Northwest **Power** and
Conservation Council

April 28, 2015

MEMORANDUM

TO: **Fish and Wildlife Committee**

FROM: **Erik Merrill and Jim Ruff**

SUBJECT: **Follow-up Discussion on ISAB Report - Density Dependence and its Implications for Fish Management and Restoration Programs in the Columbia River Basin**

BACKGROUND:

Presenters: Bob Naiman, ISAB Chair, Greg Ruggerone, ISAB Vice-Chair, and other ISAB members on the phone

Summary: In response to a March 2014 assignment from the Council, NOAA Fisheries, and Columbia River Indian tribes, the Independent Scientific Advisory Board (ISAB) reviewed the implications of density dependence in fish populations in the Columbia River Basin.

The ISAB presented its Density Dependent Report at the Council's March meeting, but the Council and the ISAB did not have time to fully discuss the implications of the report for the Fish and Wildlife Program. The May 5th Fish and Wildlife Committee discussion is intended to provide an opportunity for an in-depth dialogue on the report. In addition to questions raised during the committee meeting, the ISAB will address discussion items identified by the Council before the meeting and issues raised at several other presentations that the ISAB has given to the tribes, NOAA Fisheries, and others since the March presentation to the Council.

851 S.W. Sixth Avenue, Suite 1100
Portland, Oregon 97204-1348
www.nwcouncil.org

Steve Crow
Executive Director

503-222-5161
800-452-5161
Fax: 503-820-2370

The ISAB's key findings include:

- Many salmon populations throughout the interior of the Columbia River Basin are experiencing reduced productivity associated with recent increases in natural spawning abundance, even though current abundance remains far below historical levels. Density dependence is now evident in most of the ESA-listed populations examined and appears strong enough to constrain their recovery. This fact raises the question: *Why is density dependence more evident than expected at low abundances?*
- The ISAB reanalyzed the admittedly limited historical data to better evaluate the potential capacity for salmon and steelhead in the Columbia Basin before hydrosystem development. The ISAB concludes that historical all-species capacity was likely in the range of 5 to 9 million adult fish per year, which is less than previously published estimates (e.g., 7.5 to 16 million adults per year) but still much higher than current abundance levels (~2.3 million fish per year during 2000-2012).
- Evidence for strong density dependence at current abundance suggests that habitat capacity has been greatly diminished. Roughly one-third of the Basin is no longer accessible to anadromous salmon, and continuing changes to environmental conditions stemming from climate change, chemicals, and intensified land use appear to have further diminished the capacity of habitat that remains accessible. Density dependence was also observed in some less altered watersheds.
- Hatchery releases account for a large proportion of current salmon abundance. Total smolt densities may be higher now than historically. By creating unintended density effects on natural populations, supplementation may fail to boost natural origin returns despite its effectiveness at increasing total spawning abundance.
- Identifying mechanisms that contribute to density dependence in particular habitats and life stages—such as limitations in spawning habitat, rearing habitat or food supply, or predator-prey interactions—can help to guide habitat restoration and population recovery actions.
- Understanding density dependence (e.g., stock-recruitment relationships) in salmon populations is central to evaluating responses to recovery actions and for setting spawning escapement goals that will sustain fisheries and a resilient ecosystem.

The ISAB's key recommendations include:

Anadromous salmonids
- Account for density effects when planning and evaluating habitat restoration actions.
- Establish biological spawning escapement objectives that account for density dependence.

- 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.

Non-anadromous salmonids

- Recognize that carrying capacity for non-anadromous salmonids can be increased by restoring in-stream structure and riparian vegetation.
- Recognize that carrying capacity for non-anadromous salmonids can be reduced through competitive interactions with stocked hatchery trout or invasive non-native trout.
- Consider the probable effects of density on survival, emigration, growth, and size/age at maturity when developing angling regulations to achieve conservation and recreational goals.

Sturgeon

- Consider habitat capacity and the probable effects of density on growth and survival when developing stocking programs to conserve white sturgeon.

Lamprey

- Initiate studies to gather information about current densities of Pacific lamprey in the Basin and to learn about density dependent processes that might thwart efforts to promote their recovery.

- Consider lessons learned about supplementation and density dependence in anadromous salmonids when planning future actions to propagate and translocate (i.e., supplement) lamprey within the Basin.

