The importance of measurement uncertainty in ecological management

Carl Boettiger

2017/08/09

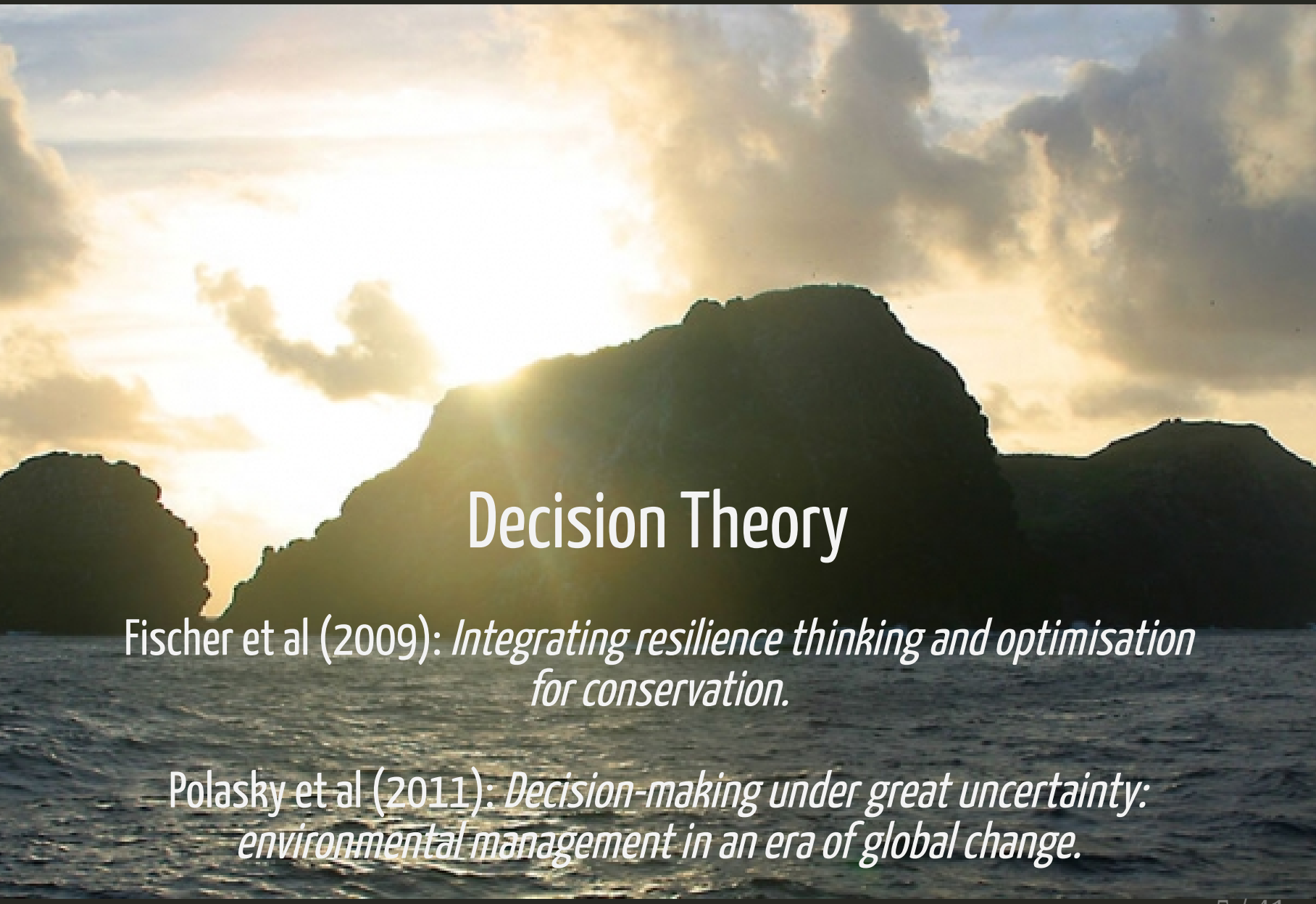
> Managing fisheries is hard: it's like managing a forest, in which the trees are invisible and keep moving around

--John Shepard, from unpublished lecture at Princeton University, ca 1978


We've gotten much better at including
uncertainties in our models


It is time to include uncertainties in our decisions


Decision Theory



Decision Theory

Fischer et al (2009): *Integrating resilience thinking and optimisation for conservation.*

Polasky et al (2011): *Decision-making under great uncertainty: environmental management in an era of global change.*

Optimal Control

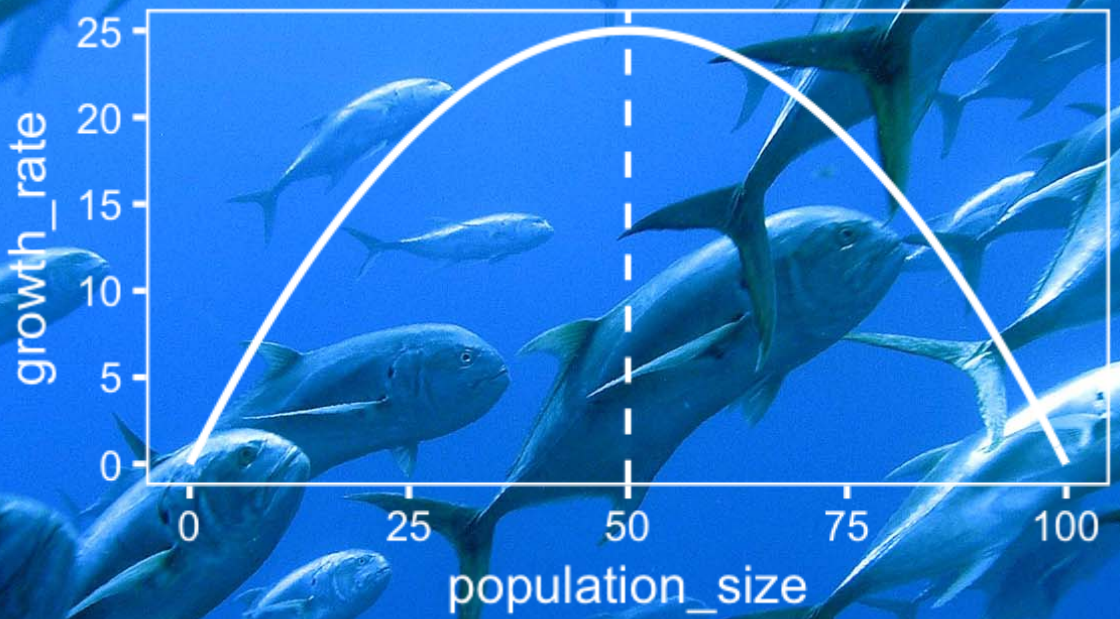
Resilience Thinking

Uncertainty about the Furture

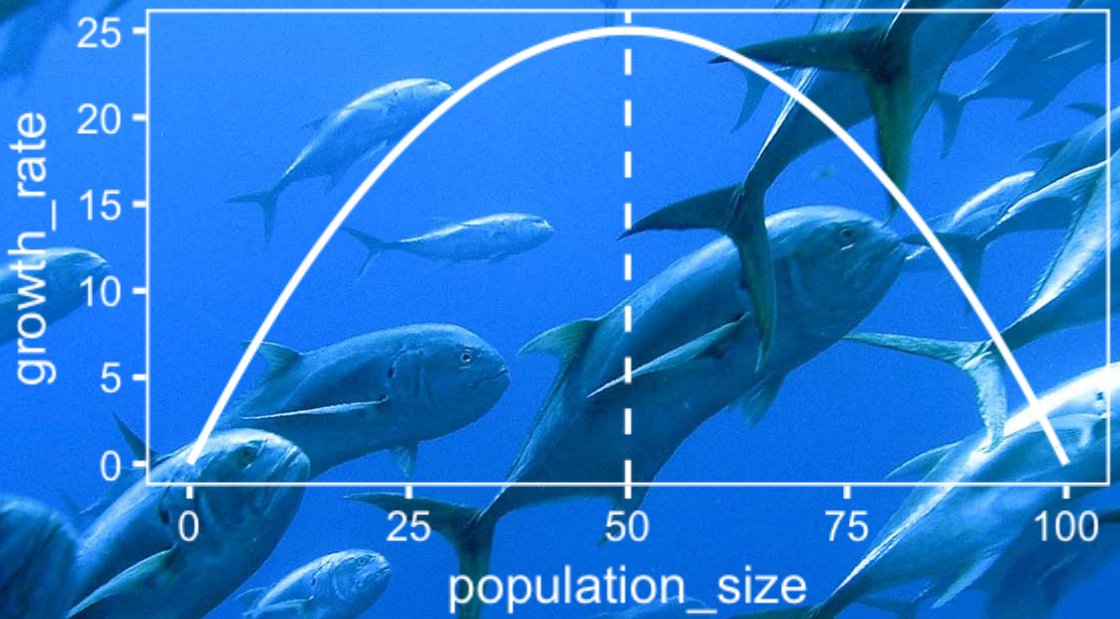
Uncertainty about the Present

Stock assessment uncertainty

MSY: a sticky idea



MSY: a sticky idea



$$\frac{dN}{dt} = \underbrace{rN\left(1 - \frac{N}{K}\right)}_{f(N)} - H$$

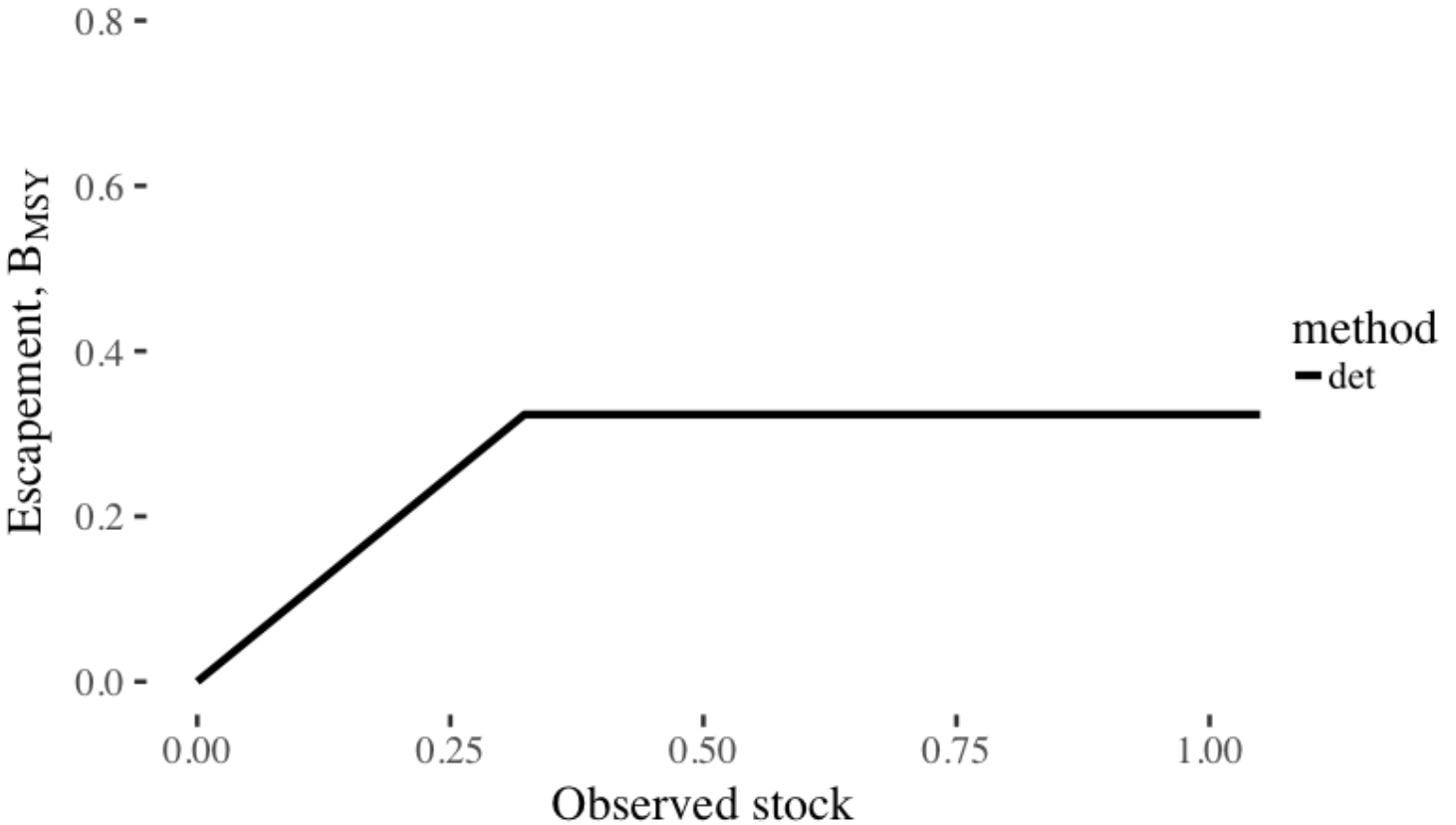
$$H_{\text{MSY}} = f(N) = rK/4, \quad B_{\text{MSY}} = K/2$$

