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Developing tools to Account~~ing~~ for population dynamics to improve~~s~~ the use of no-take marine reserves for fishery management

Victoria Quennessen and ~~Will~~ White J. Wilson

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Oregon State University

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Abstract

Today, fisheries are managed using information obtained through stock assessments. These provide reference points, such as how depleted the fishery is compared to when it is unfished, to determine optimal catch. However, these stock assessments typically need decades of catch and abundance data to accurately estimate depletion. These data may be difficult to obtain for smaller, or mostly recreational, fisheries. Populations in no-take marine reserves, that are not fished, may therefore serve as a reference point to determine depletion. One method developed in 2011 uses the ratio of fish density, or numbers of individuals per unit area, outside to inside the reserve, as a proxy for depletion. We can then explore how best to use this ratio to determine optimal catch using control rules, which dictate whether fishing effort should decrease, remain the same, or can increase based on the density ratio. The density ratio is especially useful because it does not require as many years of data, and it can be applied at a local scale that is relevant to annual recruitment. One limitation to the original method is that it did not model strong, periodic recruitment pulses that we see in many fish species off the coast of Oregon. It also did not account for differences between the short-term and the long-term, unfished population dynamics after a marine reserve has been implemented. Using age-structured spatial population modeling of Black Rockfish (*Sebastes melanops*) populations, I show how these factors can be accounted for to help determine consistent, sustainable catches.

Shorten + make plain English

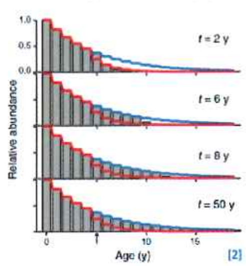
Background ~~Information~~

Short-term change to pop in MR

Fishing changes the age structure of a stock by removing older, larger individuals

Reserve reverses

This different age structure changes population dynamics (the way the population size changes over time)



- Marine protected areas (MPAs) can help protect the age structure, and are increasingly popular – as of 2015, 3.5% of the oceans are in MPAs, 1.6% of which are no-take (reserves) [1]
  - But how do reserves help with management?
- After protections, the age structure fills back in over time
- The blue line is the unfished age structure, the red line is the age structure after many years of fishing
- During the transition from a fished to an unfished age structure, the stock has **transient dynamics** (these dynamics are different from **equilibrium dynamics**, the dynamics unfished stocks have)
- Timescales depend on M (natural mortality), such that species with a lower M have longer transient dynamics [2]
- Transient dynamics lead to more fluctuations in population size than equilibrium dynamics, which complicates assessments and therefore management

Key points:
1) MRs could be reference point
2) But there are time lags

This section is too much + too technical.

The density ratio is a new reference point that can be used to manage fisheries using reserves

The current west coast groundfish fishery has a 40:10 control rule:

- A control rule dictates how high fishing effort can be based on a biological reference point
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$$\text{Density ratio: } \frac{\text{\# ind./ area outside reserve}}{\text{\# ind./ area inside reserve}}$$

- First proposed by [3]
- This control rule acts as a proxy for depletion
- It can be calculated based on only a few years of sampling data
- The density ratio can be calculated at local scales that affect marine protected areas and recruitment
- This reference point can help improve management for data-poor fisheries

Add pictures of fish?

Research Questions and Hypotheses

Research Questions

1. How can we best use information from within reserves to help adaptively manage fisheries following reserve implementation?
2. How does the inclusion of transient dynamics influence the short-term effect of control rules on yield and biomass?
3. What happens when we don't have an accurate estimate of natural mortality?

Hypotheses

1. Using a density ratio will allow for effective adaptive management of smaller or recreational fisheries, where effective means minimizing loss of yield and biomass.
2. Including control rules that account for transient dynamics will reduce losses of yield and biomass.
3. Transient control rules will perform better than static (unchanging) control rules when M is over or underestimated.

