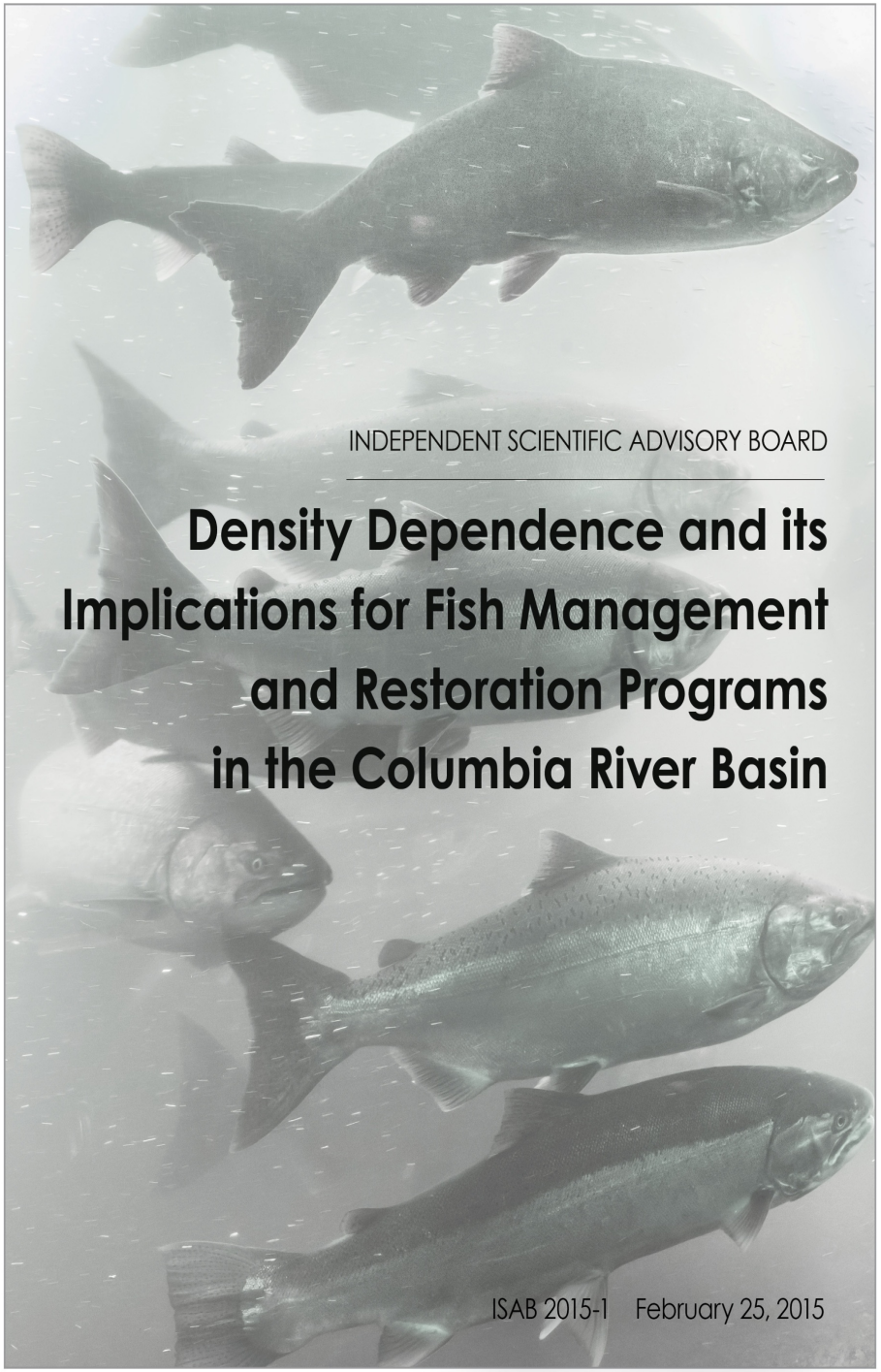

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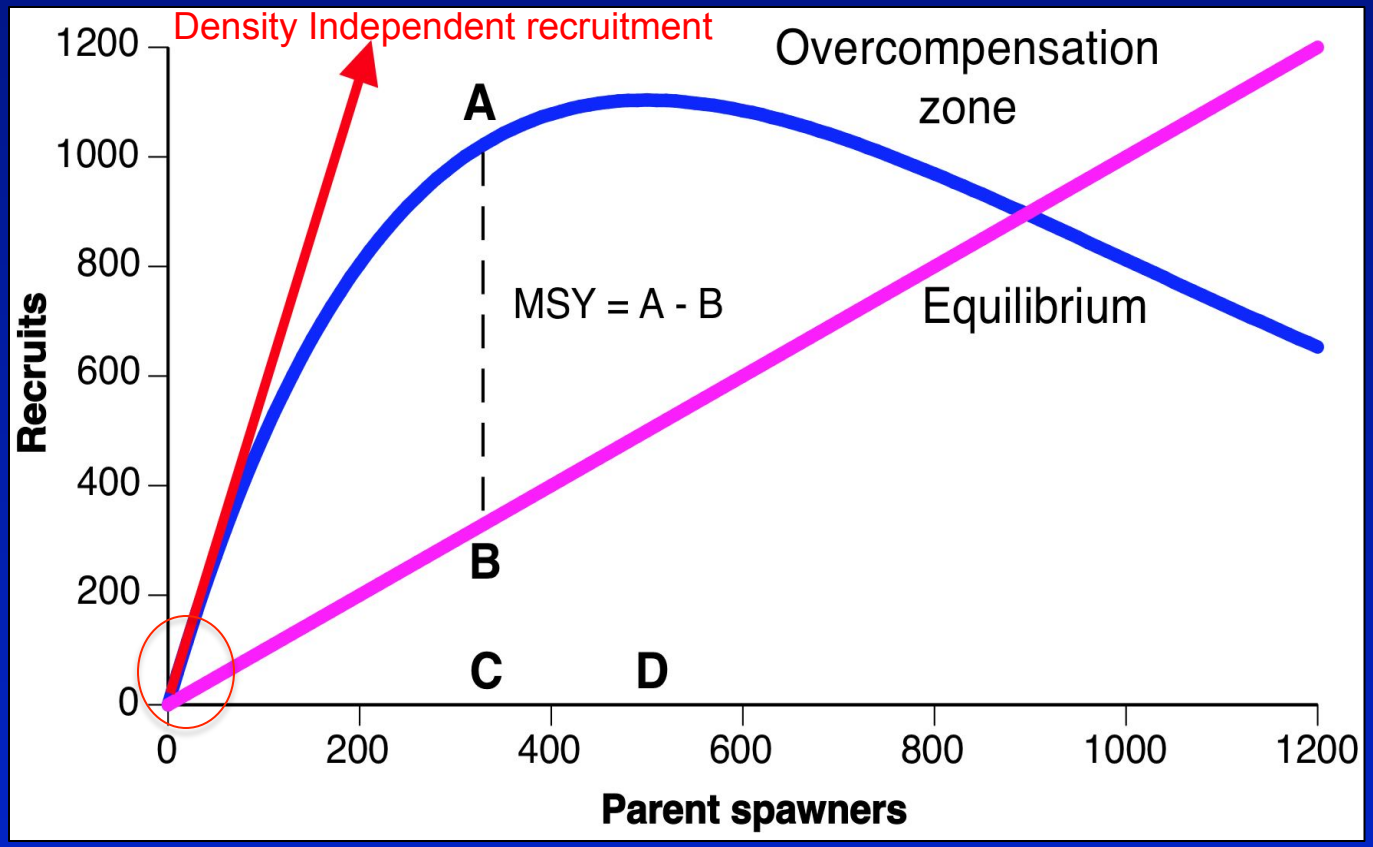
Presentation to Ocean Forum
March 4, 2015

Key Questions

- What is density dependence and why is it important?
- Why is density dependence more evident than expected at current relatively low abundances?
- Where—and at what life stages—has density dependence been detected in the Basin?
- How can density dependent limitations be ameliorated as a means to enhance population rebuilding and recovery?
- How can we detect and diagnose density dependent limiting factors?

What is density dependence and why is it important?