Stochastic Models: Reed 1979

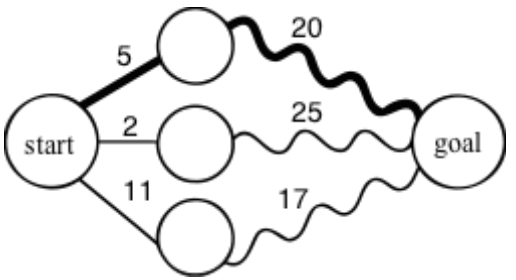
THEOREM 2. *Under the conditions of Theorem 1 if the level* σ *(at which the expected discounted annual growth in the immediate harvest value of the population is maximized) is self-sustaining then the optimal escapement is at* σ *(i.e.,* $S = \sigma$*). If on the other hand* σ *is not self-sustaining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

Constant Escapement vs MSY



Sequential Decision problems: Dynamic Programming

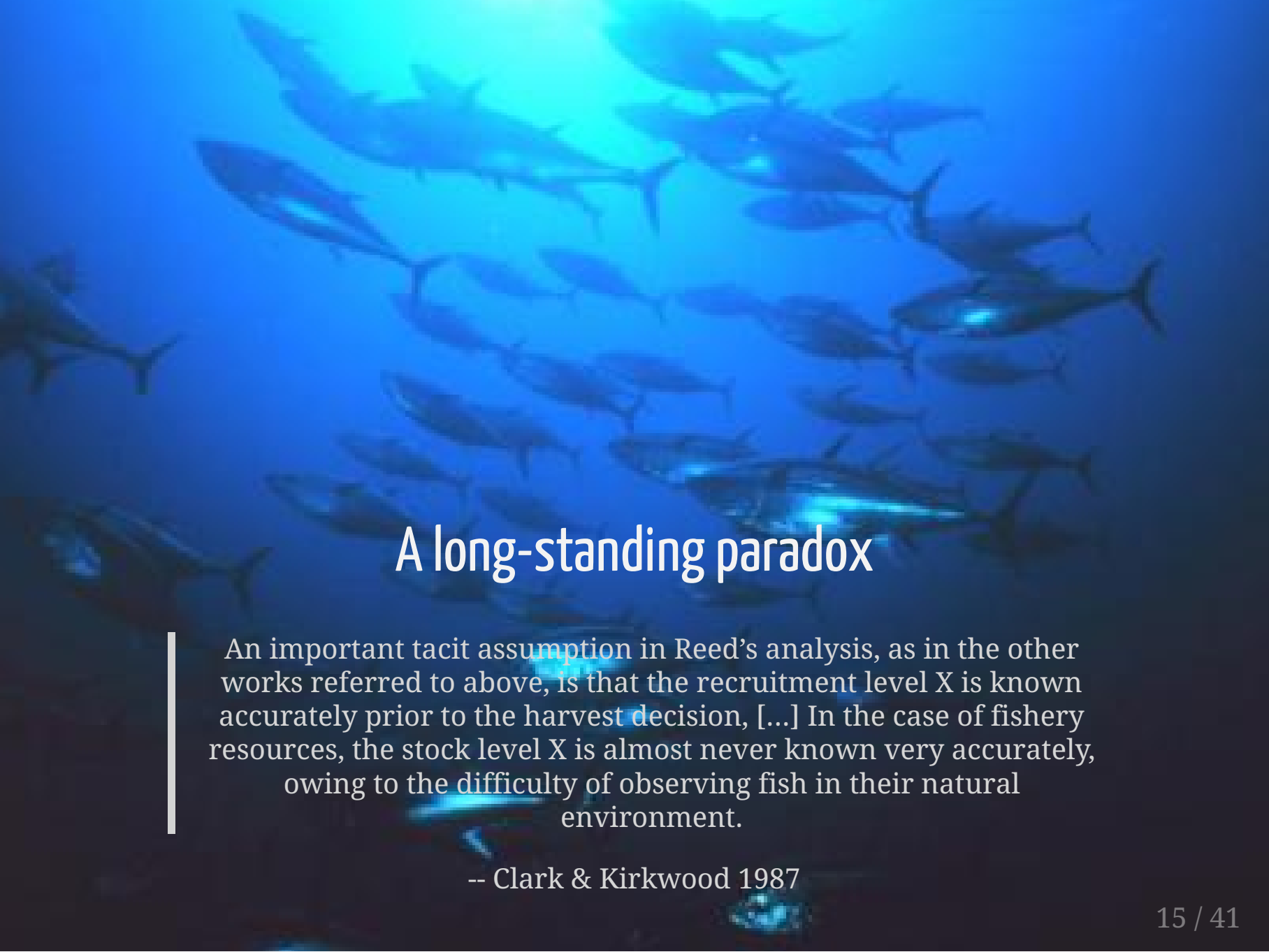


Reed's legacy

–

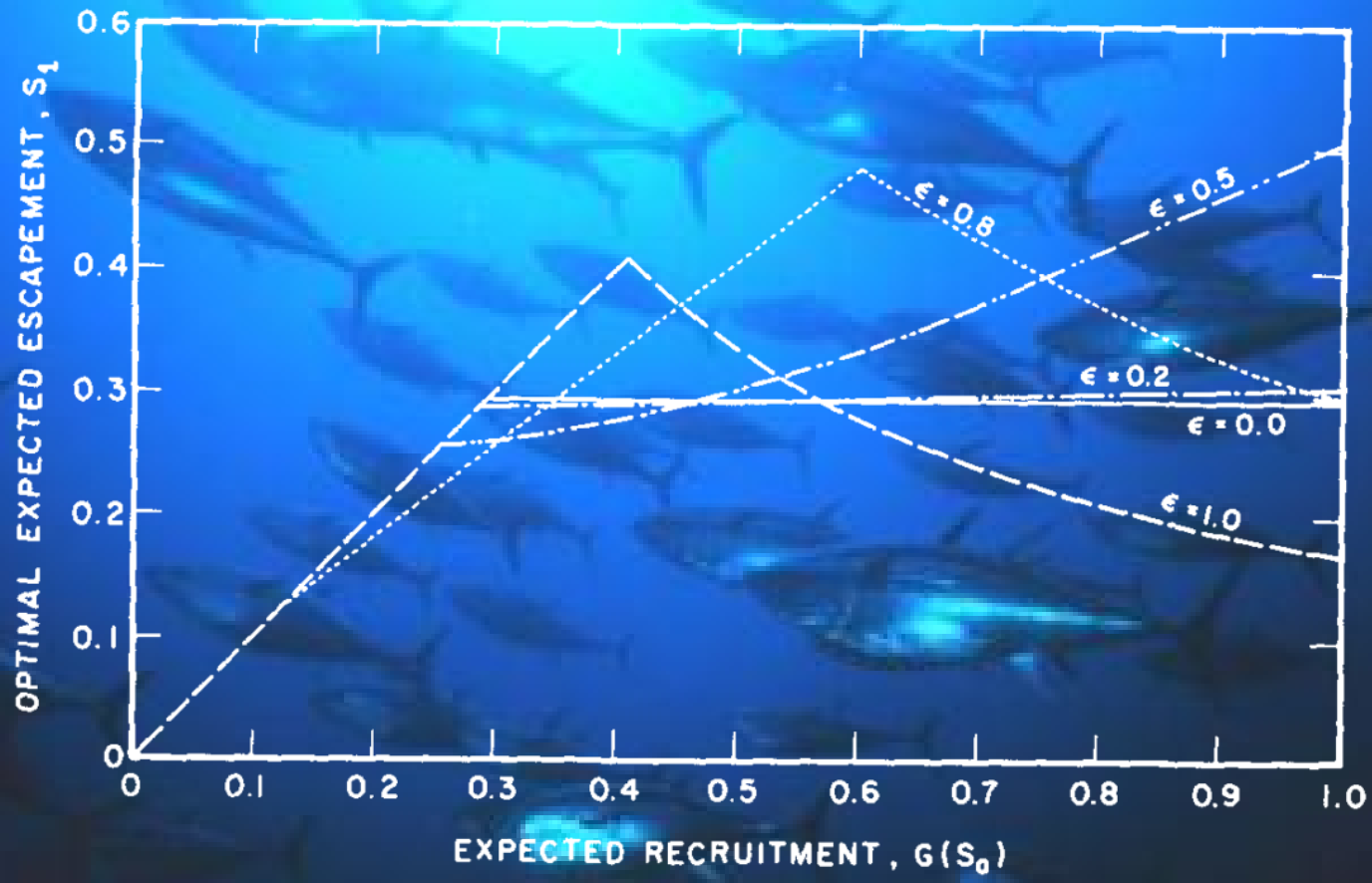
We can ignore troublesome dynamic programming ...