Relevance: Understanding density dependence—the relationship between population density and population growth rate—is important for effective implementation of the Columbia River Basin Fish and Wildlife Program, biological opinions, recovery plans, and tribal programs. Information on how density dependence limits fish population growth and habitat carrying capacity is vital for setting appropriate biological goals to aid in population recovery, sustain fisheries, and maintain a resilient ecosystem. Habitat restoration and population recovery actions can be planned and implemented more effectively by understanding mechanisms that cause density dependence in particular cases, such as limited food supply, limited rearing or spawning habitat, or altered predator-prey interactions.

Workplan: ISAB reviews are called for in the Council's work plan and the Fish and Wildlife Program.

More Info: www.nwcouncil.org/fw/isab/isab2015-1

Questions

Questions regarding ISAB Density Dependence Report

<u>Phil Rockefeller</u>

I wonder about the use of this term. It appears to be a convenient label for a variety of conditions which limit either the number or the size/strength of hatchery populations and of native stocks in shared habitat.

Question 1:

Why use the label at all?

Question 2:

Can they define and explain the sweet spot between too few and too many fish in a given reach?

Question 3:

Is the DD effect self-correcting, so not really something we need to manage?

Oregon Department of Fish and Wildlife (ODFW)

The ISAB was asked to review the implications of density dependence in Columbia Basin salmon and steelhead populations. One of the concerns across the basin is that many interior salmon populations have adult recruits / spawner values that are persistently below replacement (R/S < 1.0) even though adult abundance is low. The ISAB was asked to consider whether density dependence was contributing to this pattern, and whether density dependence might limit recovery of ESA-listed populations.

Density dependence is the relationship between population density and population growth rate. Adult recruits / spawner are influenced by both fresh water productivity (production of smolts) and the survival of the smolts to adults (SARs). At abundances below carrying capacity, density dependence provides population resiliency as increased recruits/spawner facilitates population growth. At carrying capacity, population abundance should approach a stable equilibrium where productivity and survival are sufficient for spawning adults to replace themselves. The ISAB did a credible job of explaining these population dynamics.

We have several questions that warrant further discussion:

1. The factor that might limit recovery is whether freshwater carrying capacity is too low to support a population at a viable abundance. Has the ISAB compared the capacities of populations, measured by stock-recruitment functions, to abundance delisting goals set for them in recovery plans? If so what were the results, if not then should this comparison be completed to better understand capacity limitations on recovery.

2. One of the questions originally posed to the ISAB was "*How can density dependent limitations be ameliorated as a means to enhance population rebuilding and recovery?*" Could the ISAB expand their response to this question further to provide management actions that could help increase capacity, equilibrium abundance, productivity and resilience as ways to ameliorate the current limitations? Those actions should include steps to improve wild freshwater productivity (production of smolts), SARs, and increased diversity.

3. We generally support habitat improvements, especially in populations where freshwater capacity appears to be impaired and too low to support recovery goals. However there are many populations that are in relatively pristine unaltered freshwater tributary habitat that are well below viability goals. If freshwater capacity is too low in these pristine habitats, the ISAB appears to recommend that we improve marine derived nutrient inputs into those areas. We believe that this can only be accomplished by improving SAR's to increase wild adult returns to those areas. Does the ISAB agree with this approach? Does it have alternative ideas?

4. We would like the ISAB to further expand on its discussion of smolts per spawner and SARs. The report includes a figure on page 130 that compares smolt to adult return and smolts per spawner. The ISAB discusses this largely from the perspective that observed SARs will require a certain level of smolts per spawner, but the ISAB ultimately concludes that major actions are necessary to increase the both smolts/spawner and SARs. Could the ISAB elaborate further on this discussion?