Example: Ricker Curve



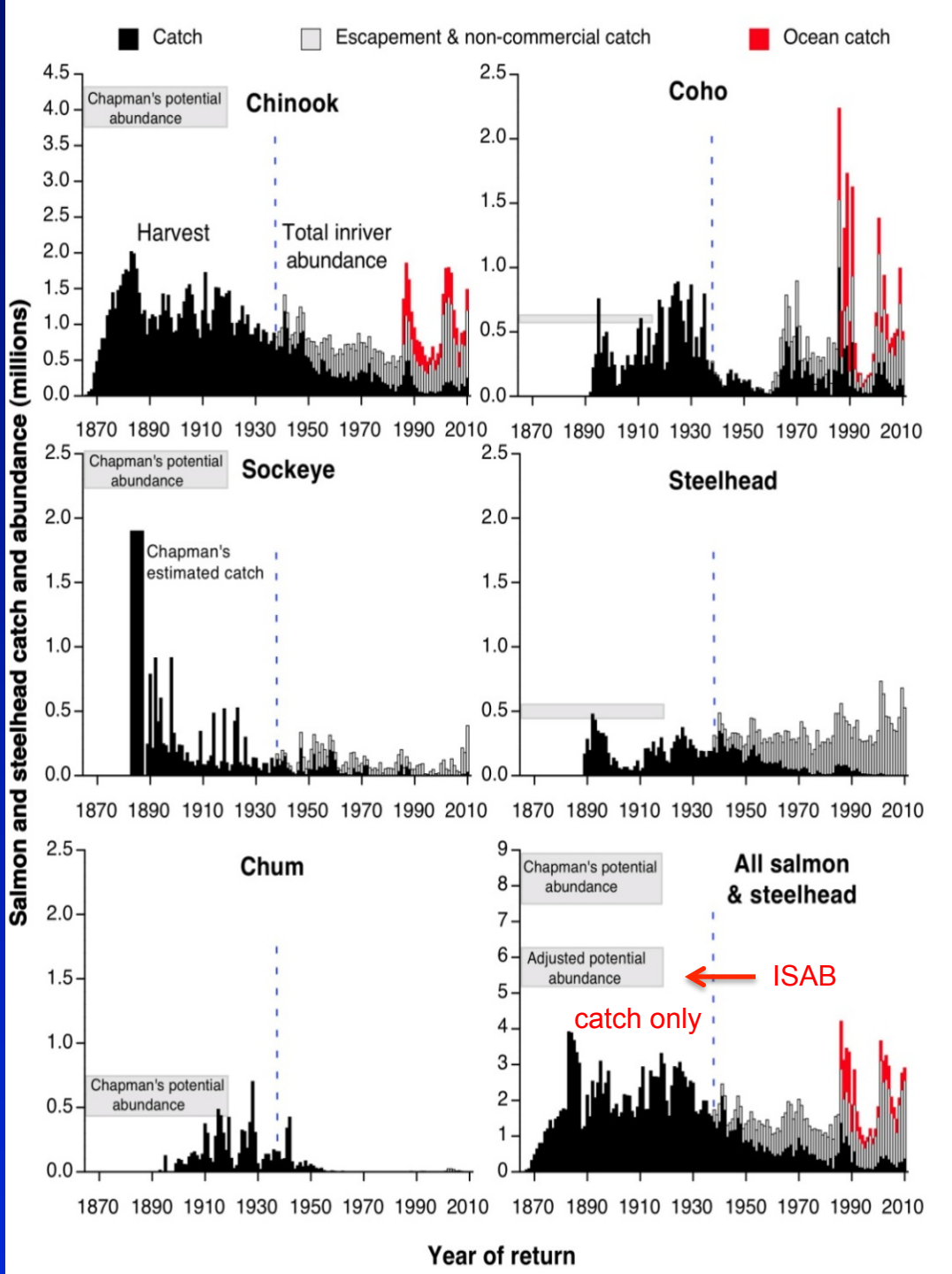
1) More resources per individual at lower densities: better growth & survival.
2) Compensatory density dependence provides resilience for populations to rebound from low abundance and enables stability.

Pre-development Capacity of the Columbia River Basin

All Salmon & Steelhead

- Chapman (1986):

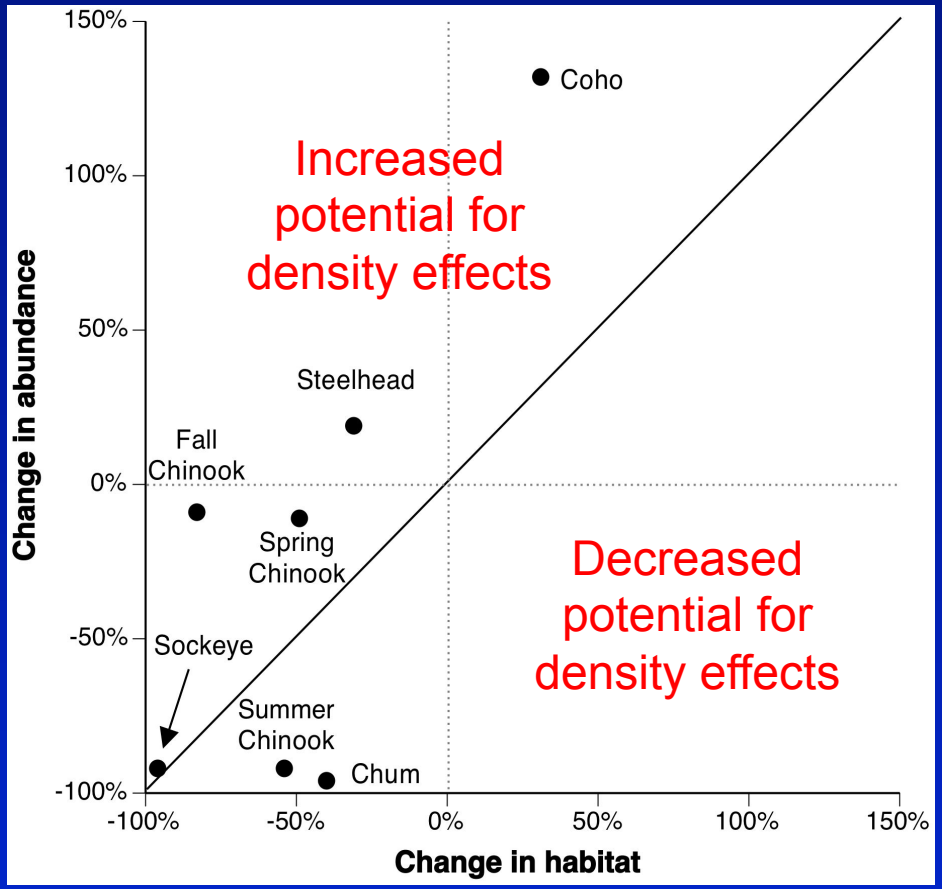
  7.5-8.9 million
- NPPC (1986): 9-16 million
- ISAB: ~~5-9 million



Could “density” (wild & hatchery salmon) be greater today?