...and just stick with $S = B_{MSY}$ value from a model's deterministic skeleton

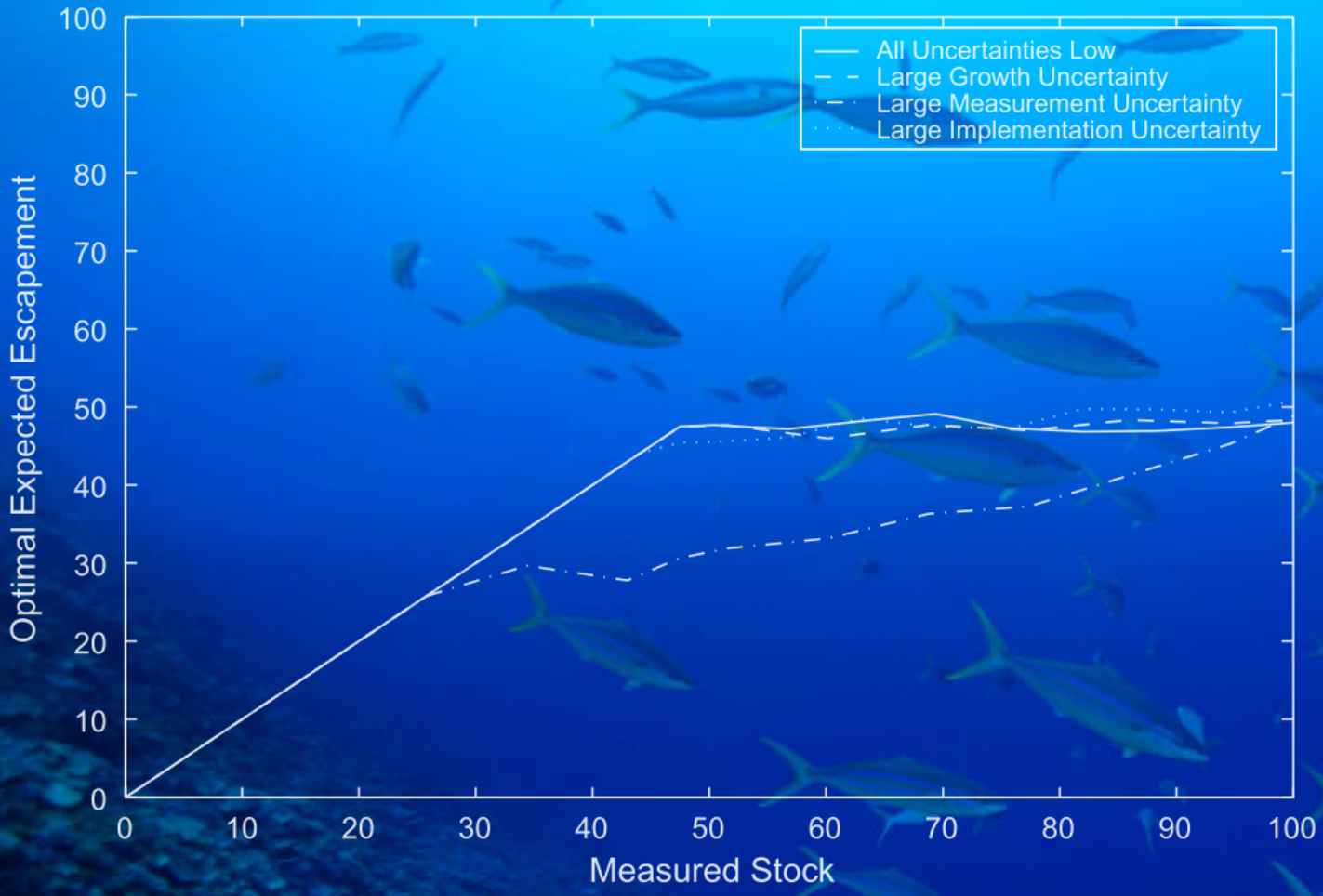


A long-standing paradox

> 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 1987



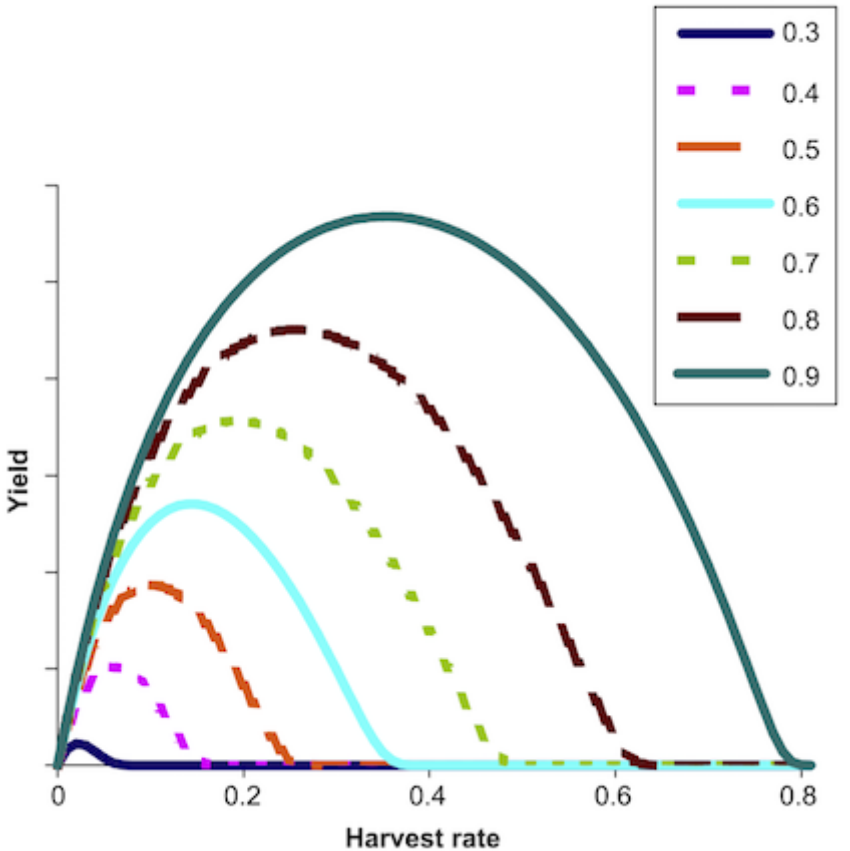
> The above results appear to contradict the conventional wisdom of renewable resource management, under which high uncertainty would call for increased caution in the setting of quotas.
>
> -- Clark & Kirkwood 1986



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


The uncertainty paradox:
More uncertainty = Less precautionary?

Pretty Good Yield (PGY)



Measurement uncertainty -> Non-Markovian

Previous work simply assumes the Markov property: prior history doesn't matter

A Tough Problem

> 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.)

A Solution?

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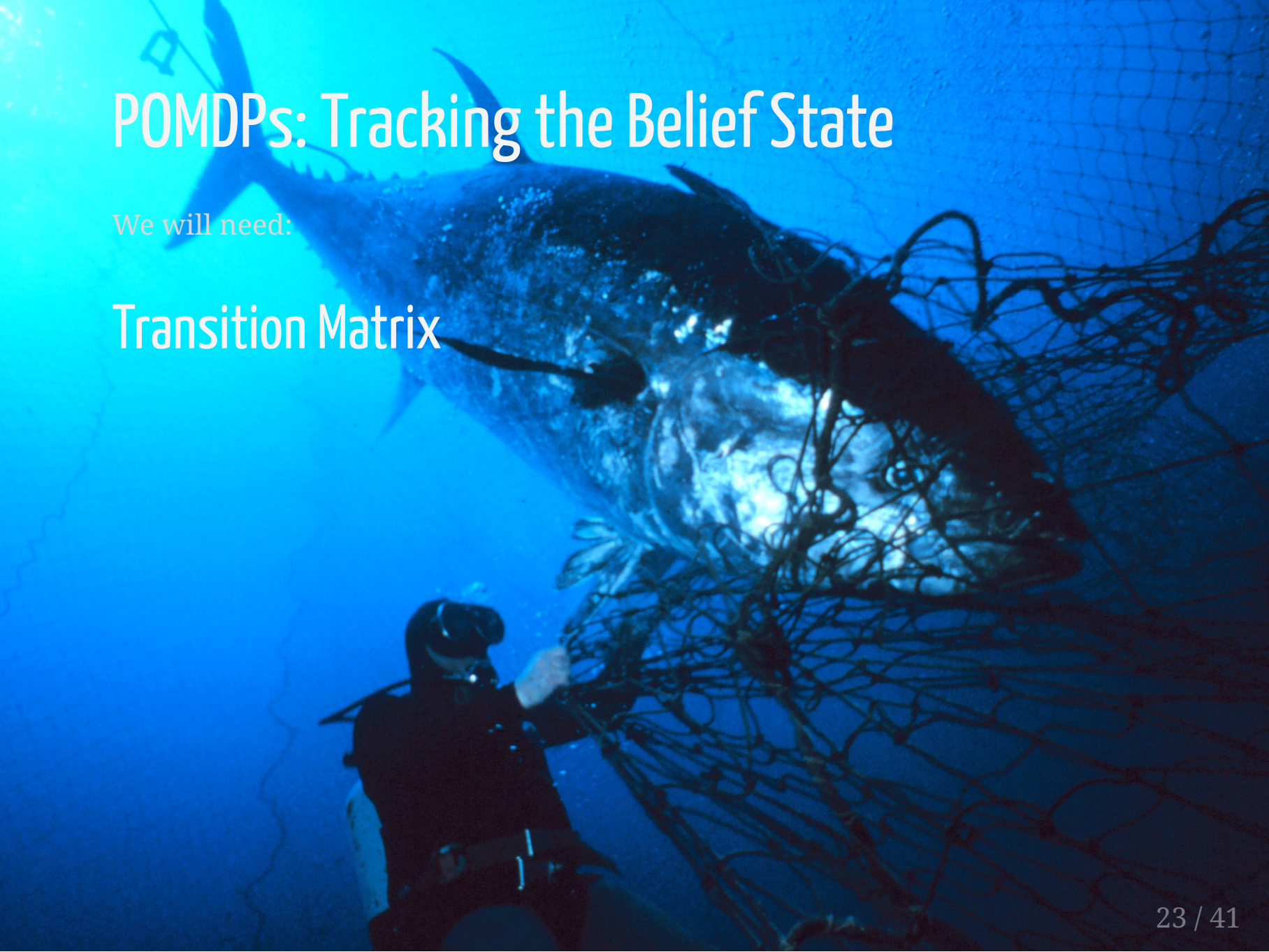
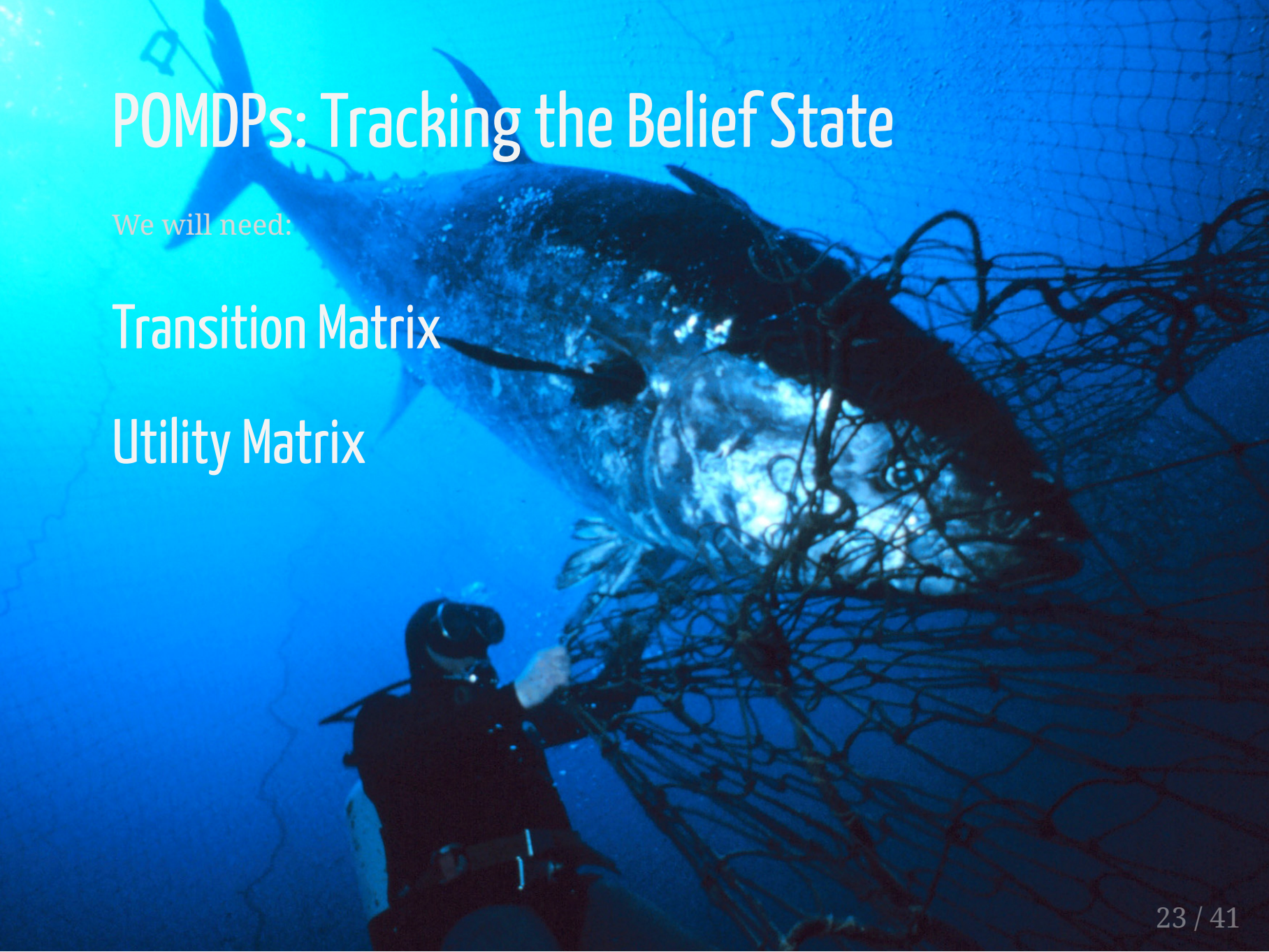
POMDPs: Tracking the Belief State

We will need:

