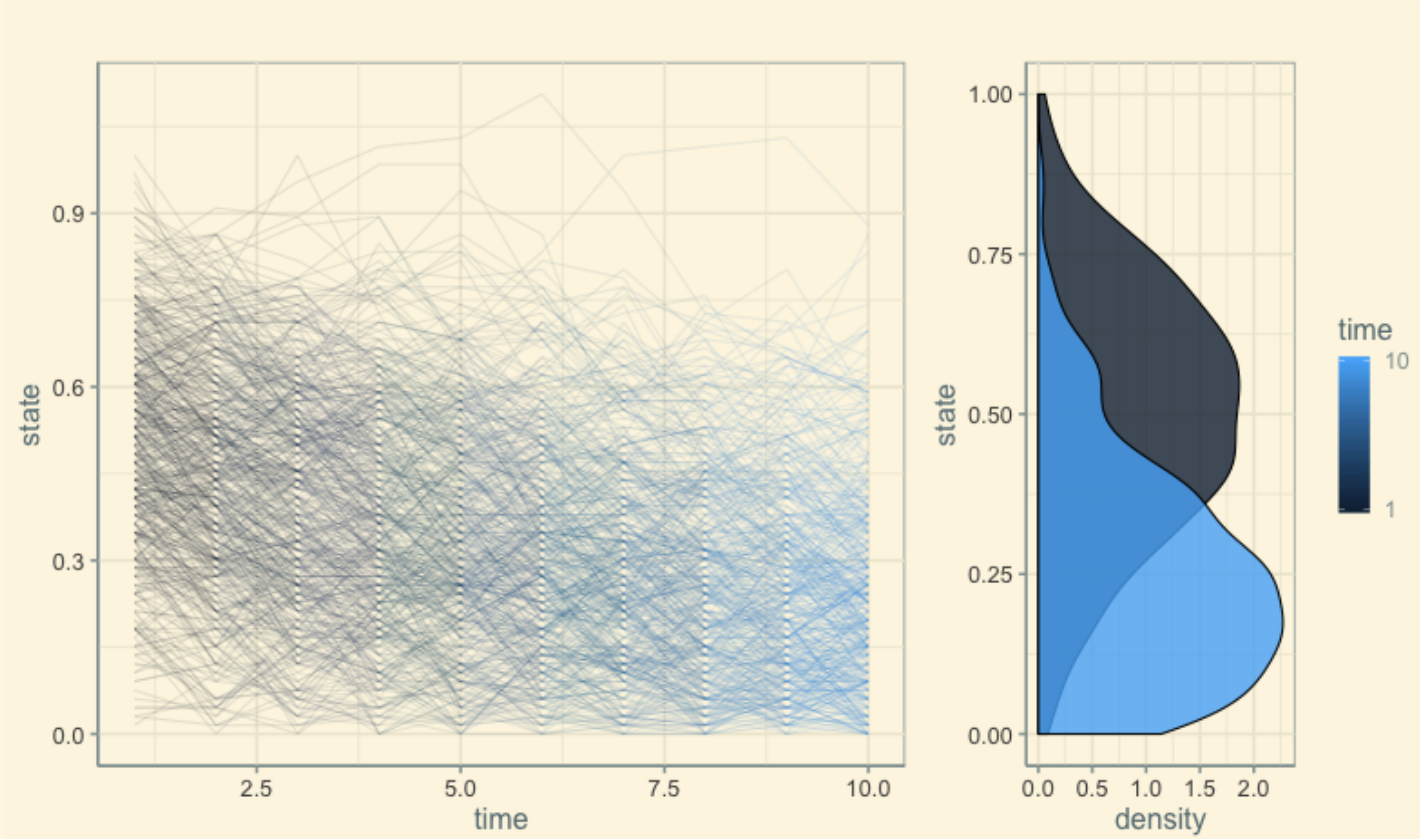


Tipping Point Dynamics?