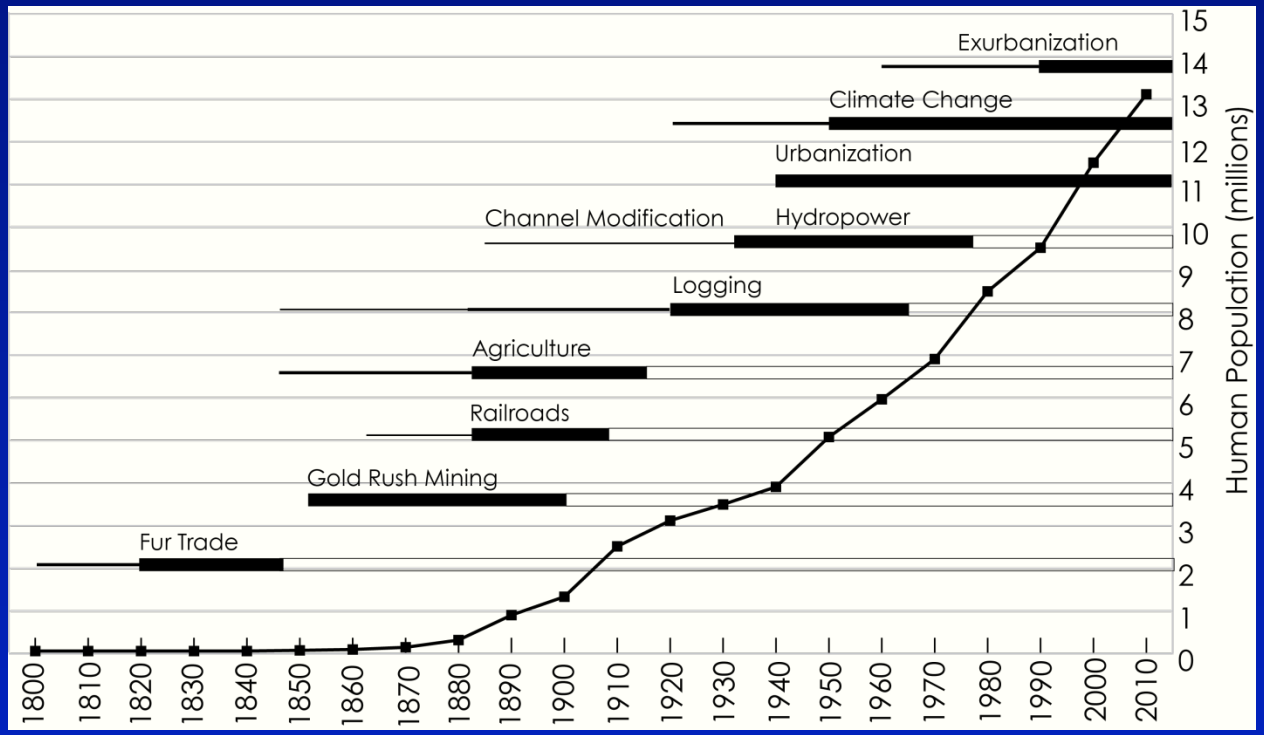
- Initial evaluation of potential density effects.
- Change (%) in abundance versus accessible habitat:

  ~1850 to 1986-2010
- Spring & fall Chinook, coho, steelhead
- Caution!



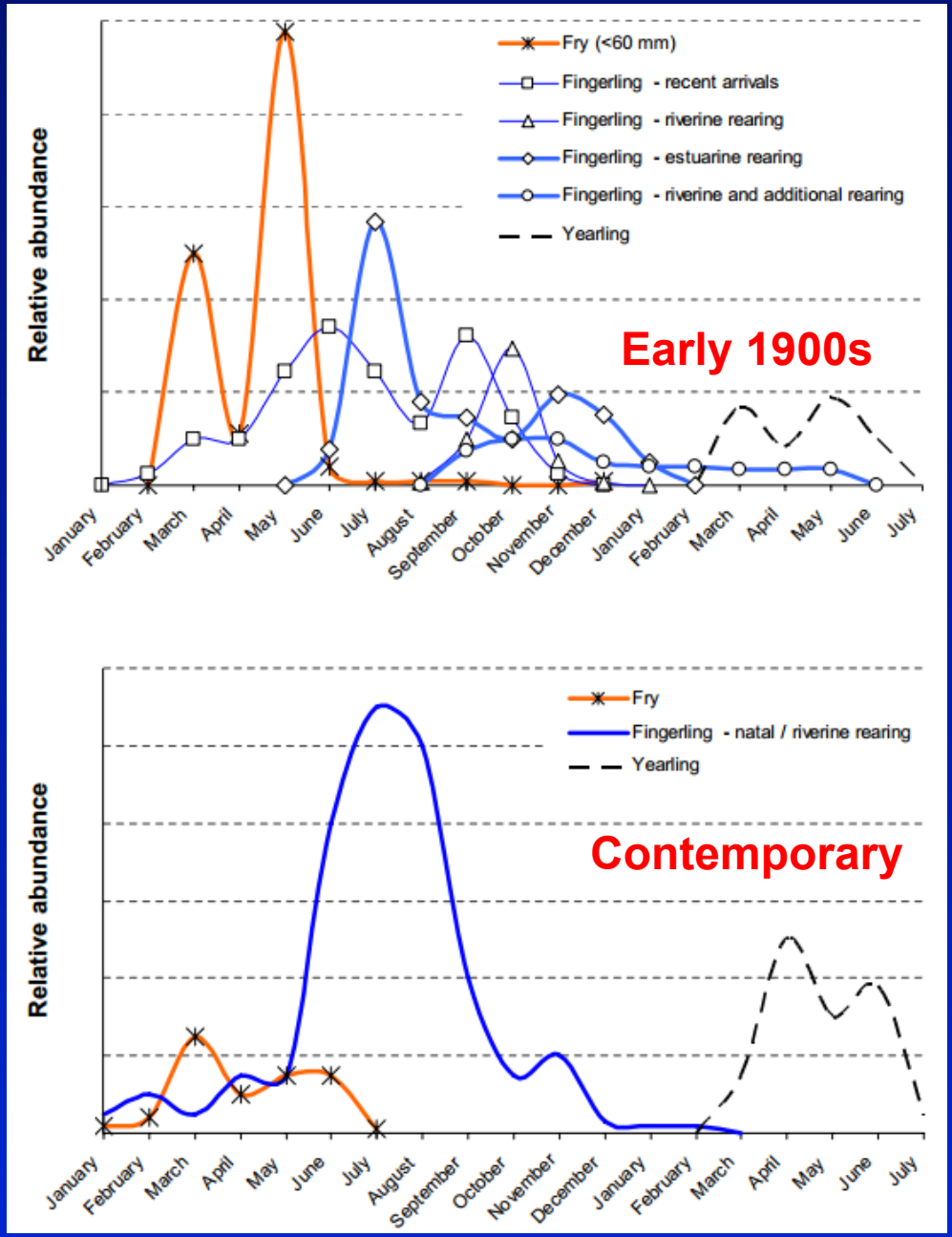
Columbia is Novel Ecosystem

- Habitat change impacts *intrinsic* productivity & capacity
- Salmon capacity reduced by loss of diverse habitats that support diversity of life histories.



Chinook life history diversity

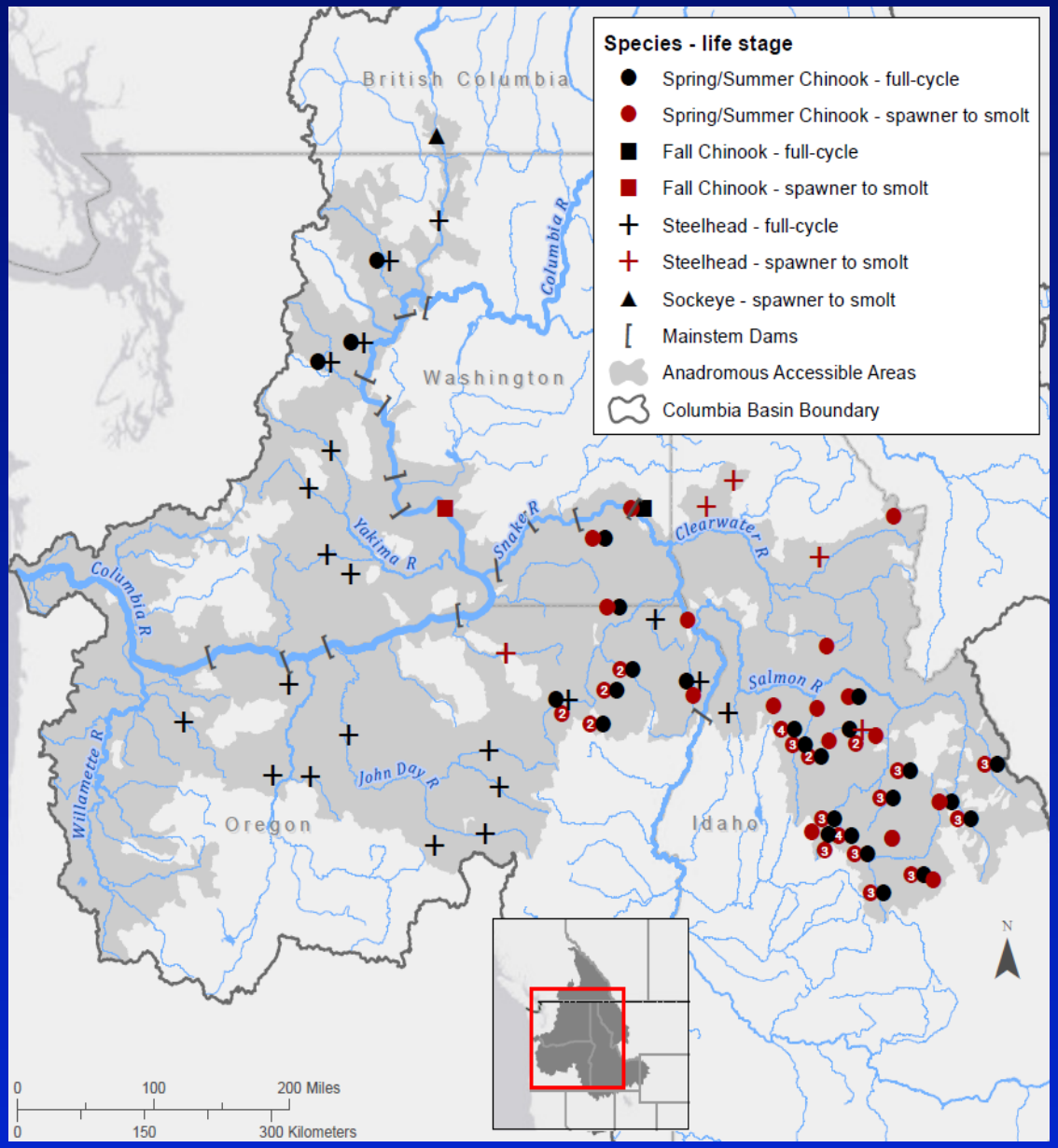
- Loss of diversity concentrates fish in river and estuarine habitats, leading to potential density effects & lower overall capacity.