Transition Matrix





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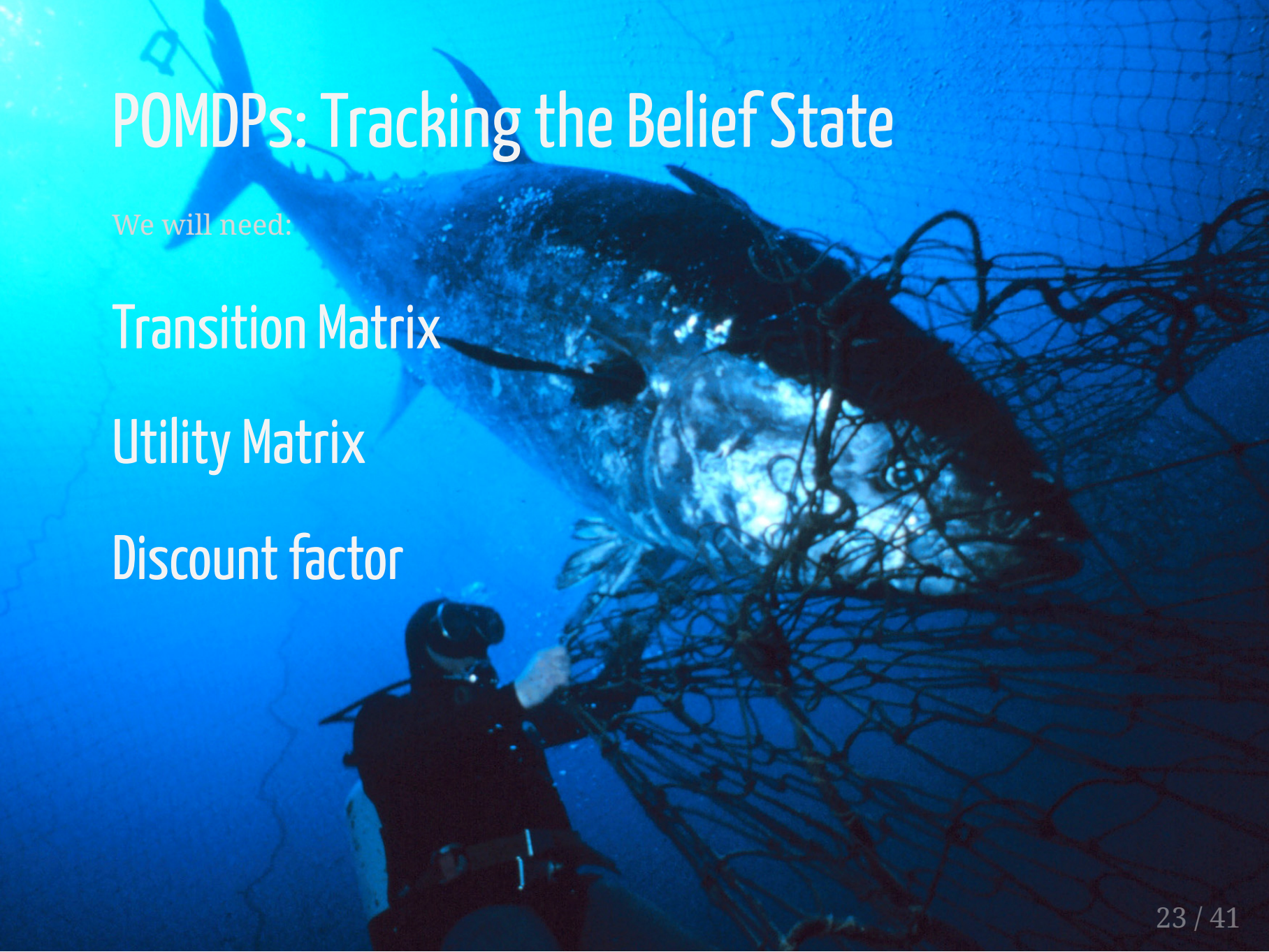
Utility Matrix



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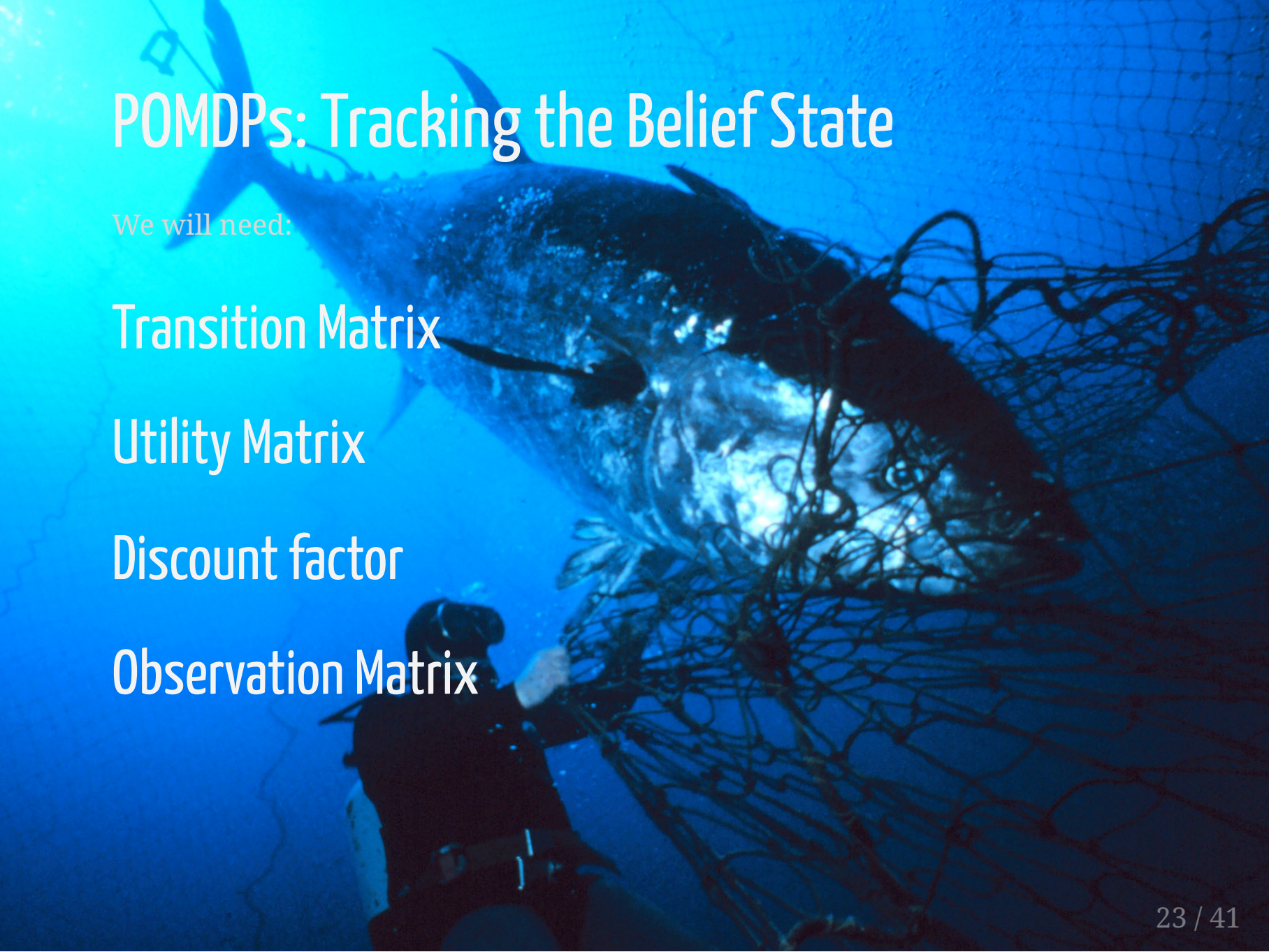
Discount factor



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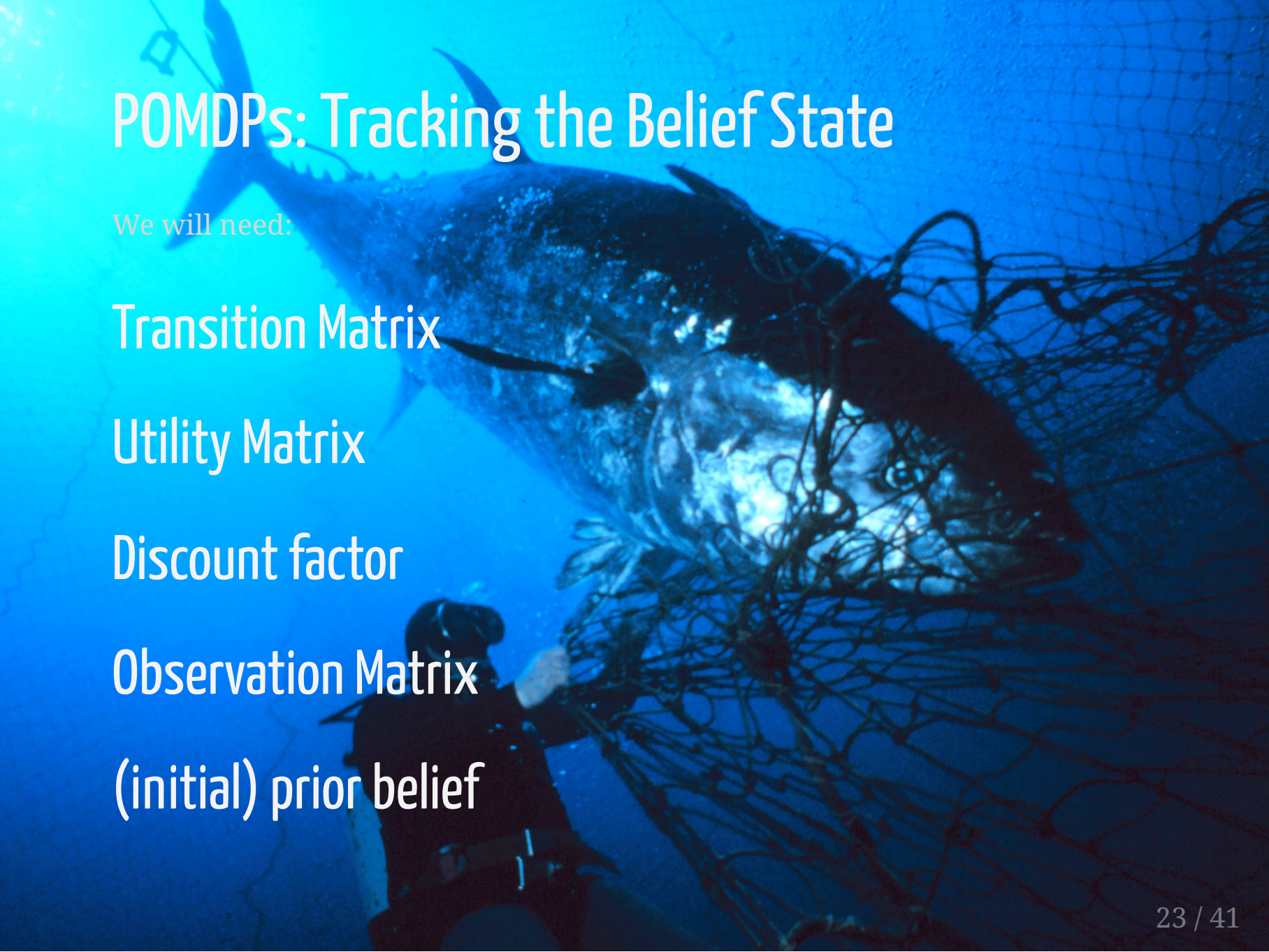
Observation Matrix



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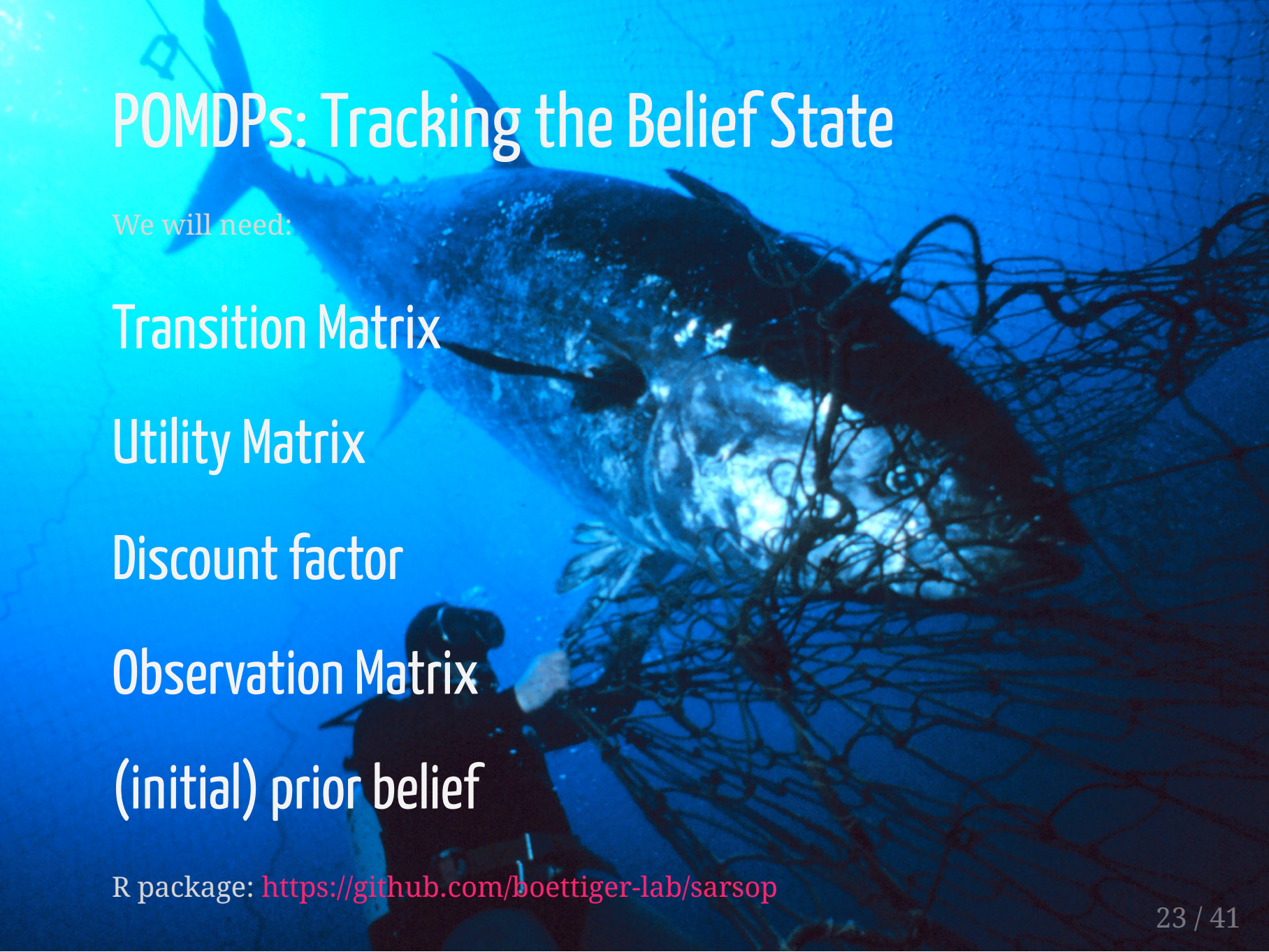
(initial) prior belief