Methods – a.k.a. my really cool model

Fishery Simulation Model

Dangerous to make jokes like this

My computational model is age-structured and spatially implicit

Population dynamics (moves the population forward one year based on life history characteristics) → Imperfect sampling (calculates a reference point) → Fishing (removes fish from the population) → Management (applies a control rule for the next year) → Population dynamics

* Adapted from [3]

Area 1
Area 2
Area 3
Area 4
Area 5

- Used life history characteristics from Black Rockfish (*Sebastes melanops*)
- Started the population with the unfished age structure
- Model ran with only population dynamics and fishing for 50 years to get depleted
- At year 50, a marine reserve is implemented in Area 3, and no fishing occurred there
- Fishing effort is re-distributed between the other areas based on biomass of fish

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Define "M"

Comparing static and transient control rules and accounting for inaccurate estimates of M

CR	1	2	3	4	5	6
Type	Static	Static	Static	Transient	Transient	Transient
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Eq. 1: $\text{Target DR} = 1 - (1 - \text{Final DR}) \cdot e^{-Mt}$

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- At year 0, the target density ratio is 1, and the time it takes to get to a target density ratio equal to the final density ratio depends on M (what if M is wrong?)

For each area and control rule, there are 3 ~~populations~~ scenarios:

- Population 1 (Underestimated M) → Calculate density ratio for control rules 1 & 4
- Population 2 (Correct M "True" population) → Calculate density ratio for control rules 2 & 5
- Population 3 (Overestimated M) → Calculate density ratio for control rules 3 & 6

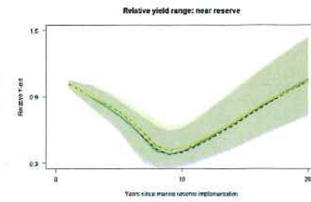
→ Apply control rule and set fishing effort for next year

Results

Transient control rules perform better on average, but the effect may be masked

- Plots show results from 10,000 simulations
- Yield, biomass, and spawning stock biomass (SSB) are plotted relative to values at the time the marine reserve was implemented
- Lines are median values and **shaded areas** show interquartile ranges (50% of the values)

Explain where variability comes from



Yield, biomass, and SSB close to the reserve

On average, the transient control rules lead to higher overall yield, biomass, and SSB over time after reserve implementation, although the differences may be washed out due to variability in recruitment.

translate into plain English take-home message

Control Rule
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- Static Correct M
- Static High M
- Transient Low M
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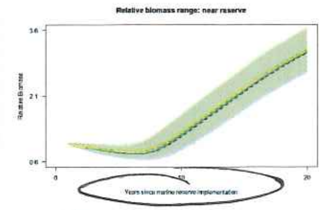

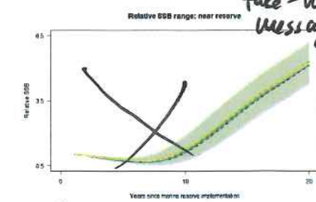

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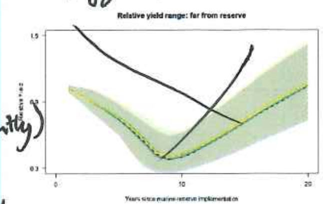

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Again, on average, the transient control rules lead to higher overall yield, biomass, and SSB over time after reserve implementation, although the differences may be washed out due to variability in recruitment. There is not a large difference between these two sets of results.

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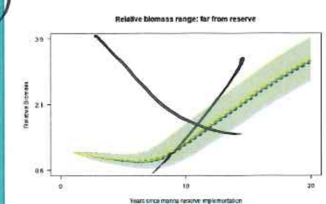

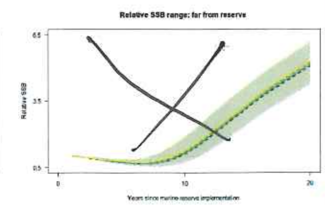

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Kaplan et al 2019
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Next steps

- Explore the effectiveness of different control rules that incorporate different target density ratios and sample different ages of fish, fish from different areas, or for longer amounts of time.
- Incorporate more realistic variability in recruitment.
- Explore effects of increasing inaccuracy of natural mortality estimates
- Explore effect of control rules on different species: cabezon (*Scorpaenichthys marmoratus*), lingcod (*Ophiodon elongatus*), and copper rockfish (*Sebastes caurinus*).
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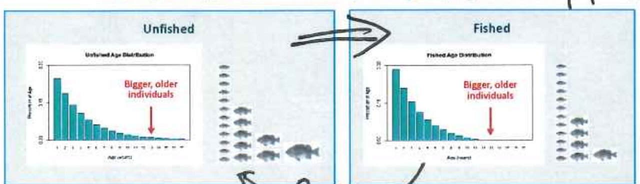