Source: Bottom et al. 2005b, Fresh et al. 2005

Where has DD been looked for?

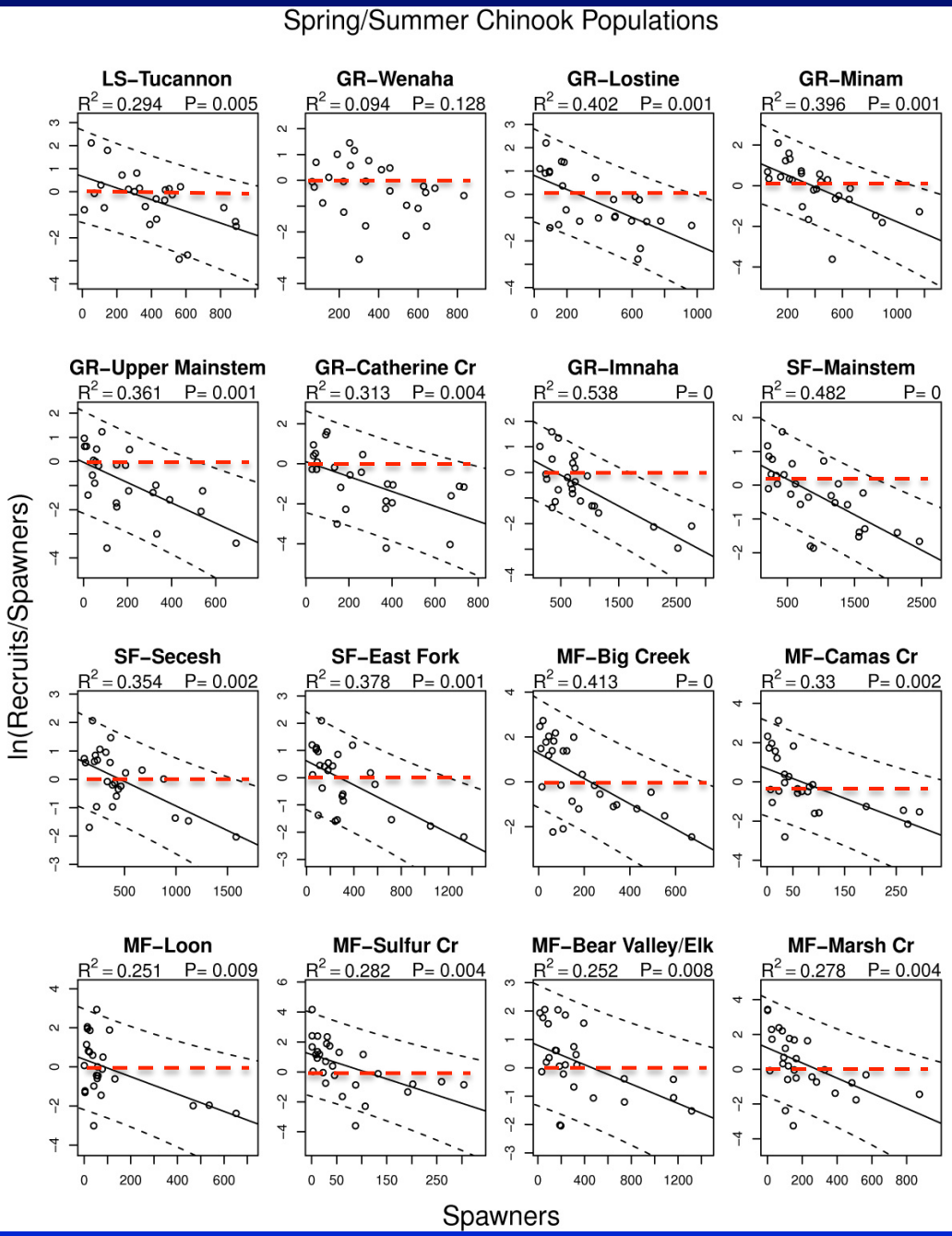
- Primarily spring/ summer Chinook & steelhead in the interior.
- Few studies below Bonneville & during juvenile emigration.
- Few coho studies.



Map produced for ISAB by Brett Holycross and Van C. Hare, PSMFC.

Life Cycle Density Dependence

- 27 Interior Columbia River spring and summer Chinook populations (ESA-listed)
- Snake R fall Chinook (ESA-listed)
- 20 Interior Columbia River steelhead populations (ESA-listed)
- R/S often < 1
  (must improve conditions to achieve recovery)
- What life stage?