Stacy Horton

Topic: Improvements in the life-cycle

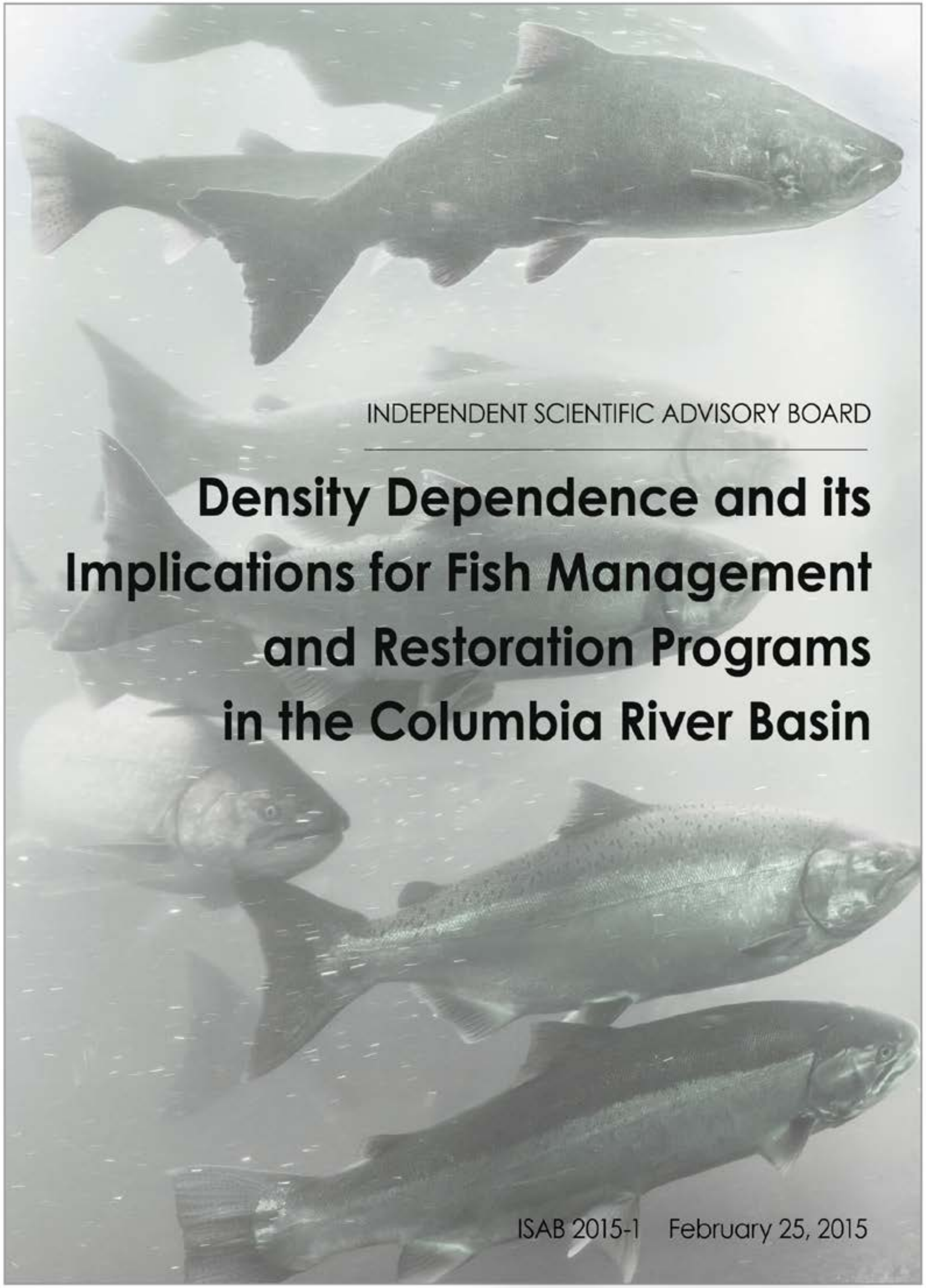
1. Spawning fish often utilize the same spawning areas- even when other habitat appears available- something the ISAB referred to as 'clumping'. Superimposition of the eggs can occur. Does this phenomena reduce the effectiveness of habitat improvement to enhance this particular part of the life history? (Pg 198)
2. There are escapement targets used by the states in fisheries- why aren't these adequate? Should escapement numbers include both minimum and maximum targets?
3. Why do you think we're seeing density dependence in less altered watersheds? If we're already seeing density dependence in reference streams, does it compromise their usefulness?
4. Your report notes on pg 124 that the escapement goal of spring Chinook counted at Bonneville Dam have been met or exceeded each year since 2008. Shouldn't we also be concerned with weaker populations like upper Columbia spring Chinook?
    a. Is it possible endangered populations like upper Columbia spring Chinook are experiencing depensatory density dependence (a populations growth rate *decreases* at low densities, opposite of what's expected at low population levels) from pinniped and avian predation?
    b. Is it possible that pinniped predation is counteracting positive reactions to other areas of improvement in the life cycle?
5. What can we do to improve or expand life history diversity? Can we overcome novel ecosystems?