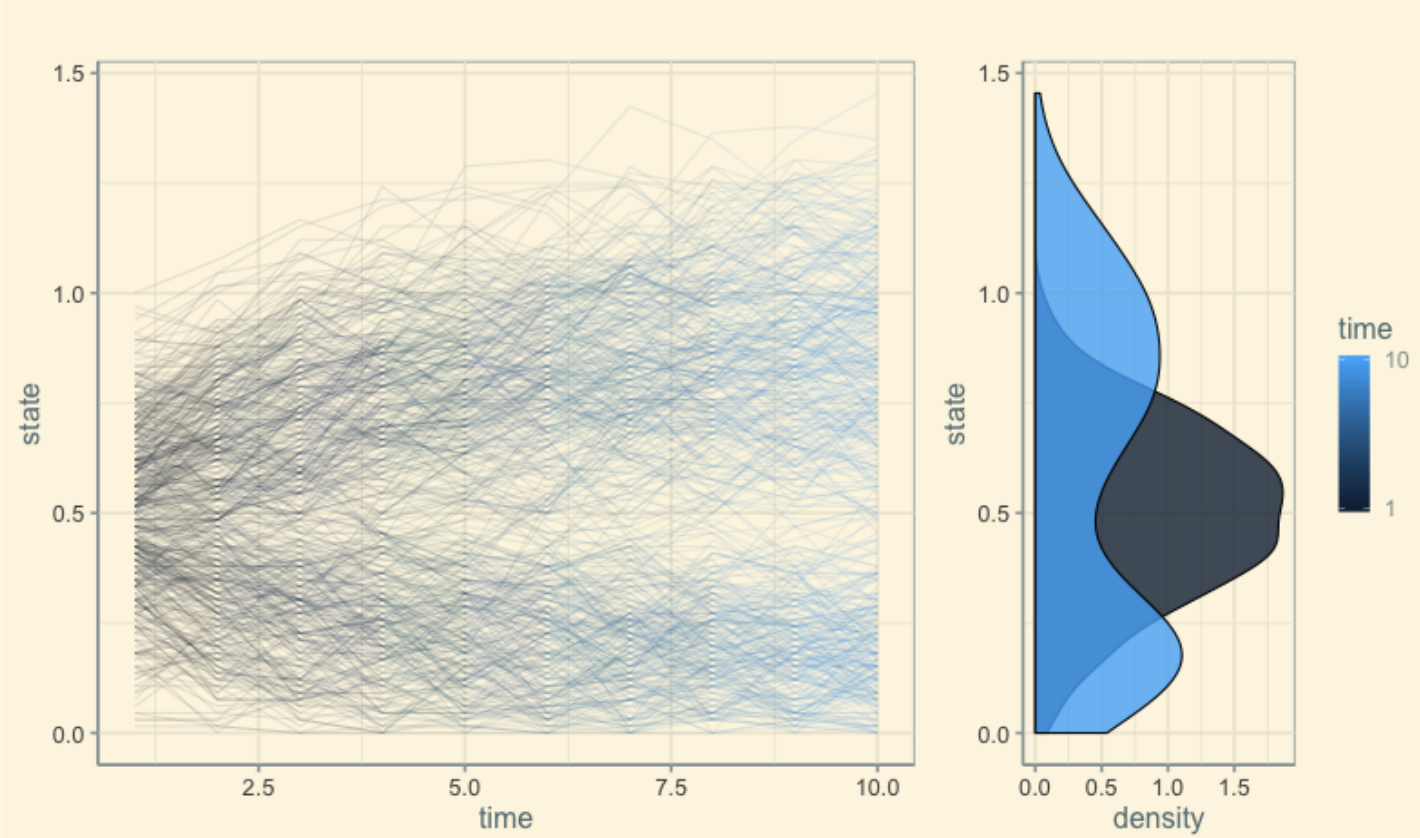
Role of land tenure

Short (2-yr) land tenures:



Role of land tenure

Long tenures / ownership



How would subsidies influence adoption of diversified practices?