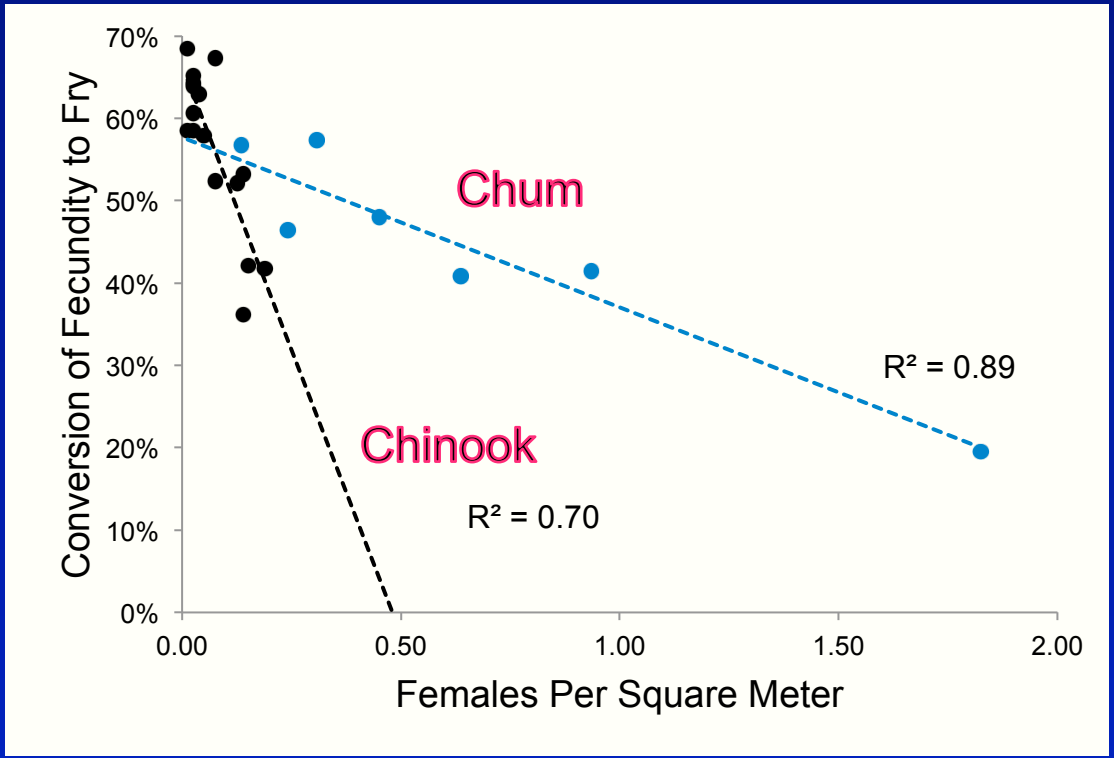


Source: Zabel & Cooney 2013

Spawning Stage: Chinook & Chum

Experimental Spawning Channel

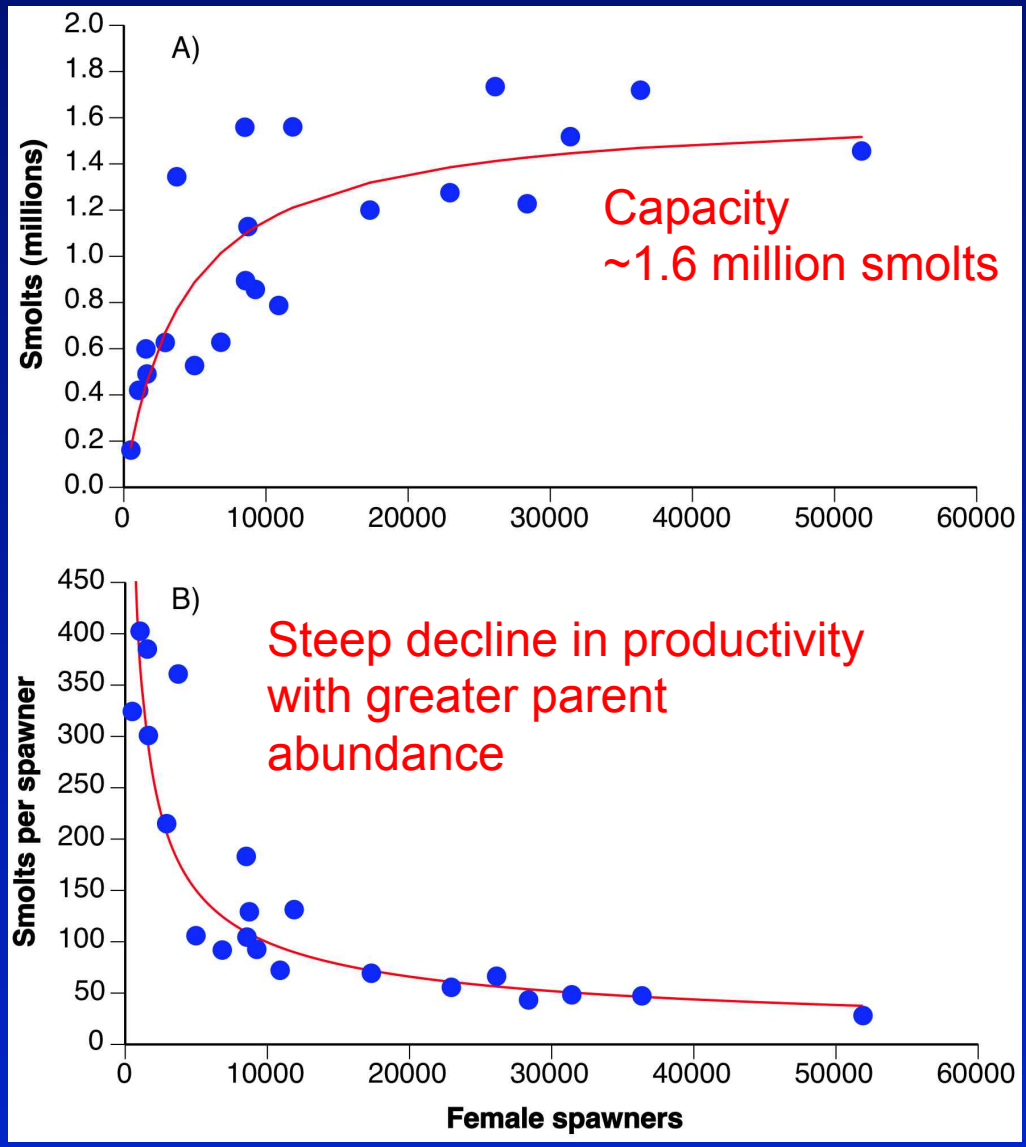
- Egg to fry survival is density dependent
- Density dependence "stronger" in Chinook
- Chum do better than Chinook when high spawning density
- Little information for spawning stage in Columbia



Source: Schroder 1974, Schroder et al. 2008

Snake R Spring/ Summer Chinook: spawner to smolt

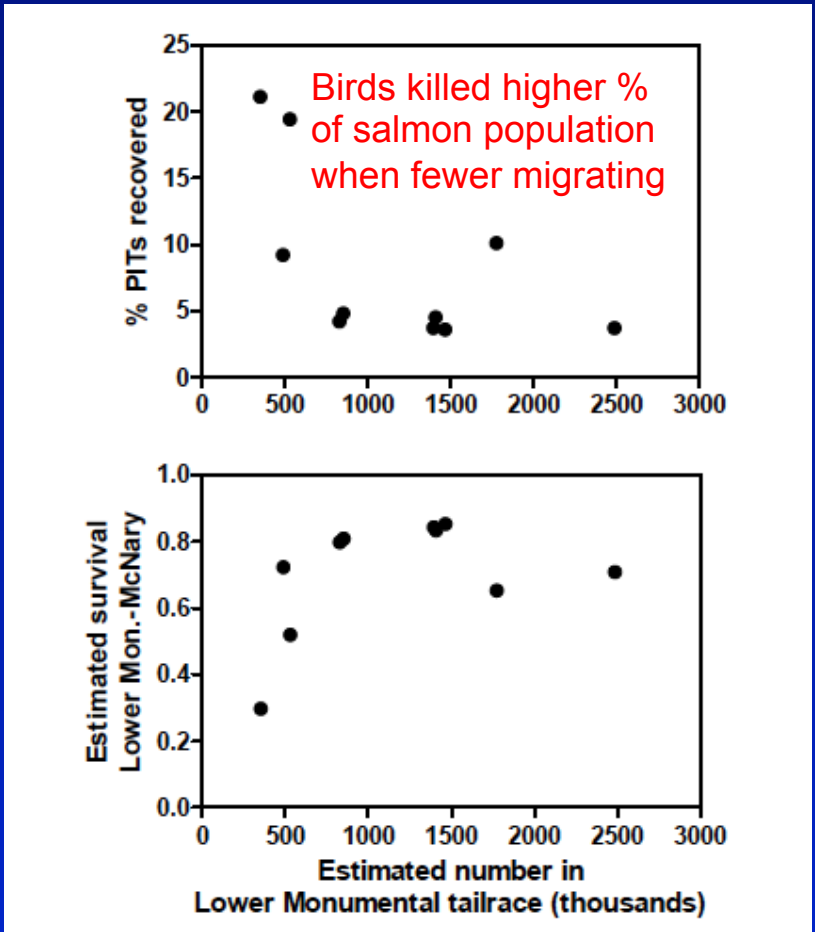
- Strong density dependence
- > ~20,000 females may not produce more smolts
- Smolt production in 1960s: ~2-4 million.
- Population resilience at low abundance.
- Growth & emigration is DD.



Source: Raymond (1979), Petrosky et al. (2001), Zabel et al. (2006), Kennedy et al. (2013), T. Copeland, IDFG.

Depensatory Predation

- Percentage of salmon killed increases at lower salmon abundances.
- Pinniped & bird predation on salmon: likely depensatory & destabilizing, but…..
- Depensation not evident in life-cycle recruitment
  - Spring Chinook escapement goal at Bonneville (115k) essentially met or exceeded each year since 2008.

