Cumulative impacts of changing population productivity, variability, and synchrony on Pacific salmon

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NPAFC-IYS Workshop
Current Status of Salmon and Their Environments
May 18, 2019
Pacific salmon catches are stable or increasing throughout the North Pacific…
• Pacific salmon catches are stable or increasing throughout the North Pacific… but not everywhere.
• Catches of all Pacific salmon species have declined in British Columbia.
Declines in BC Pacific salmon catches are *partially* driven by reduced harvest rates across most sectors.
Despite dramatic reductions in exploitation rates, **stocks have generally continued to decline**

Status of Fraser River sockeye salmon (DFO 2018a **CSAS**)

Status of southern BC Chinook salmon (DFO 2018b **CSAS**)

**Status**
- Healthy
- Declining
- Depleted
Pacific salmon catch has declined in British Columbia
1) Reduced harvest rates across most sectors (controlled by management)
2) Changes in population dynamics (not controlled by management)

Pacific salmon catch has declined in Canada due to:

1) Reduced harvest rates across most sectors (controlled by management)

2) Changes in population dynamics (not controlled by management)
Changes in population dynamics

1. Reduced productivity
   • Fewer adult recruits produced per spawner
   • Driven by changes in fecundity, age-at-maturity, or natural mortality
Changes in population dynamics

1. Reduced productivity
2. **Increased variability**
   - Recruitment anomalies (deviations from expected abundance) are larger
   - Forecasts underperform; boom-and-bust fisheries become more common
Changes in population dynamics

1. Reduced productivity
2. **Increased variability**
   - Recruitment anomalies (deviations from expected abundance) are larger
   - Associated with more extreme, less stable conditions in freshwater and marine habitats

Greater variability in large-scale environmental indices (Black et al. 2018 *Global Change Biol.*)
Changes in population dynamics

1. Reduced productivity
2. Increased variability
3. **Increased synchrony**
   - Recruitment *among* stocks becomes more strongly correlated
   - Aggregate variability increases as localized swings become widespread
Changes in population dynamics

1. Reduced productivity
2. Increased variability
3. **Increased synchrony**
   - Recruitment anomalies *among* stocks strongly correlated
   - Driven by anthropogenic impacts or environmental drivers

Increased synchrony in systems with hydropower and hatchery impacts (Satterthwaite and Carlson 2015 *CJFAS*)
Changes in population dynamics

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Coherence among stocks related to North Pacific Gyre Association (Kilduff et al. 2015 *PNAS*)
How have productivity, variability, and synchrony of Fraser River sockeye salmon changed through time?

- 23 component stocks range from abundant to severely depleted
- Managed using an abundance-based harvest control rule
- Primarily mixed-stock fishery
Fraser River sockeye salmon

- Declines in productivity
- Greater variability within individual stocks
- Unprecedented increase in synchrony among stocks
Fraser River sockeye salmon

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How will persistent changes in these dynamics influence fisheries management?
Closed-loop simulations

- Simulate the biological dynamics of a population, as well as the fishery that harvests them
- Includes multiple sources of uncertainty
  - E.g. recruitment deviations, maturation age, outcome uncertainty
- Can be used to evaluate management strategies across different ecological scenarios
1) Match productivity, variability, and synchrony “scenarios” with each stock’s dynamics
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2) Simulate each scenario

- 1500 trials
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2) Simulate each scenario

3) Calculate median performance across conservation and catch metrics
Impacts of recruitment variability and synchrony on abundance
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Recruitment variability increases median abundance if synchrony is low.
Probability of meeting escapement targets reduced when recruitment variability and synchrony are high
• Catch stability strongly impacted by interaction between recruitment variability and synchrony
• May result in more frequent closures and increased costs to industry
Effects of productivity on recruitment variability and synchrony

1. Generally productivity impacts are more severe
2. Reduced productivity moderates the impacts of other population attributes; e.g. when productivity is low:
   • Variability increases probability of escapement goals met
   • The impacts of variability on stability weaken
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Divergent effects of hatcheries

Hatcheries may simultaneously:
1. Increase productivity by reducing mortality
2. Increase variance by reducing genetic diversity and increasing synchrony

Results in greater abundance over the short-term, but may reduce long-term resilience and stability

Greater hatchery supplementation increases mean abundance and variability (Dedrick and Baskett 2018 Am. Nat.)
The cumulative effects of aggregate dynamics on management outcomes:

- Interactions between productivity, variability, and synchrony vary among management objectives
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• Even if abundance stays high on average, as synchrony and variability increase, boom-and-bust fisheries will become more common
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- Negative outcomes may be most severe when managers are data-limited
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• Tailor management interventions to address specific objectives
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- Negative outcomes may be most severe when managers are data-limited.
- Tailor management interventions to address specific objectives.
- Preserve stock diversity wherever possible to maintain resilience.