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Scenario A: High value incentive (reducing cost of diversified practice) over short duration (2 years)

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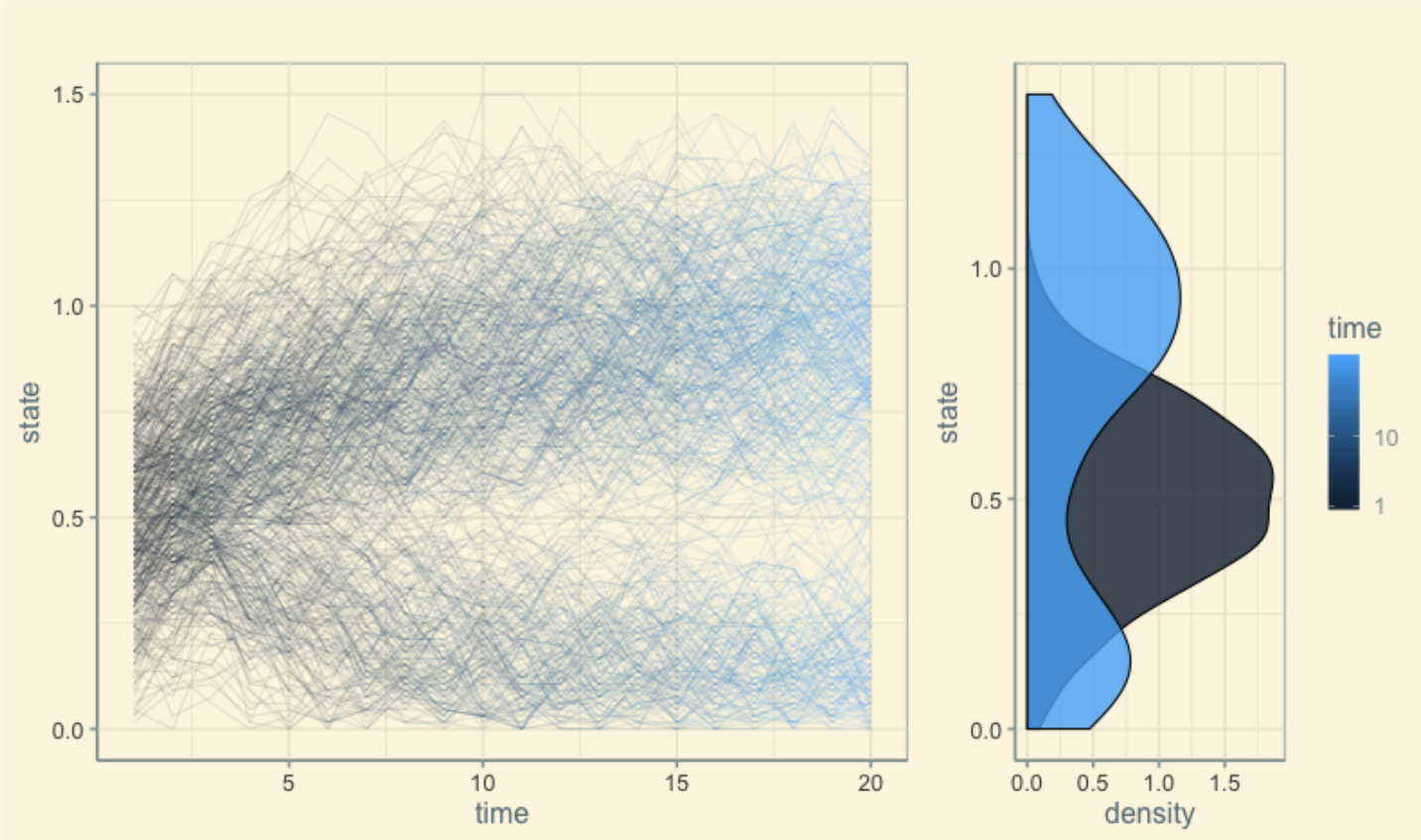
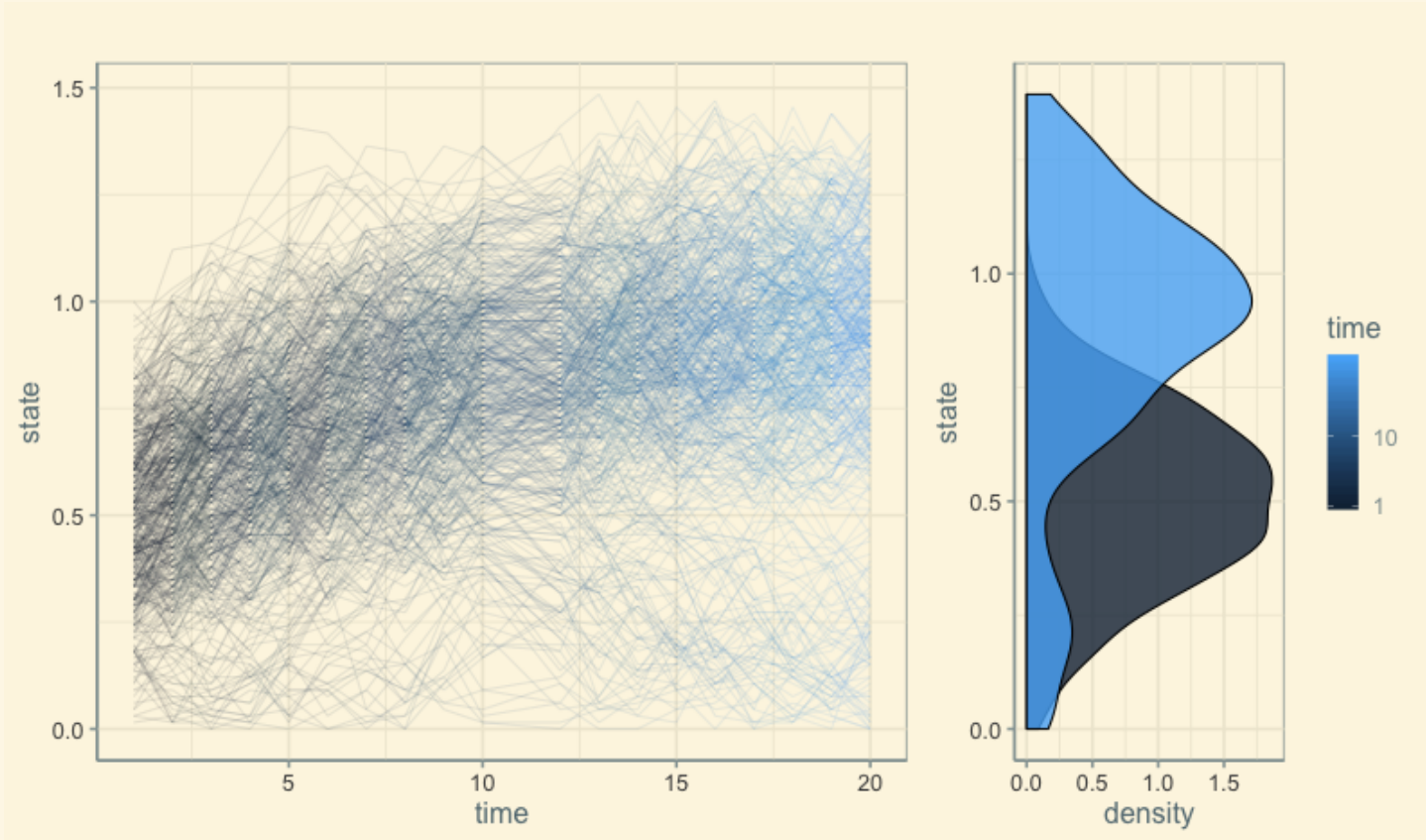
Scenario A: High value incentive (reducing cost of diversified practice) over short duration (2 years)