Topic: Improvements in habitat

1. How much can habitat investments improve carrying capacity?
2. To demonstrate changes in habitat capacity, are there specific fish measurements that BPA-funded projects should collect and report on? For example, smolt at age; size at emergence; size at smolt; adult escapement; etc. What are the key metrics that should be measured and reported at each life stage? Is that data being collected on a broad scale in the Columbia River basin?
3. Can we overcome the increase in smolt abundances with habitat improvements and expanded access?
4. Have you seen evidence that the addition of nutrients to a stream will improve juvenile growth?
5. Have IMW's demonstrated the value of habitat improvements as a strategy to counteract density dependence?

Topic: Other

1. You note on page 139 that 25 of 27 spring/summer Chinook populations exhibit strong density dependence. Is there something we can learn from the two populations that are not showing signs of density dependence?
2. On page 140-141, the report states: "In addition, increases in both forage-fish and predator densities in coastal waters are strong predictors of large decreases in survival of hatchery and (especially transported) natural-origin Columbia River Chinook salmon." Why *especially transported?*
3. The concern seems to be about returns per spawner of less than 1. But even if 10,000 hatchery fish on the spawning grounds only returns 8,000 natural origin fish, isn't that still better than no hatchery fish?
4. Is the science clear that lower productivity is caused by the number of fish (density) rather than the type of fish (hatchery). For example, can you be sure that if we had the same returns but all fish were natural origin that productivity would still be low? If the problem could be hatchery fish, aren't the policy solutions different?



ISAB Contributors

J. Richard Alldredge, Ph.D.
Kurt D. Fausch, Ph.D.
Alec G. Maule, Ph.D.
Katherine W. Myers, Ph.D.
Robert J. Naiman, Ph.D.
Gregory T. Ruggerone, Ph.D.
Laurel Saito, Ph.D., P.E.
Dennis L. Scarnecchia, Ph.D.
Steve L. Schroder, Ph.D.
Carl J. Schwarz, Ph.D.
Chris C. Wood, Ph.D.,

ISAB Ex Officio & Coordinator

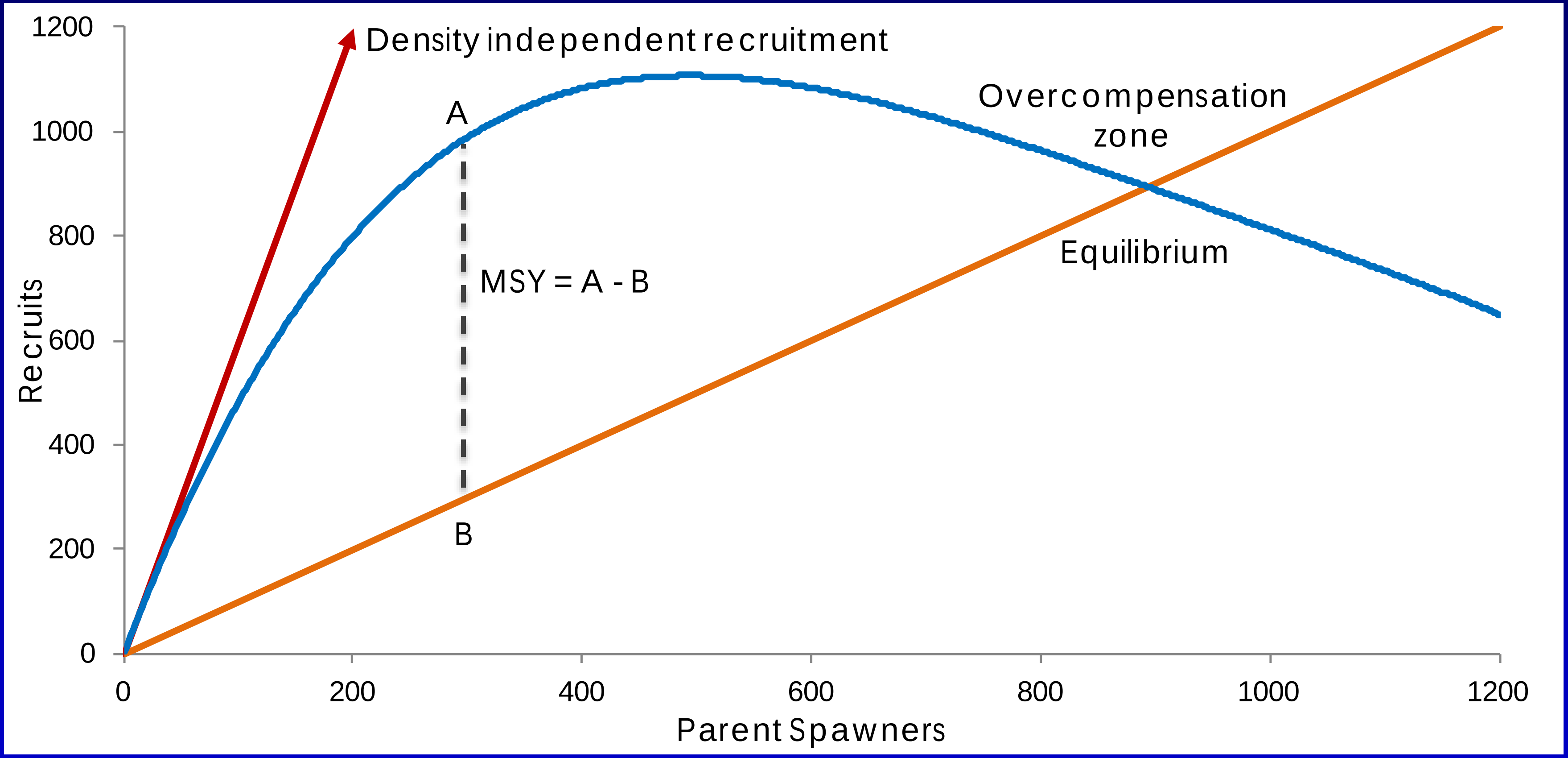
Michael Ford, Ph.D.
Jim Ruff, M.S., P.H.
Phil Roger, Ph.D.
Erik Merrill, J.D.