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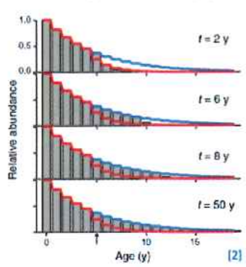

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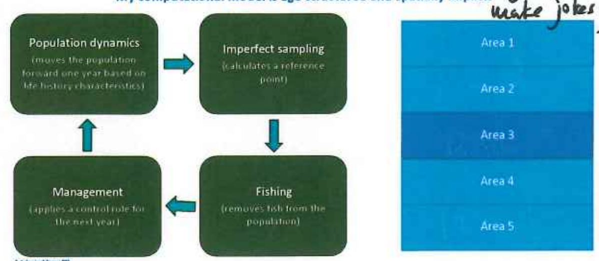

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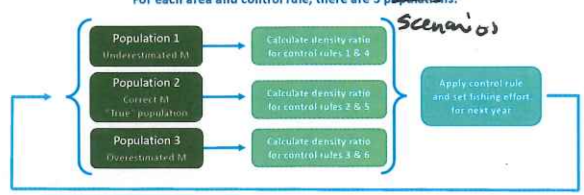

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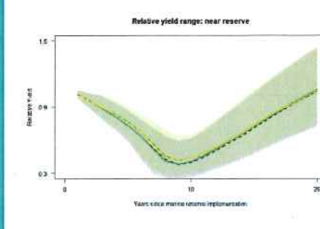

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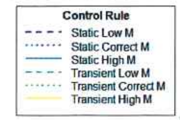
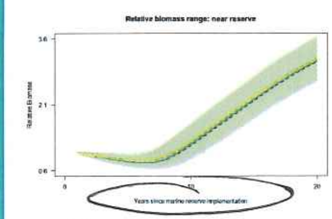
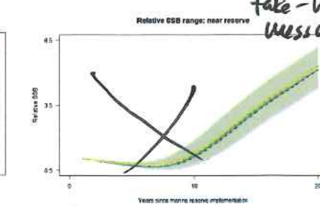
take-home message







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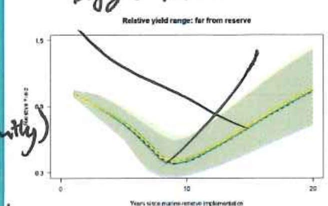

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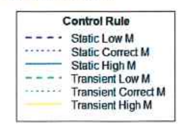

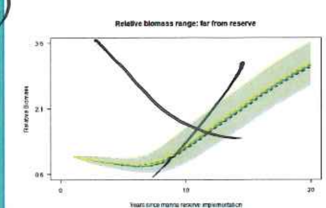

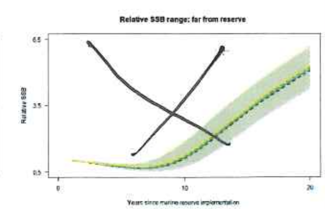

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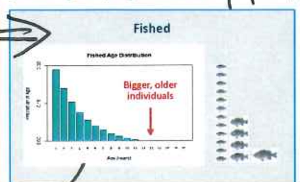

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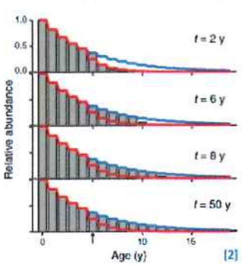

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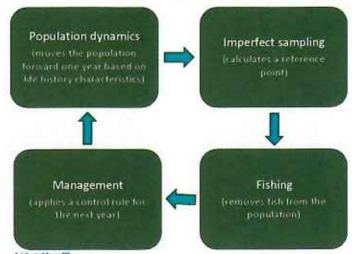

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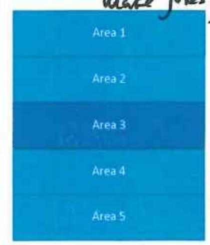

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- Model ran with only population dynamics and fishing for 50 years to get depleted
- At year 50, a marine reserve is implemented in Area 3, and no fishing occurred there
- Fishing effort is re-distributed between the other areas based on biomass of fish

Define "M"

Comparing static and transient control rules and accounting for inaccurate estimates of M

CR	1	2	3	4	5	6
Type	Static	Static	Static	Transient	Transient	Transient
M	Low	Correct	High	Low	Correct	High