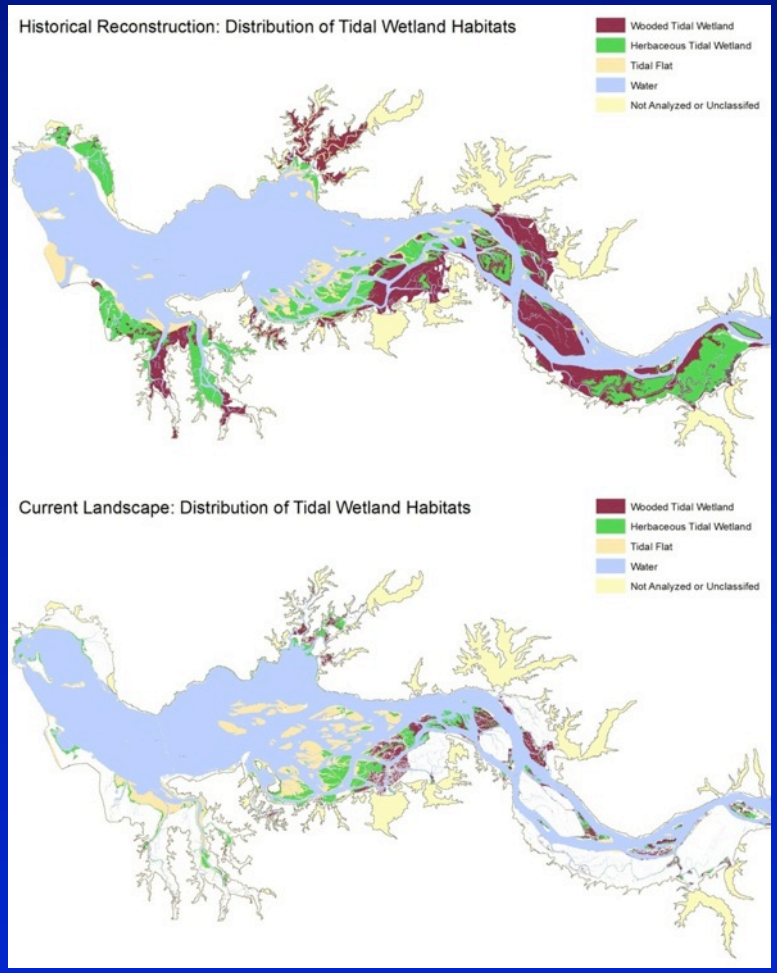


Faulkner et al. (2008)

ESTUARY REARING STAGE

Columbia River Estuary

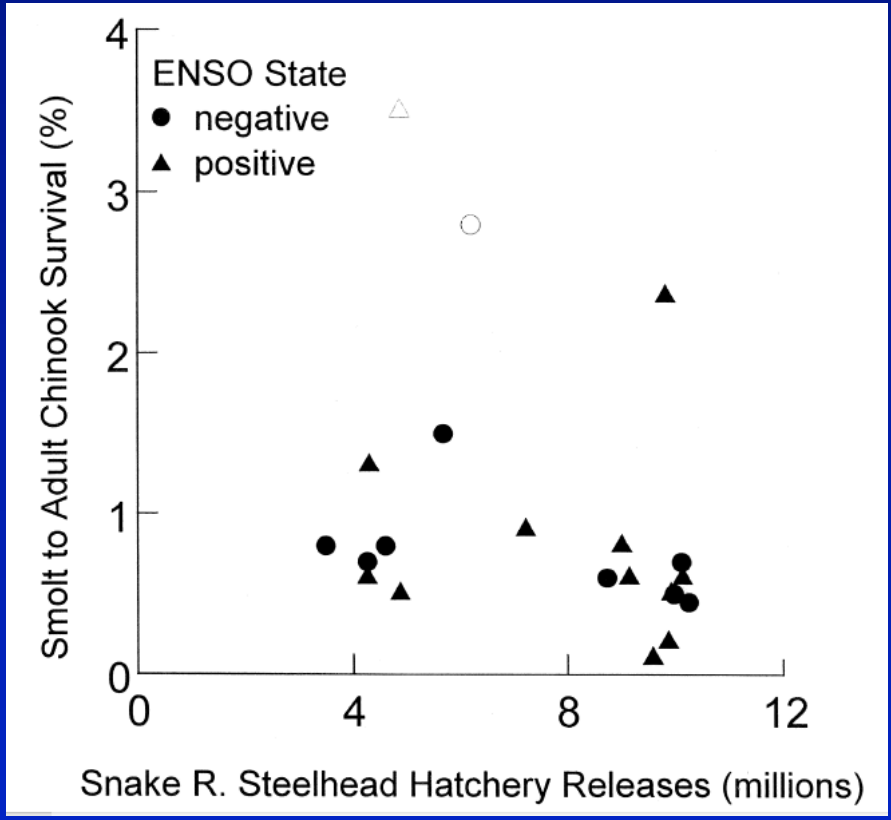
- Loss of species diversity
- Loss of habitat diversity
- Habitat capacity may be exceeded by current smolt production
- Starting in 2000s, research focus on restoration of habitat diversity and habitat capacity



Source:http://coast.noaa.gov/digitalcoast/stories/columbia-river

Few studies directly test density effects in the Columbia River estuary

- Interspecific effects on foraging (Dawley et al.1986)
- Hatchery effects on survival (Levin & Williams 2002)
- Interspecific effects on movements (Eaton 2010; Bottom et al. 2011)



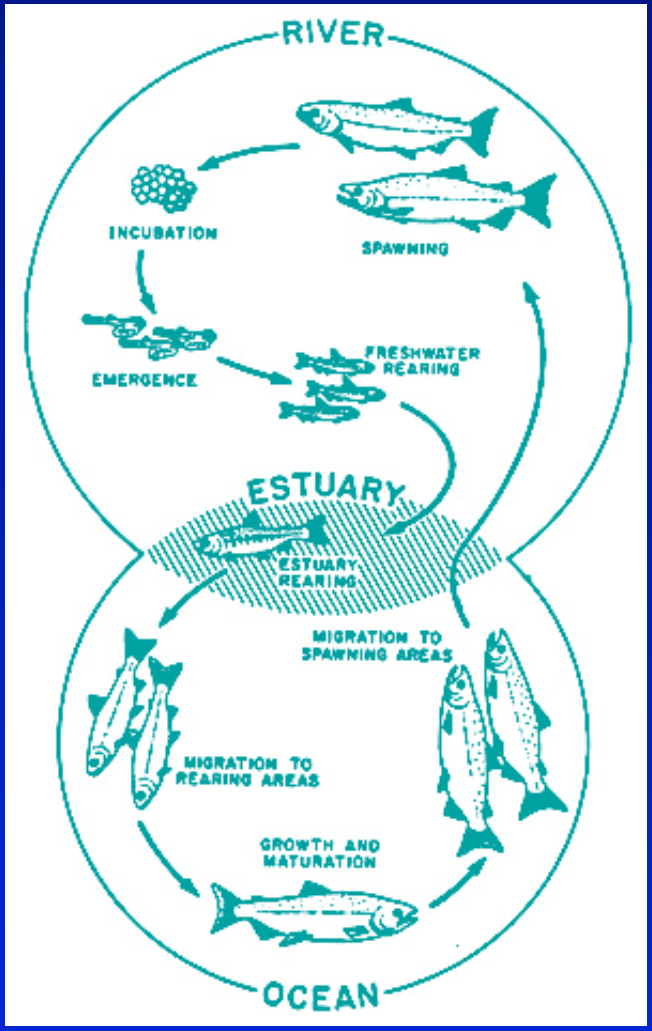
Source: Levin & Williams 2002

Columbia River estuary recovery plans have identified density dependence data gaps

- Washington Lower Columbia Salmon Recovery Plan : Hatchery & natural-origin competition for food & space a critical uncertainty (LCFRB 2010)
- ESA Recovery Plan Estuary Module: Degree of density-dependent mortality in the estuary, role of large hatchery releases, & cumulative impact of hatchery releases on density-dependent mechanisms (NMFS 2011)

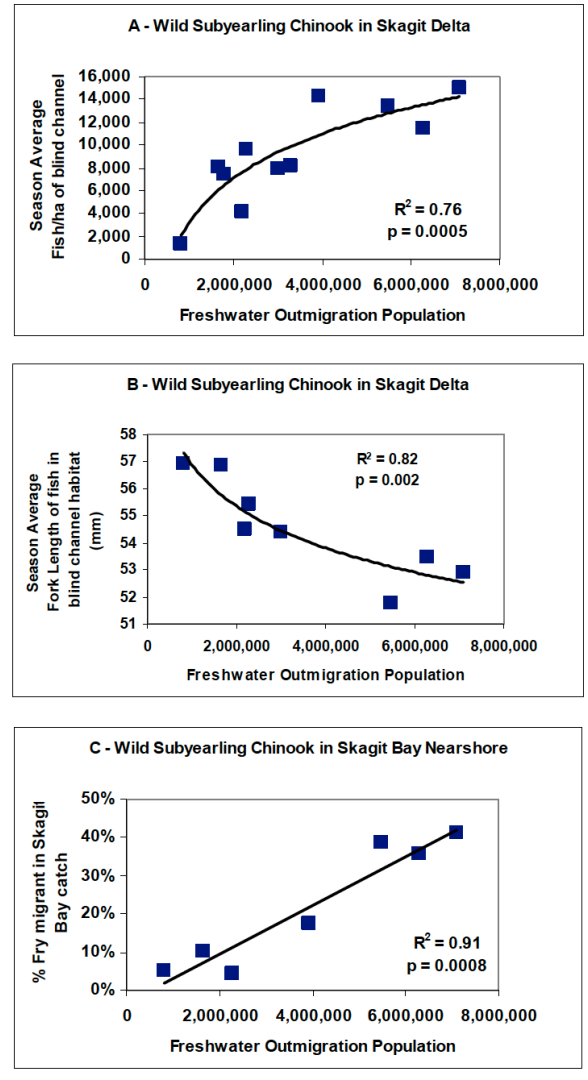
Data needed for multi-state life history models of salmon survival

- Modelers often assume density independence during the estuary rearing stage (e.g., NOAA 2010)
- Estuary and early ocean survival often lumped into one annual estimate (e.g., NOAA 2013).
- Preliminary models with separate step for estuary stage include only the effects of avian predation (NOAA 2013).