Scenario B: Small subsidy sustained over longer duration (10 years)

large subsidy over 2 years



smaller subsidy over 10 years



Future of Decisions

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Artificial intelligence meets fisheries ...

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Or would rights-based fisheries already be self-driving cars?

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Diversified farming: individual decisions vs policy scenarios

Future of Decisions

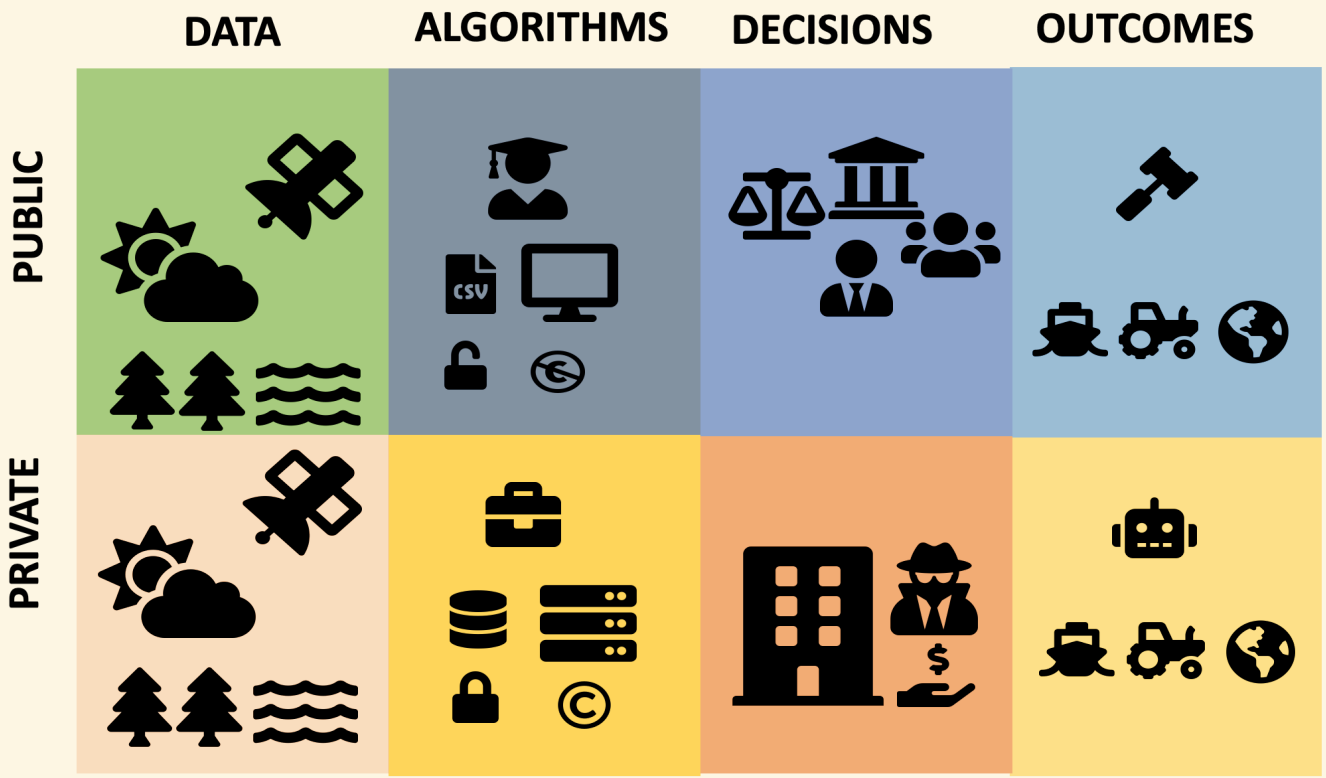
Artificial intelligence meets fisheries ...

Or would rights-based fisheries already be self-driving cars?

Diversified farming: individual decisions vs policy scenarios

What if decisions algorithms actually made decisions?

Ethics and Algorithms in Ecological Conservation & Management?