Presentation to Basin, April 2015

Key Finding

Density dependence is now evident in most of the ESA-listed populations examined and appears strong enough to constrain their recovery.

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.

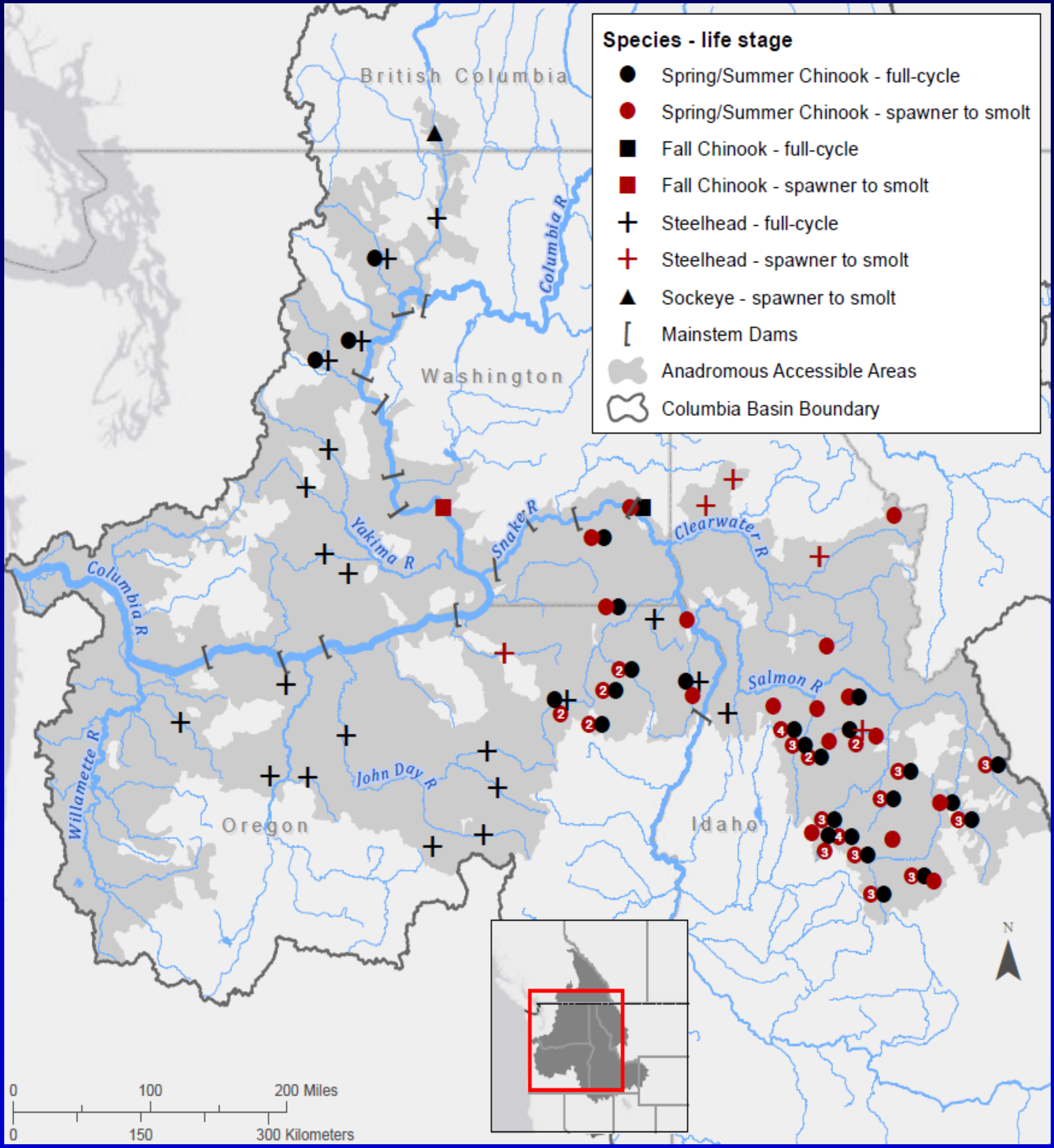
Key Recommendation

Account for density effects when planning and evaluating:

- Habitat restoration actions
  -- Improve action efficiency