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Transition Matrix

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Discount factor

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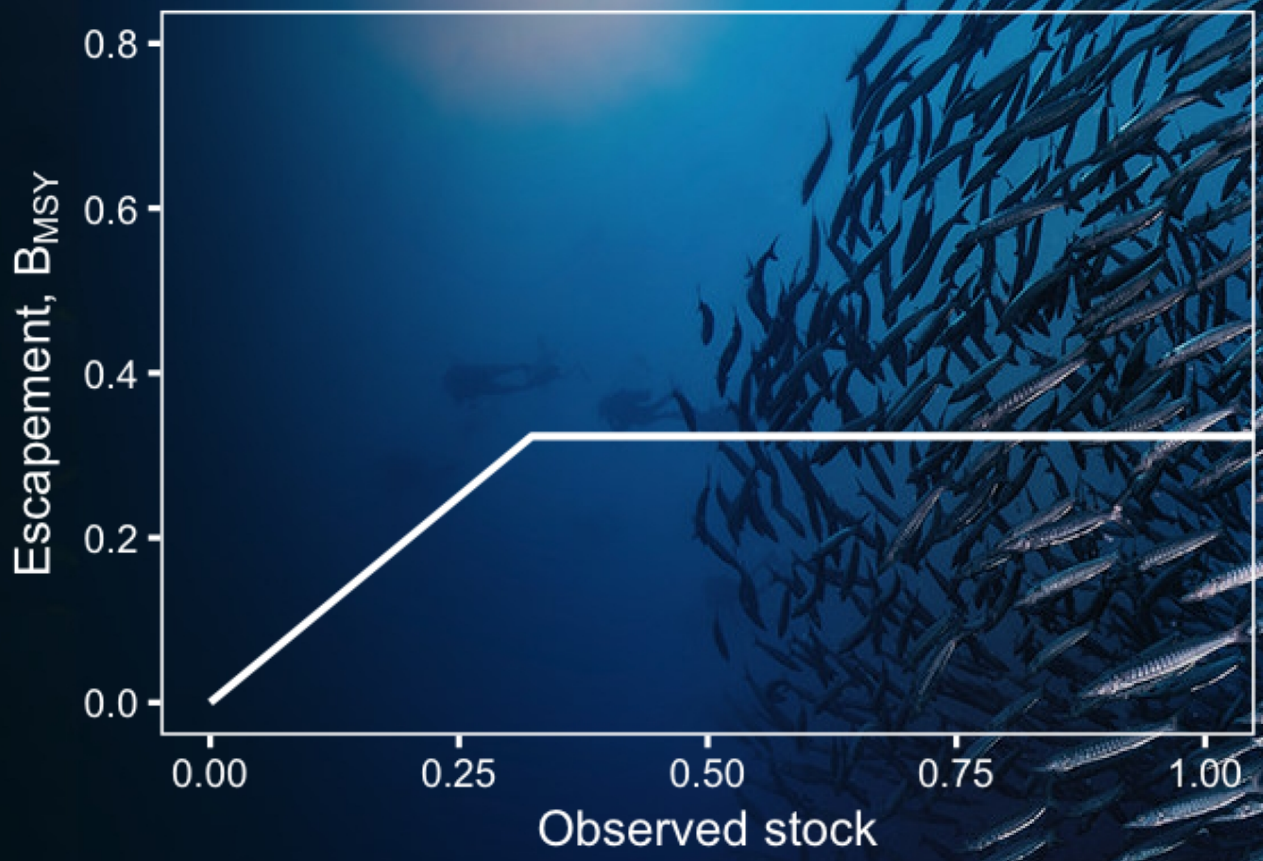
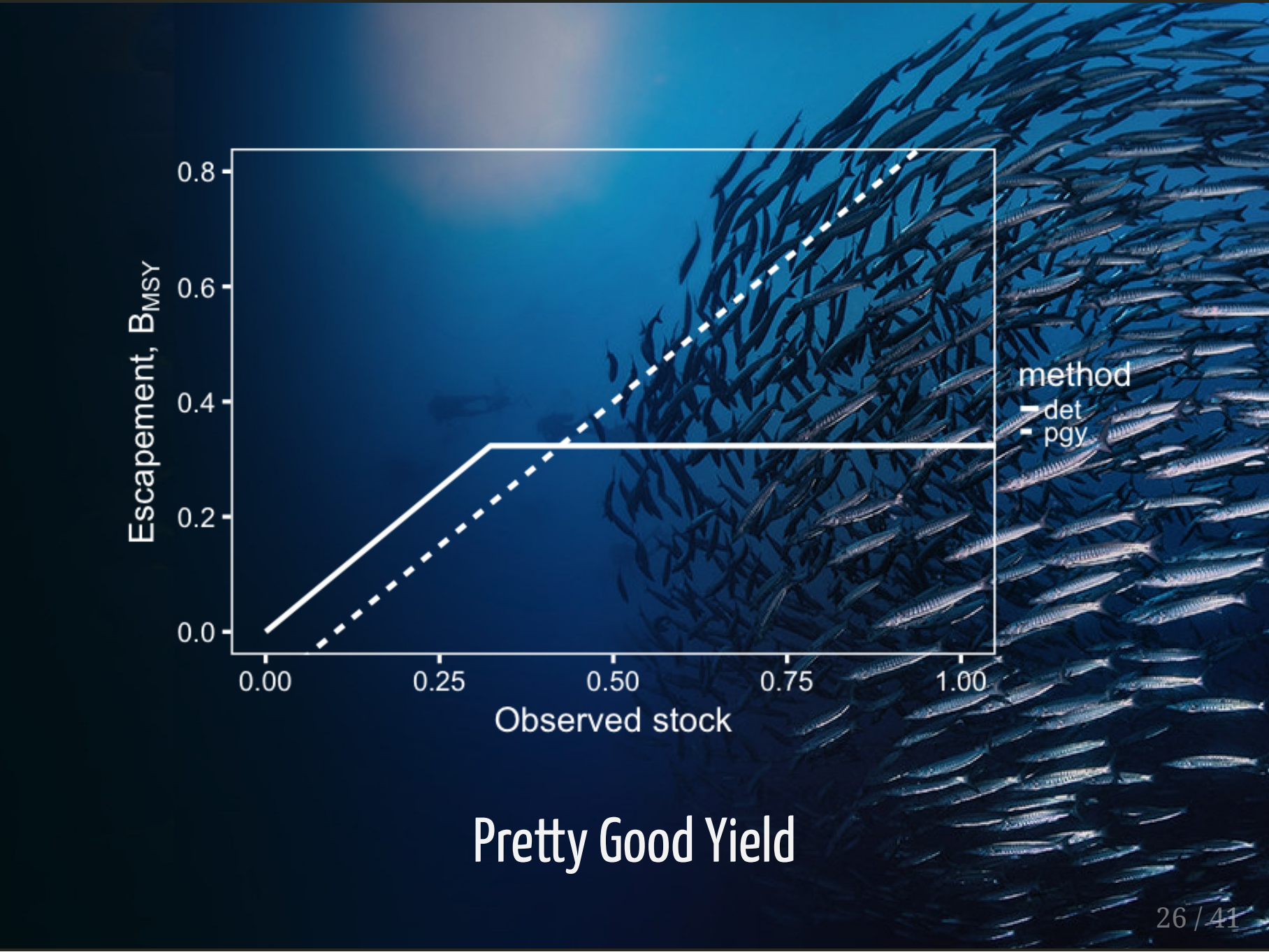
R package: https://github.com/boettiger-lab/sarsop