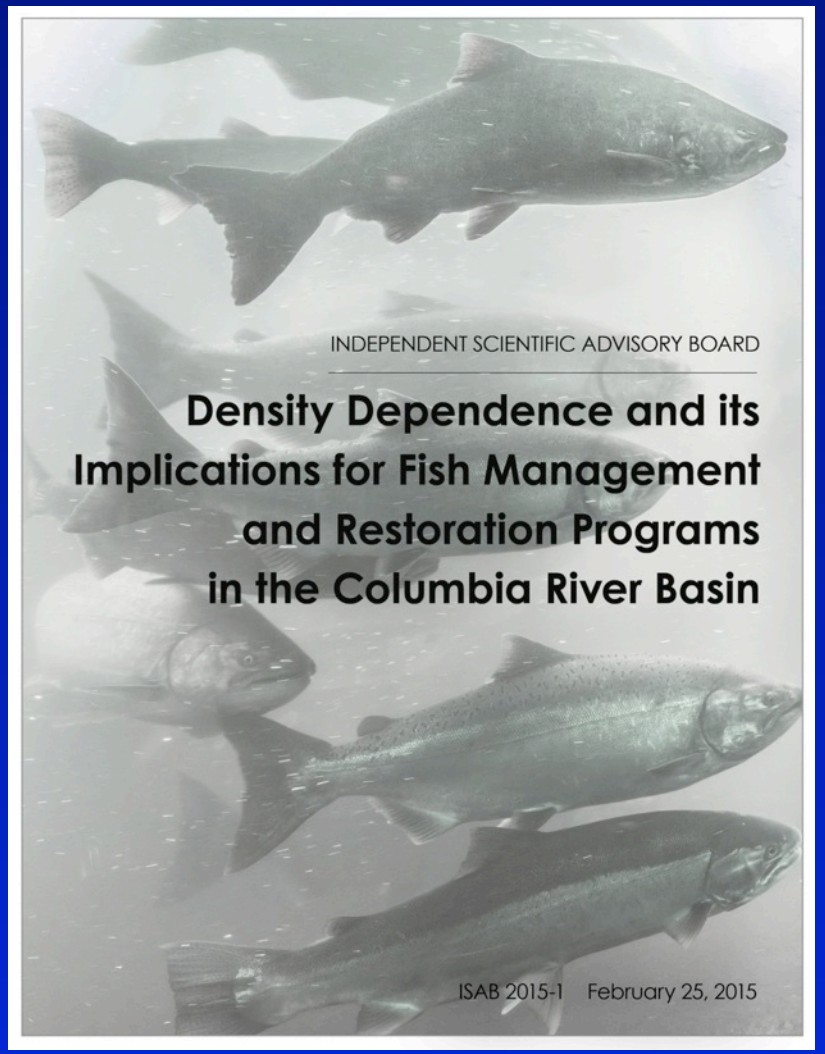
Research in other estuaries

- Skagit R. investigation of density-dependent movements of natural-origin juvenile Chinook along the freshwater–estuary continuum (Beamer and Larsen 2004, Beamer et al. 2005)
- Results show larger fish (which have higher survival) force smaller fish out of the prime habitat



ISAB Estuary Stage Conclusions

- Density-dependent processes in the estuary “suspected” to contribute to overall density-dependent regulation of salmon
- Important information gap because a key goal is to restore estuary habitat for salmon
- Evaluation of restoration activities against current management goals may be confounded if density dependence in the estuary is not considered.



OCEAN REARING STAGE

- Unlimited ocean carrying capacity was original justification for industrial-scale hatchery production
- Growing body of evidence has established the importance of density-dependent ocean growth & survival

Juvenile salmonids released by Columbia R. Basin hatcheries, 1877-2010

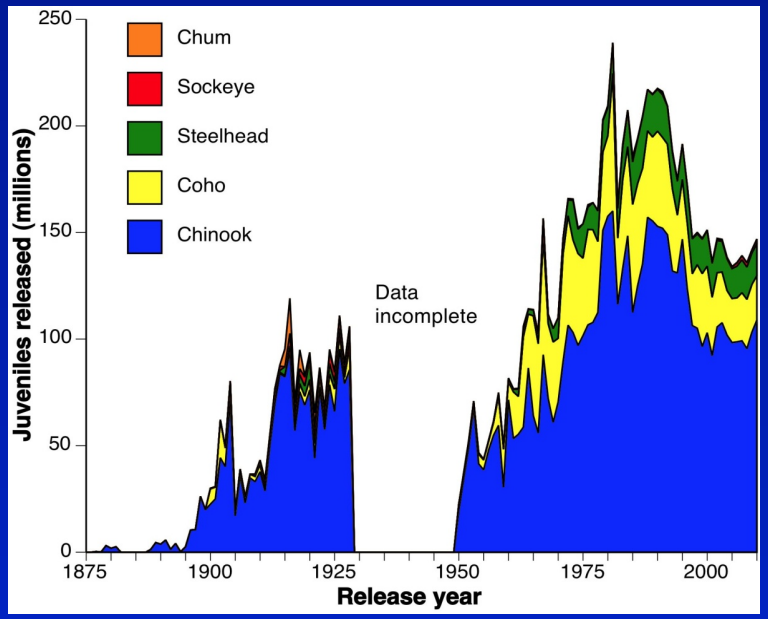


Fig. source: ISAB 2015-1

Important Conclusions--Past Reviews

- Both climate effects on salmon carrying capacity and density-dependent effects on growth & survival are important (Nielson & Ruggerone 2008)
- Large production of hatchery fish in the Columbia River is a potential source of competitors for listed ESU's (NMFS 2014)
- Industrial-scale hatchery releases can result in competition & reduced growth of salmon populations that share common ocean feeding grounds (Holt et al. 2008)