- Hatchery supplementation
  -- Improve stock rebuilding & sustainability
- Spawning escapement goals
  -- Increase harvest of surplus hatchery fish
  -- Plan for additional nutrients via carcasses

Compensatory Density Dependent Studies: Where?

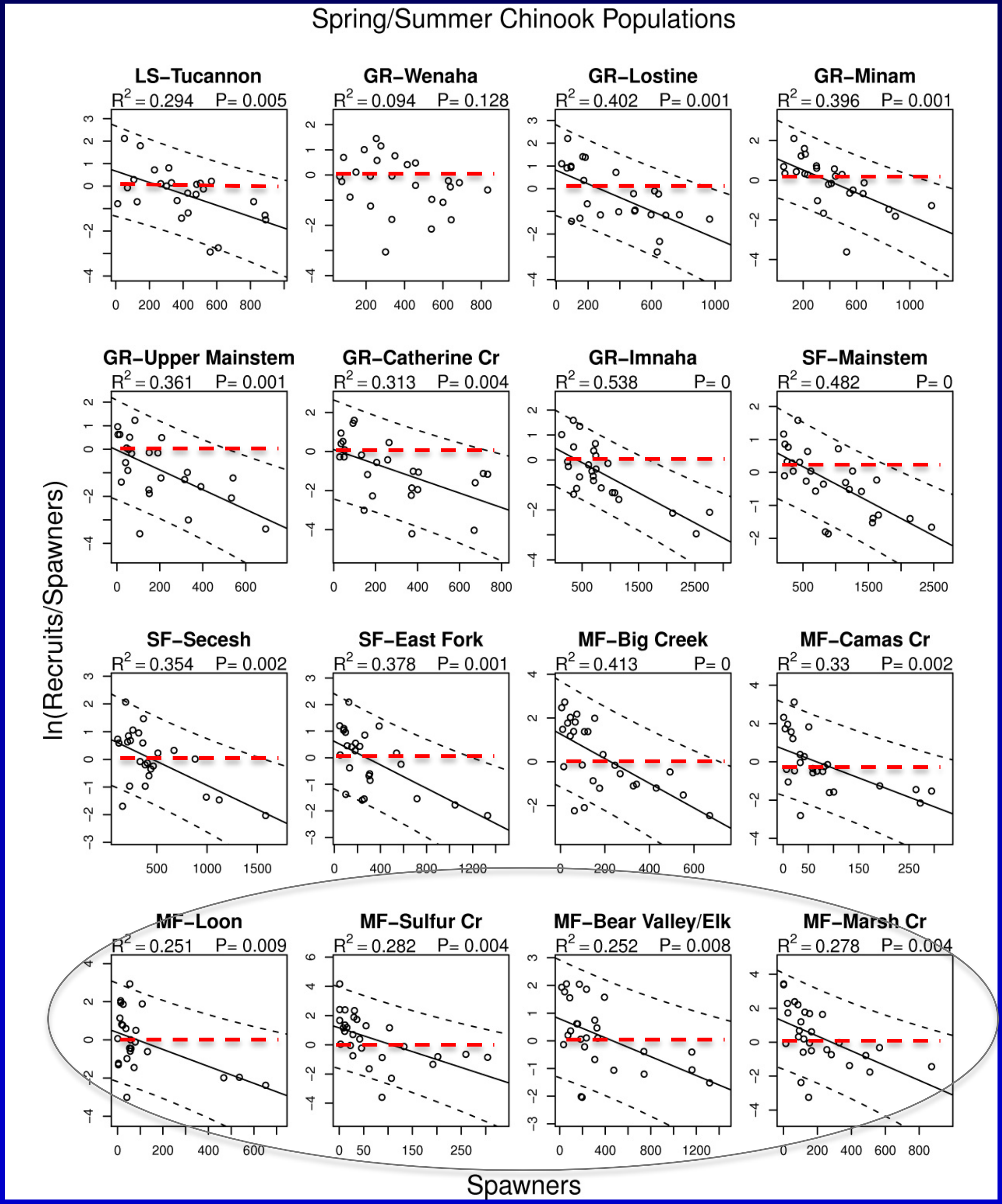
- Primarily spring/summer Chinook & steelhead in the interior.
- Few studies below Bonneville & during juvenile emigration.
- Few coho studies.