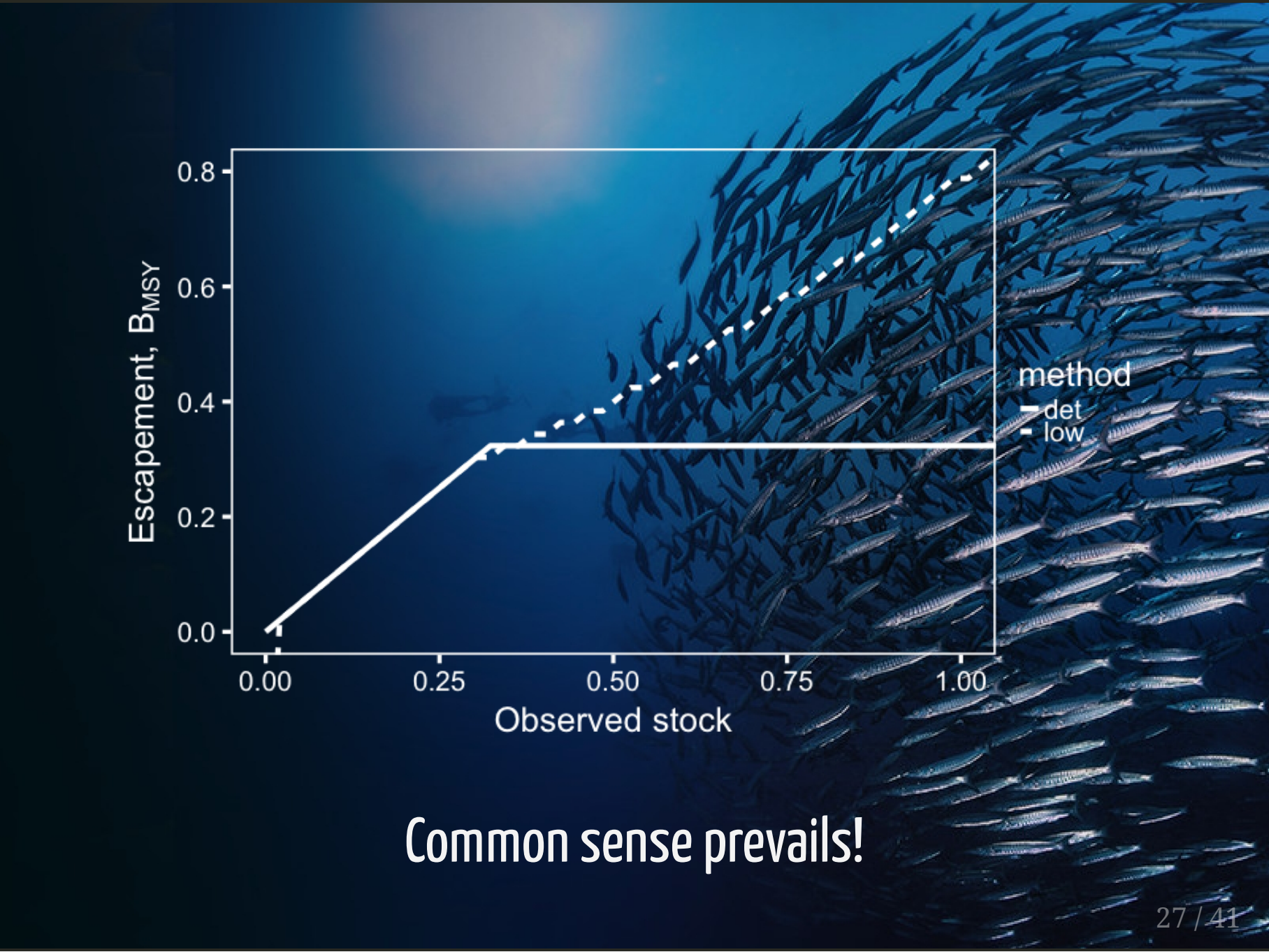

XSEDE Jetstream Cloud



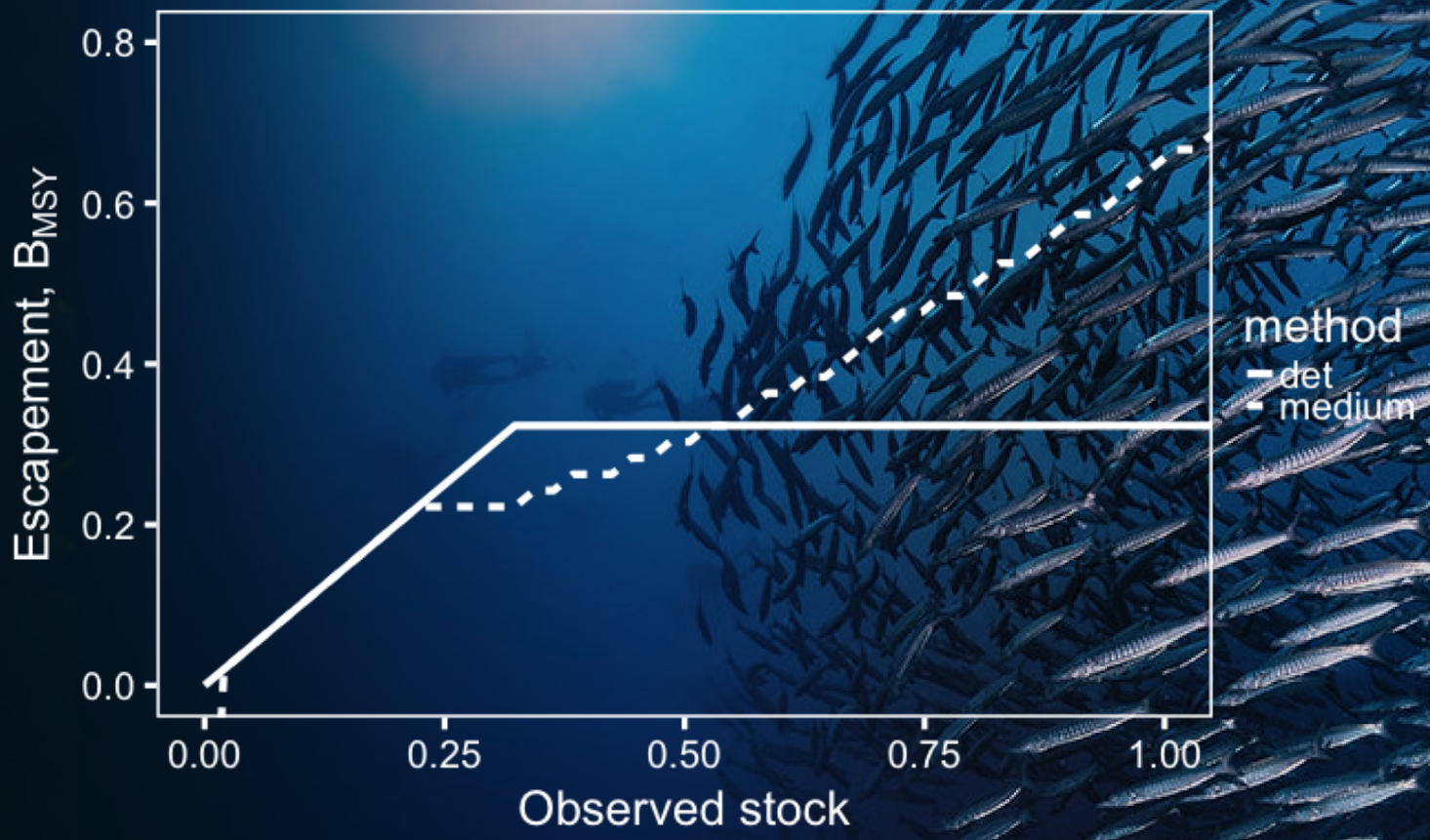
Deterministic Solution



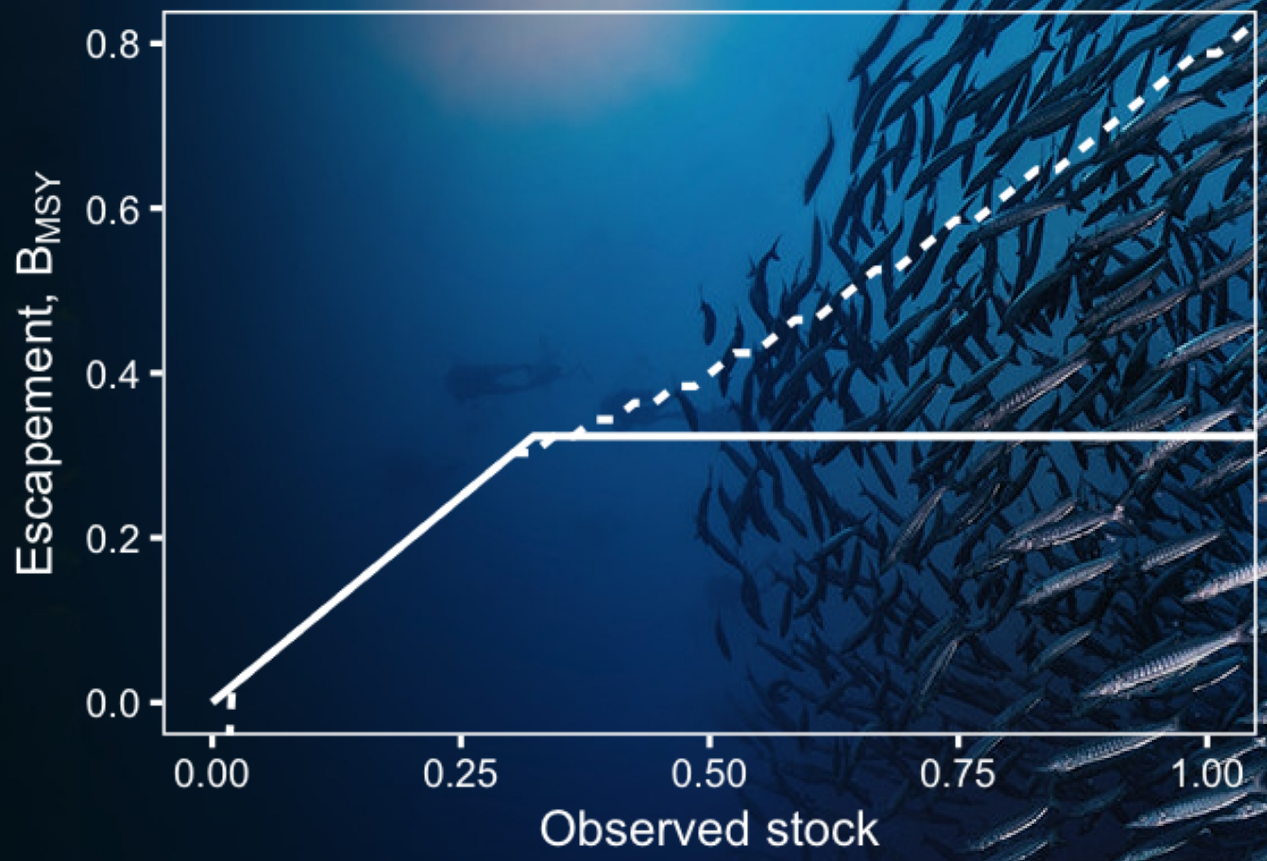
Pretty Good Yield



Common sense prevails!



(Prior) beliefs matter



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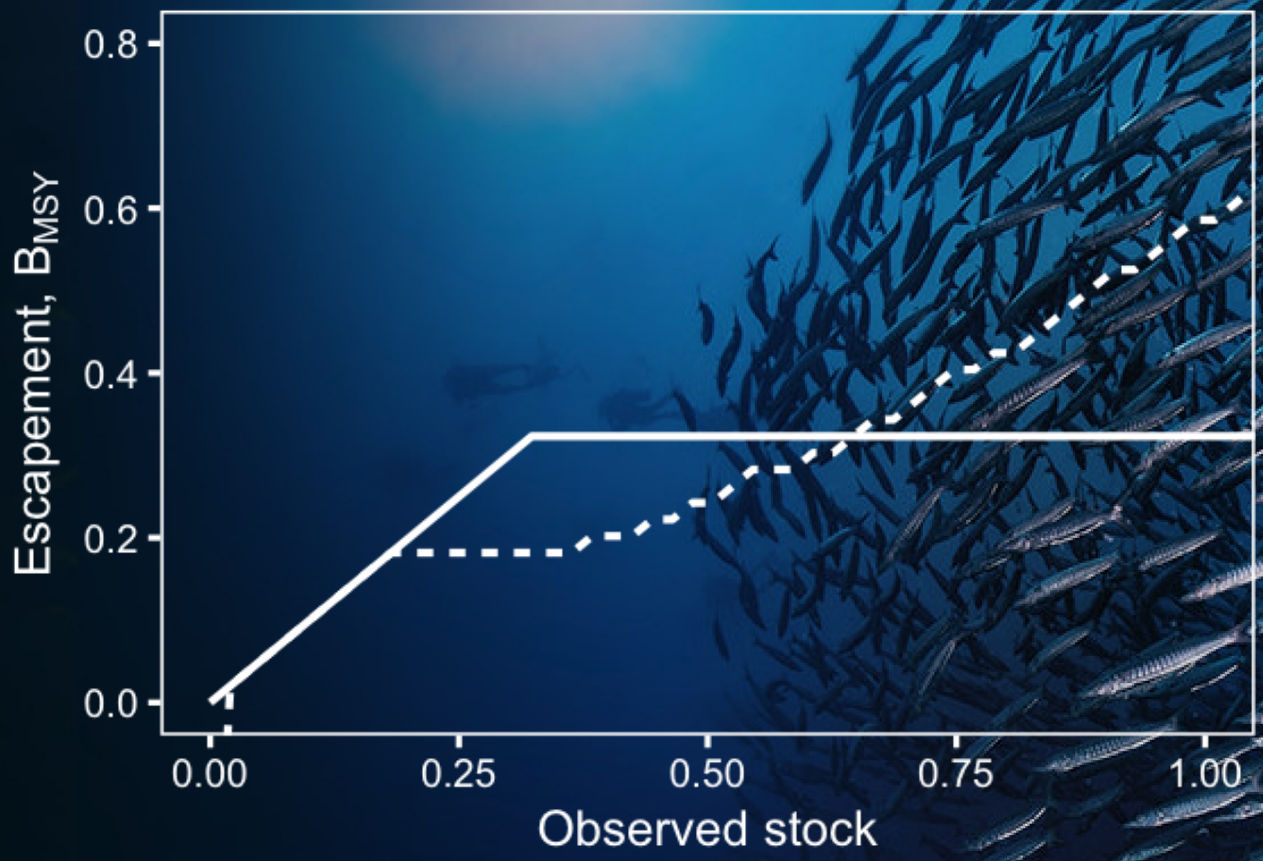