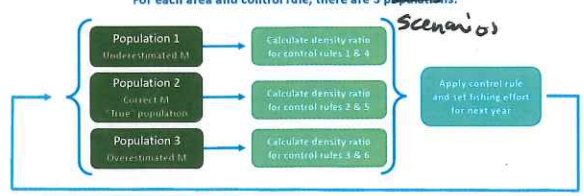
* Static control rules dapted from [3]

Eq. 1: $Target\ DR = 1 - (1 - Final\ DR) \cdot e^{-Mt}$

* Adapted from [2]

- The static control rules use the same density ratio over time (assume reserve works instantly)
- The transient control rules use a shifting target density ratio over time (Eq. 1), where t is the number of years after reserve implementation (accounts for time lag)
- At year 0, the target density ratio is 1, and the time it takes to get to a target density ratio equal to the final density ratio depends on M (what if M is wrong?)

For each area and control rule, there are 3 ~~populations~~ scenarios:

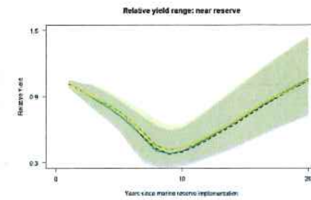


Results

Transient control rules perform better on average, but the effect may be masked

- Plots show results from 10,000 simulations
- Yield, biomass, and spawning stock biomass (SSB) are plotted relative to values at the time the marine reserve was implemented
- Lines are median values and **shaded areas** show interquartile ranges (50% of the values)

Explain where variability comes from

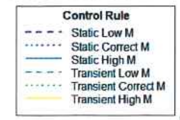


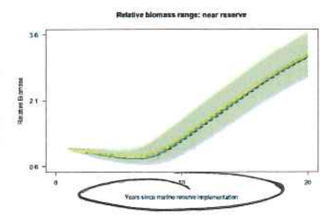
Yield, biomass, and SSB close to the reserve

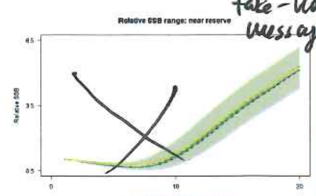
On average, the transient control rules lead to higher overall yield, biomass, and SSB over time after reserve implementation, although the differences may be washed out due to variability in recruitment.

translate into plain English

take-home message

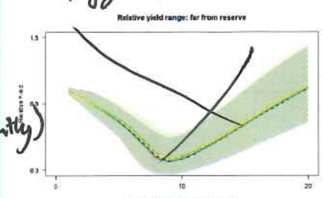






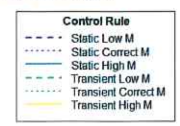
Bigger labels

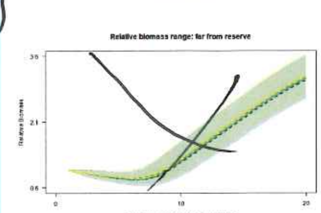
(too many figs)

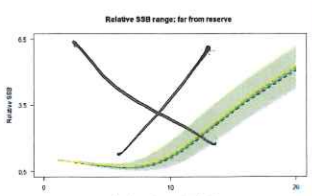


Yield, biomass, and SSB far from the reserve

Again, on average, the transient control rules lead to higher overall yield, biomass, and SSB over time after reserve implementation, although the differences may be washed out due to variability in recruitment. There is not a large difference between these two sets of results.







Acknowledgements

Thanks to support from lab mates Dr. Christian Commander, Montana McLeod, Jennifer Fisher, and Laura Storch; ~~PI Will White~~; and friends and family.
Funding: Oregon State University, The Oregon Lottery Scholarship, and the James Sedell Graduate Scholarship PISCO

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Kaplan et al 2019
Nickols et al 2019

QR code for lab website

Next steps

- Explore the effectiveness of different control rules that incorporate different target density ratios and sample different ages of fish, fish from different areas, or for longer amounts of time.
- Incorporate more realistic variability in recruitment.
- Explore effects of increasing inaccuracy of natural mortality estimates
- Explore effect of control rules on different species: cabezon (*Scorpaenichthys marmoratus*), lingcod (*Ophiodon elongatus*), and copper rockfish (*Sebastes caurinus*).
- Explore effects of inaccuracy of other life history parameters that are known to affect transient timescales, such as growth rate.