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

Life Cycle Density Dependence

- 25 of 27 Columbia R spring/summer Chinook populations: <u>strong DD.</u>
- Snake R fall Chinook: <u>strong DD</u>
- All 20 Interior Columbia River steelhead populations: <u>Strong DD.</u>
- <u>R/S often < 1</u> (must improve conditions to achieve recovery)
- <u>What life stage?</u>

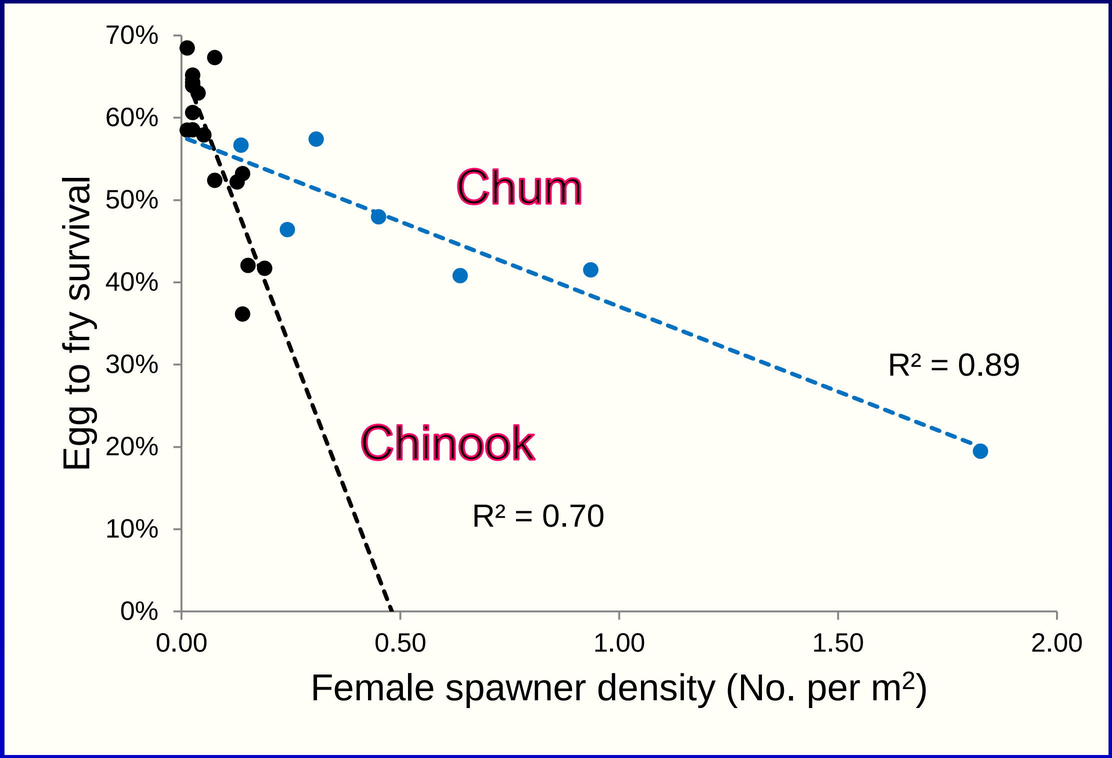