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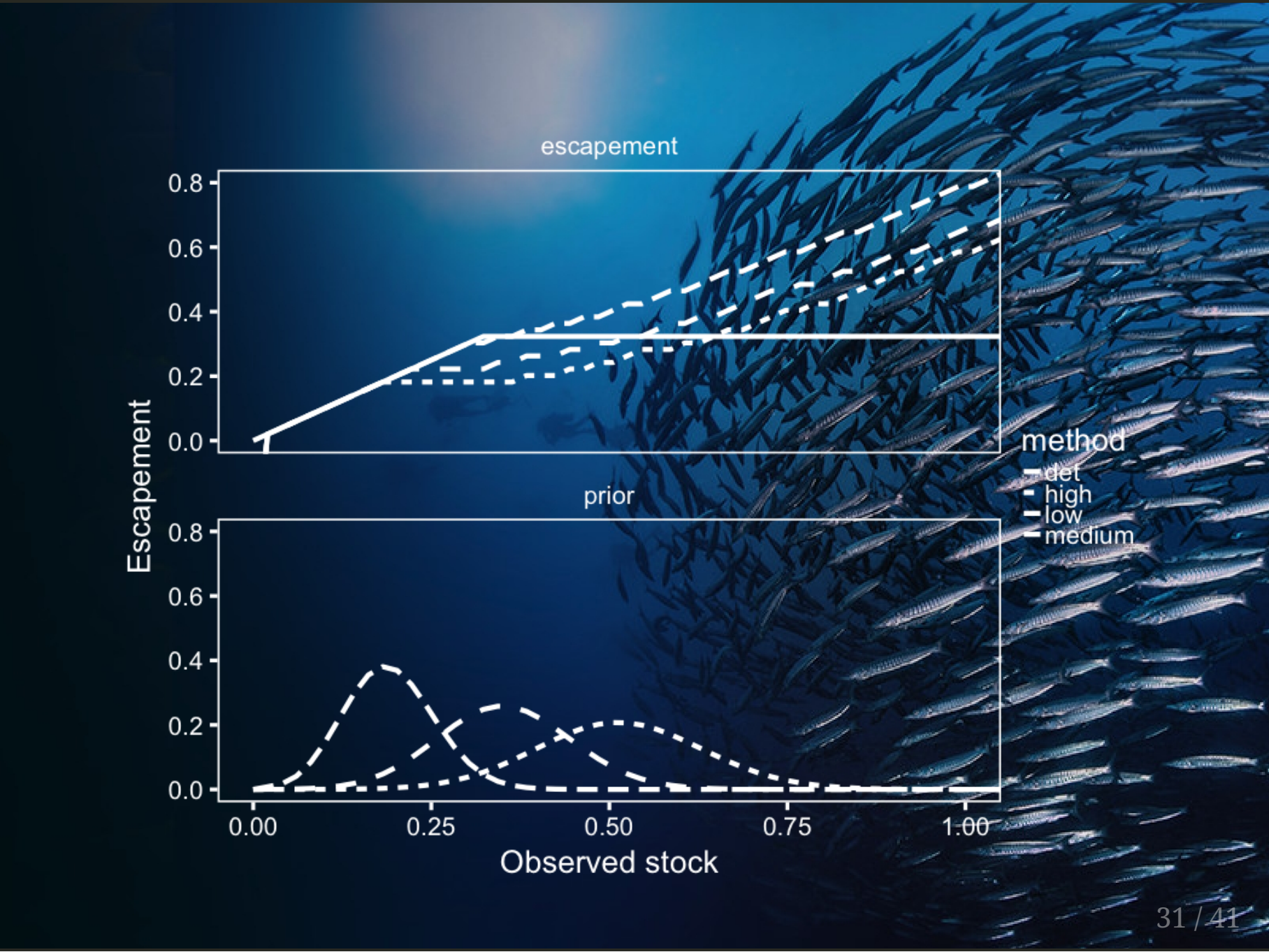
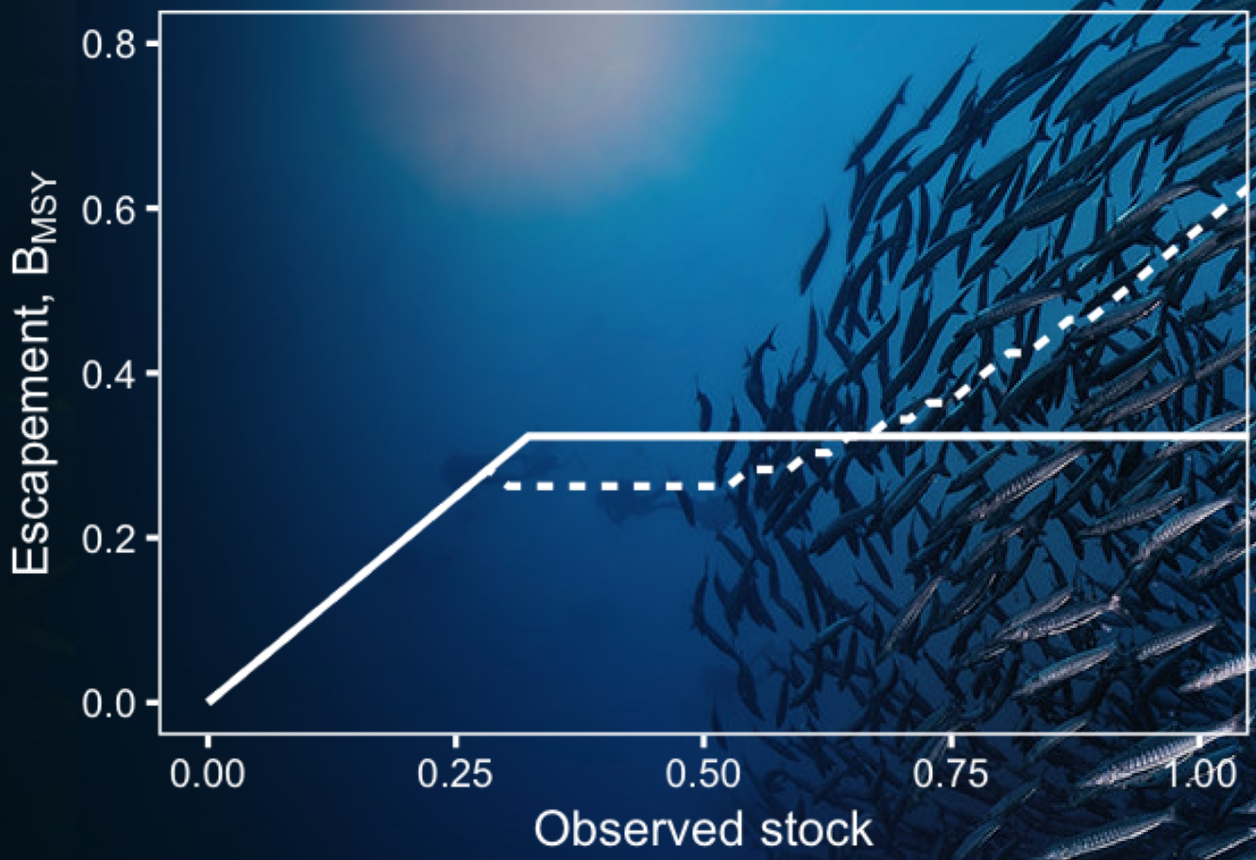
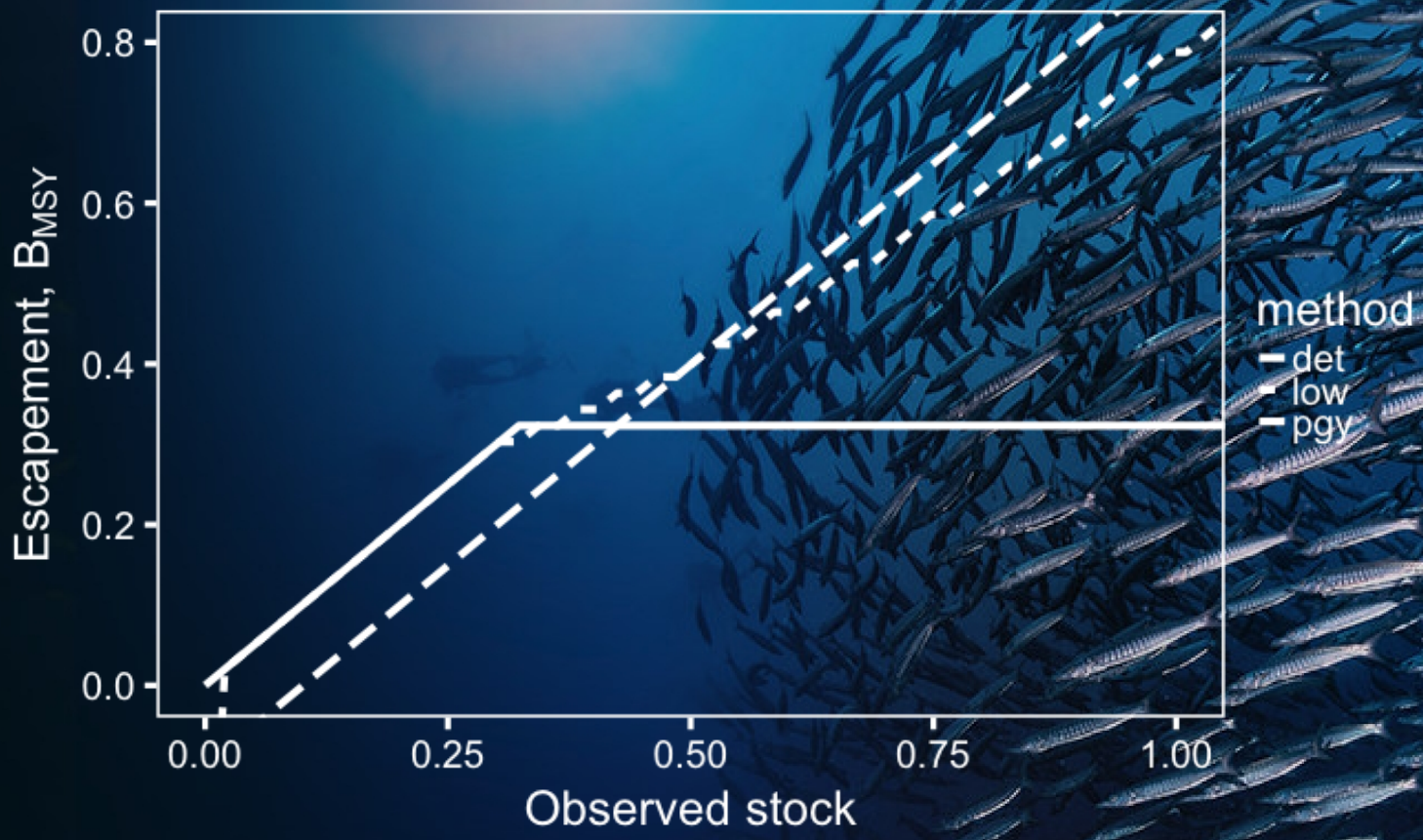

escapement
prior
Escapement
Observed stock
0.0
0.2
0.4
0.6
0.8
0.00
0.25
0.50
0.75
1.00
method
det
high
low
medium