Total N. Pacific releases of juvenile hatchery salmon ~5 billion/yr

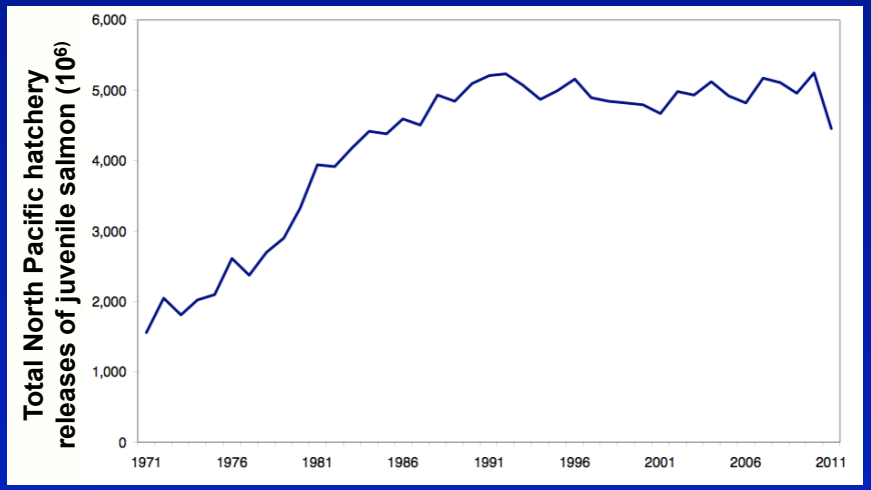
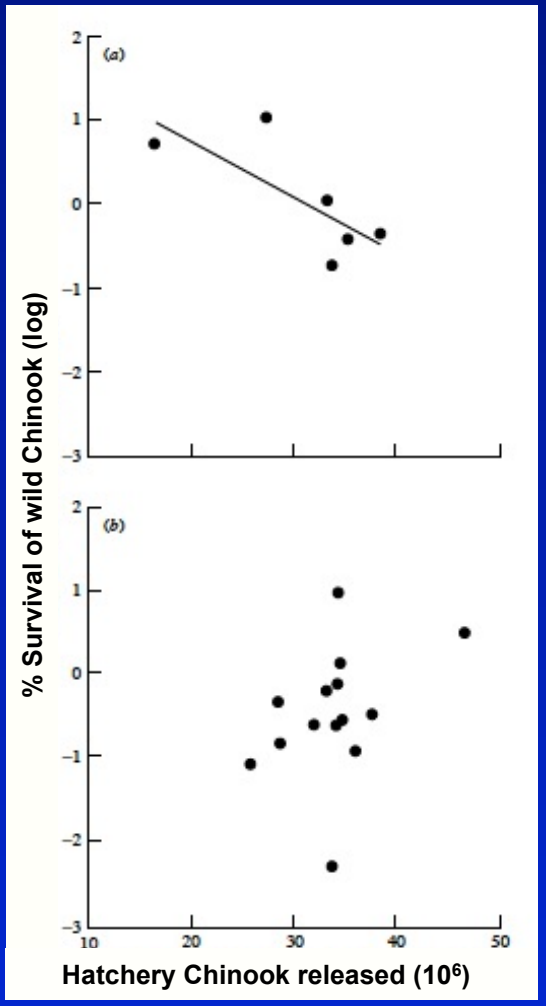


Figure source: Irvine et al. 2012

Few studies directly test density effects for Columbia River Salmon in the ocean

- Hatchery spring Chinook compete with natural-origin salmon, when ocean conditions are poor (Levin et al. 2001)
- Forage-fish & predator densities (increases) in coastal ocean strong predictors survival (decrease) of hatchery & natural-origin Snake R. spring/summer Chinook (Holsman et al. 2012)
- No evidence of density dependence among conspecifics (UCR summer/fall Chinook), but top-down effects important (Miller et al. 2013)

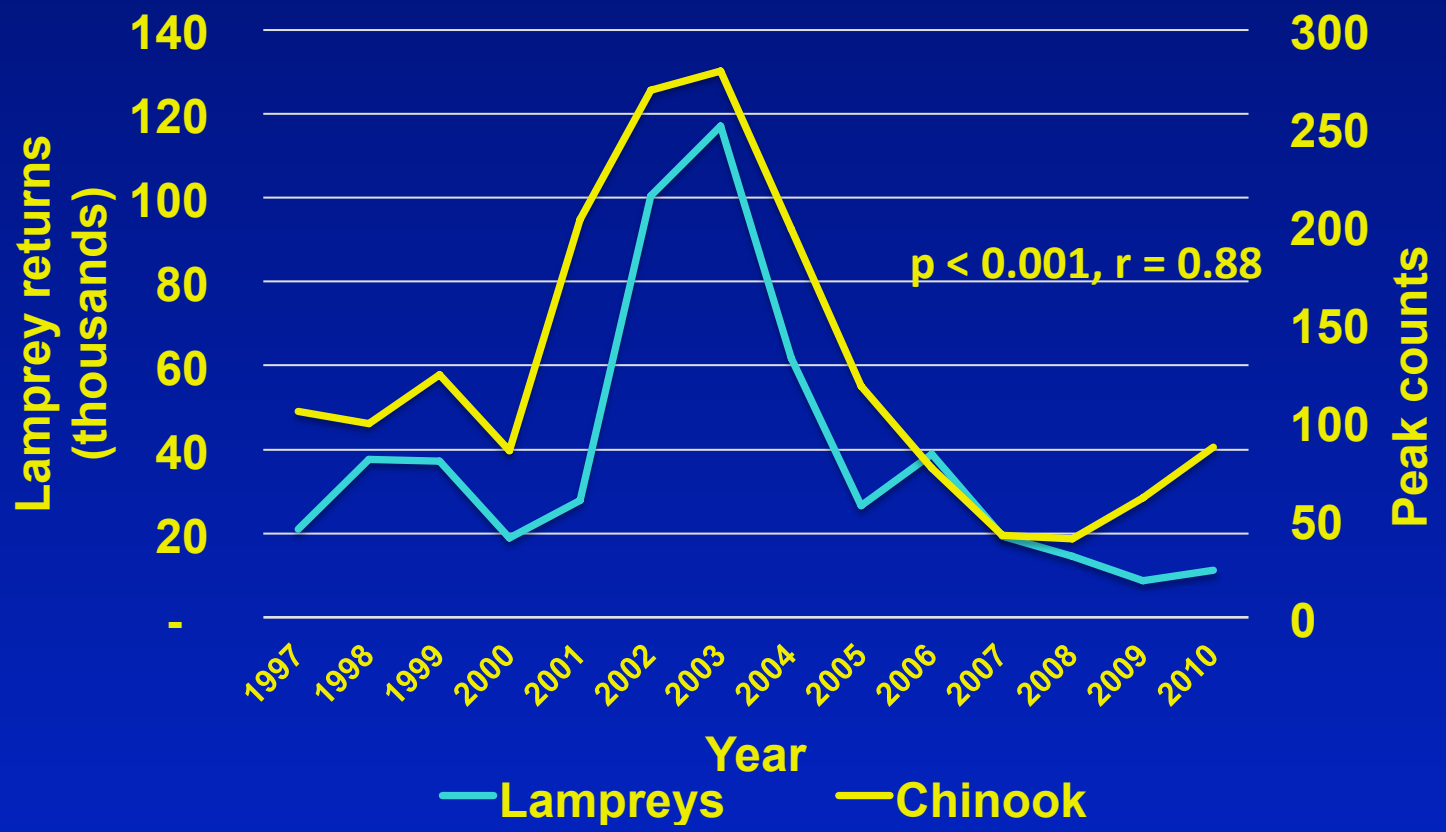


Source: Levin et al. 2001

ISAB Ocean Stage Conclusions

- Lack of information on density-dependent effects in the ocean is an important information gap that might help explain abundance patterns of natural salmonid resources in the Columbia River Basin.
- If density dependence limits abundance, then we may need to take a harder look at the effects of large-scale hatchery production, especially during periods of low ocean productivity.

Pacific Lamprey & Host Abundance



Lamprey counts at BON correlate positively with abundance of Chinook & 4 others ocean hosts. Since 1950's, ocean hosts have decreased by 68%, lamprey returns decreased by 65% -- Murauskas et al. (2013)

Pacific Lamprey
Conclusions & Recommendations

- Pacific lamprey populations in the Columbia Basin have declined sharply in the past 40 years.
- Lamprey is a key component of the Columbia food web as both prey (e.g., pinnipeds) & predator but little known about DD effects.
- Initiate a concerted effort to gather information that would help the recovery of this species.
- Consider lessons learned -- supplementation & DD of salmonids -- when planning future actions to propagate and translocate (i.e., supplement) lamprey within the Basin.

Why is Density Dependence Observed at Low Abundances?
Summary of Salmon Findings

- Density may not be so low for some species because accessible habitat has been greatly reduced.
- Degraded habitat quality has reduced productivity & capacity.
  - loss of salmon nutrients (carcasses) for many decades in “pristine” areas.
- Spawning distribution may be clumped: fish not fully utilizing available habitat.
- Natural spawning of hatchery fish may reduce capacity or reduce intrinsic productivity of the natural population.

Conclusion:

Density dependence may constrain salmon population recovery.

Overall Recommendations

- Account for density effects when planning and evaluating habitat restoration actions.
- Establish biological spawning escapement objectives (reference points).
- Balance hatchery supplementation with the Basin's capacity to support existing natural populations by considering density effects on the abundance and productivity of natural origin salmon.
- Improve capabilities to evaluate density dependent growth, dispersal, and survival by addressing primary data gaps.

Questions?

"Nobody goes there anymore. It's too crowded."

Y. Berra 1998