Reproducibility

Reproducibility

https://github.com/boettiger-lab/pomdp-intro

Resolving the measurement uncertainty paradox in ecological management

launch binder | build passing | DOI 10.5281/zenodo.2528507

- Authors: Milad Memarzadeh, Carl Boettiger

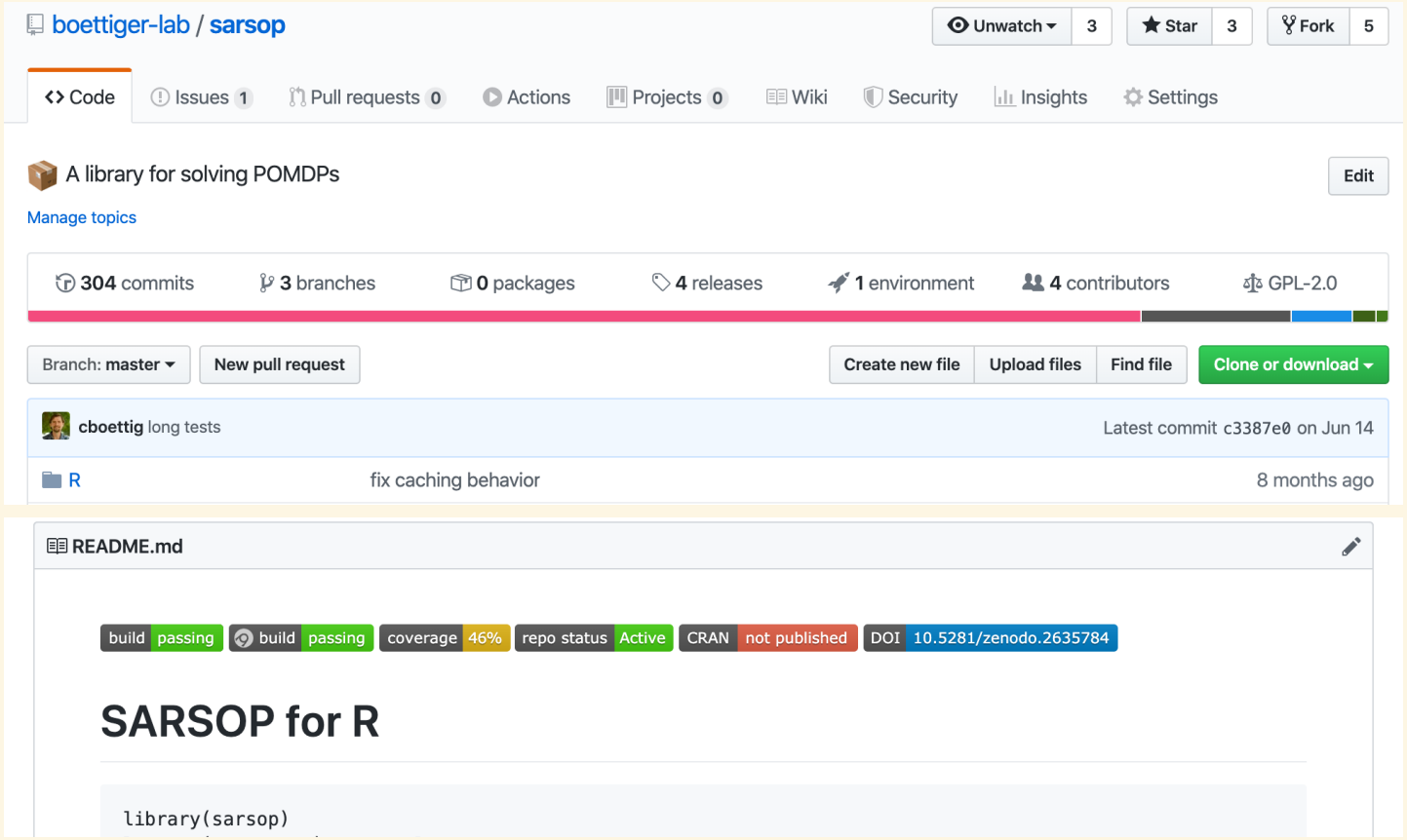
Contents

- Manuscript: R Markdown source document for manuscript. Includes code to reproduce for figures from tables generated by the analysis.
- Appendix: R Markdown source documents for both appendices, containing all necessary R code to generate all results presented in both the manuscript and appendices.
- data: Data generated in the analysis. Includes `.csv` tables shown in the figures, and the `.policyx` XML files generated by running the SARSOP algorithm.
- reviews: Encrypted reviews (copywrite of the reviewers)

Reproducibility

This repository is organized as a reproducible research compendium. Click the launch binder button above to explore in an interactive RStudio session. Binder uses rocker-project.org Docker images to ensure a consistent and reproducible

Reproducibility



Reproducibility

Acknowledgements




THE ROYAL SOCIETY

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BERKELEY INSTITUTE FOR DATA SCIENCE

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Hellman Fellows Fund

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Slides: https://cboettig.github.io/talks-2019-UBC