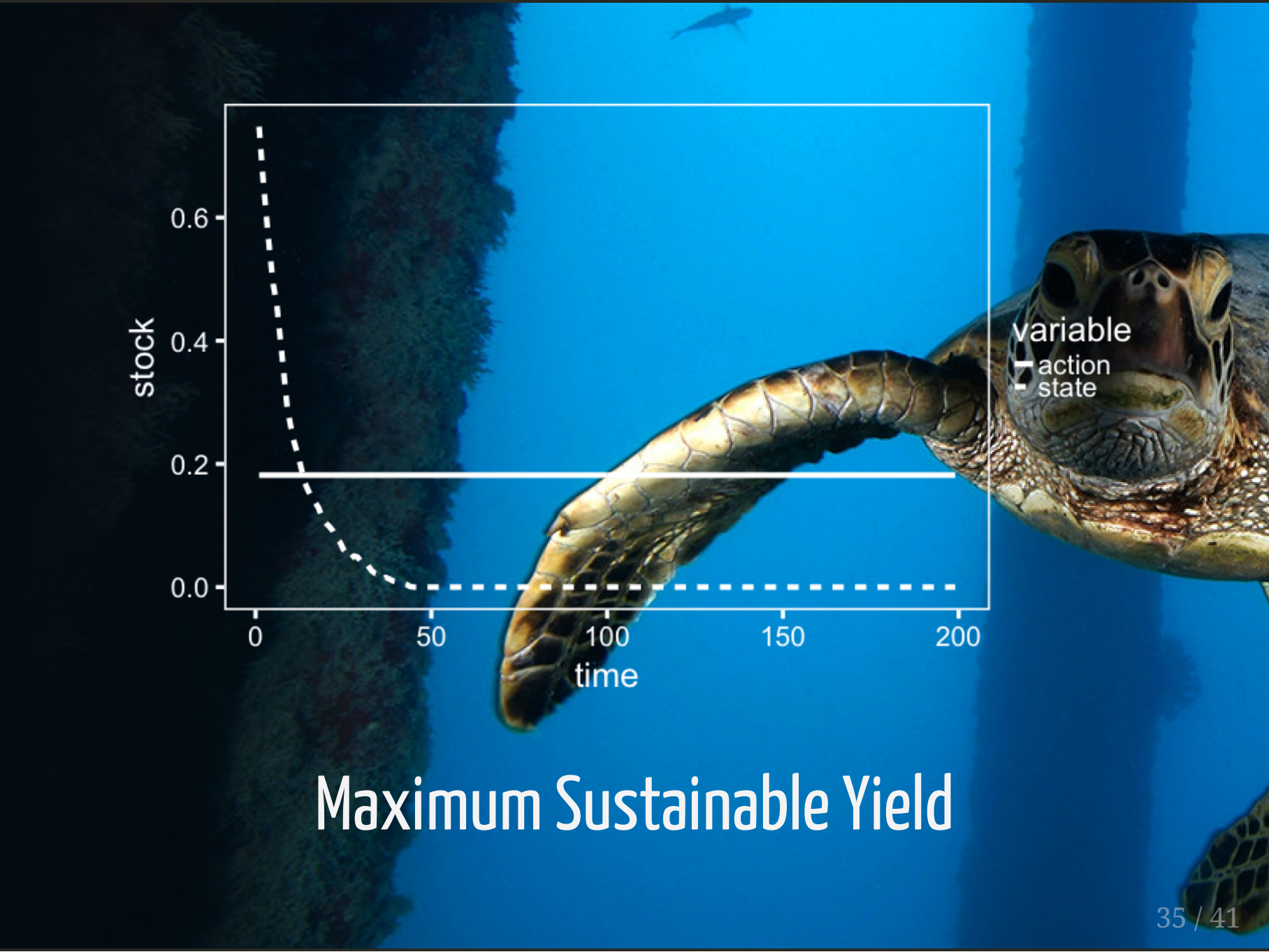


Paradoxical earlier results effectively ignored prior information

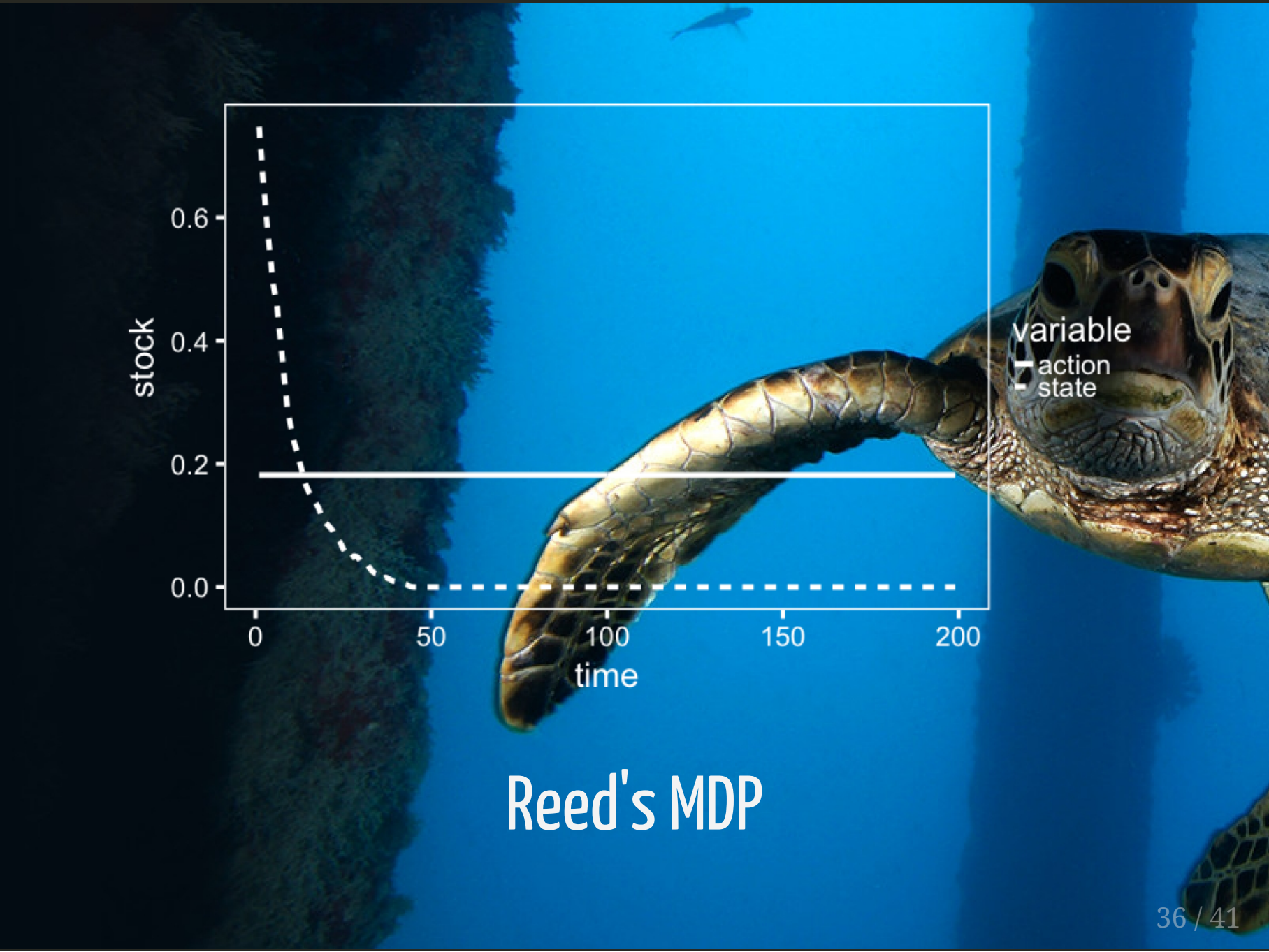


"Pretty Good Yield" isn't always more conservative

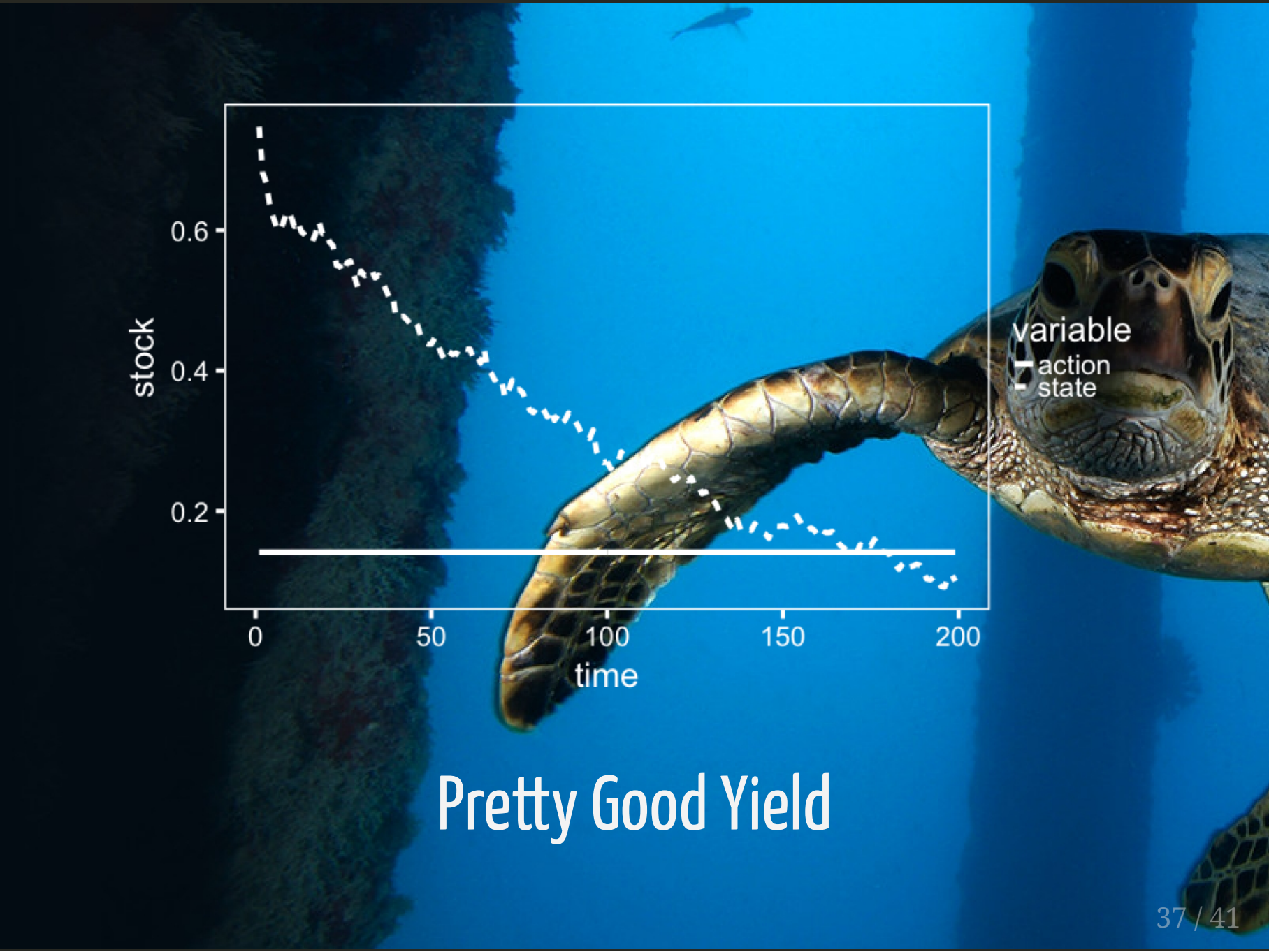

So how do these policies actually play out?



Maximum Sustainable Yield



Reed's MDP



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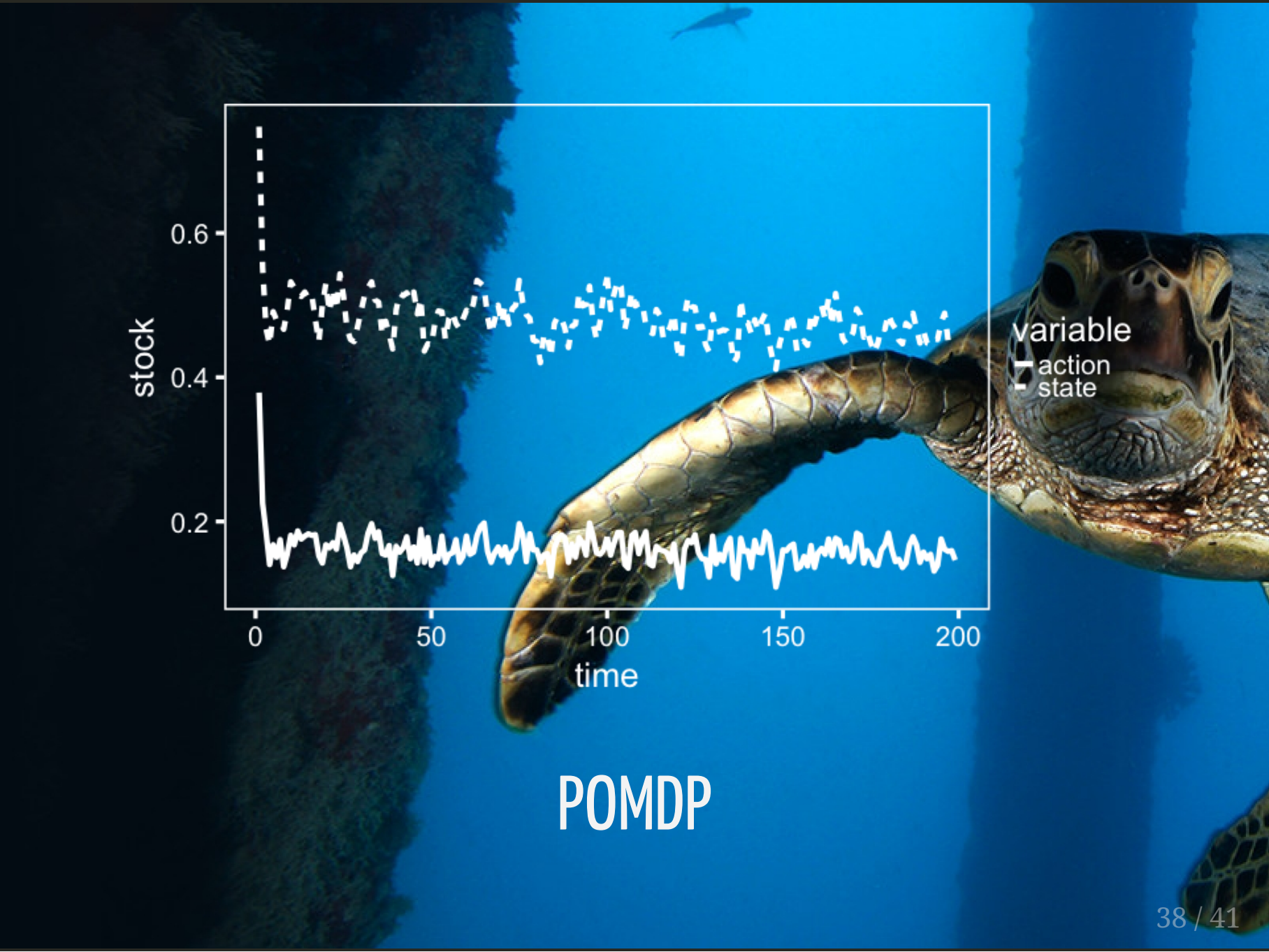

POMDP

Conclusions

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Conclusions

- Predictions are not enough: Decisions need their own theory
- Precaution cannot be tacked on
- Beliefs / prior experience matters
- Much to learn from other fields

Acknowledgements

Milad Memarzadeh

Image credits

ESPM Dept (startup)

Cloud Computing

Appendix: Age structure

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- Age+stage structured may not be an MSY (cyclical escapement, still an average B_{MSY})
- Stochastic age-structured models: also support either larger or smaller harvest than the deterministic equivalent, but still at a constant escapement policy