Source: Zabel & Cooney 2013

Spawning Stage: Chinook v. 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

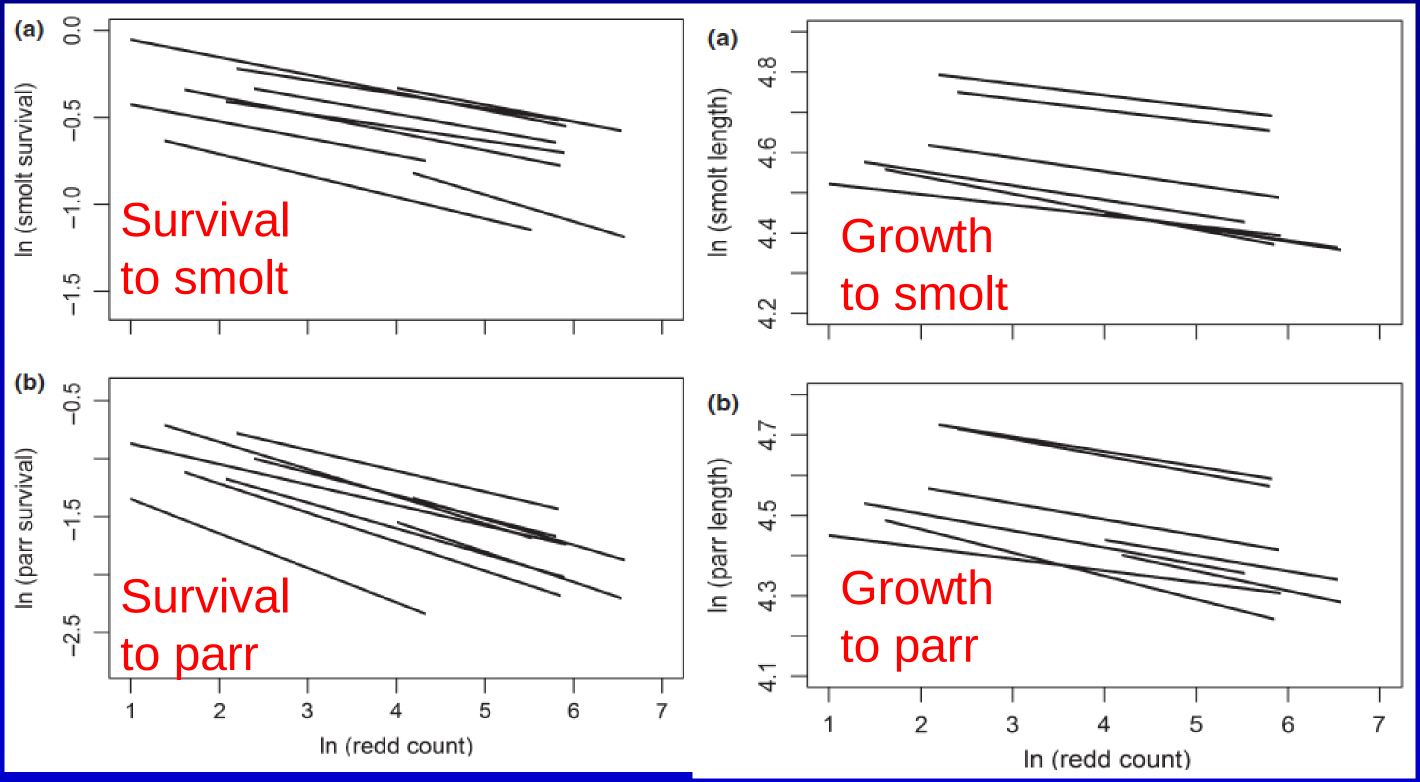


Source: Schroder 1974, Schroder et al. 2008

Spawner to Smolt Stage: Growth & Survival is Density Dependent

- Example: Snake R spring/summer Chinook
- 8 populations; other examples in report
- Density dependent dispersal observed & is key to recovery.

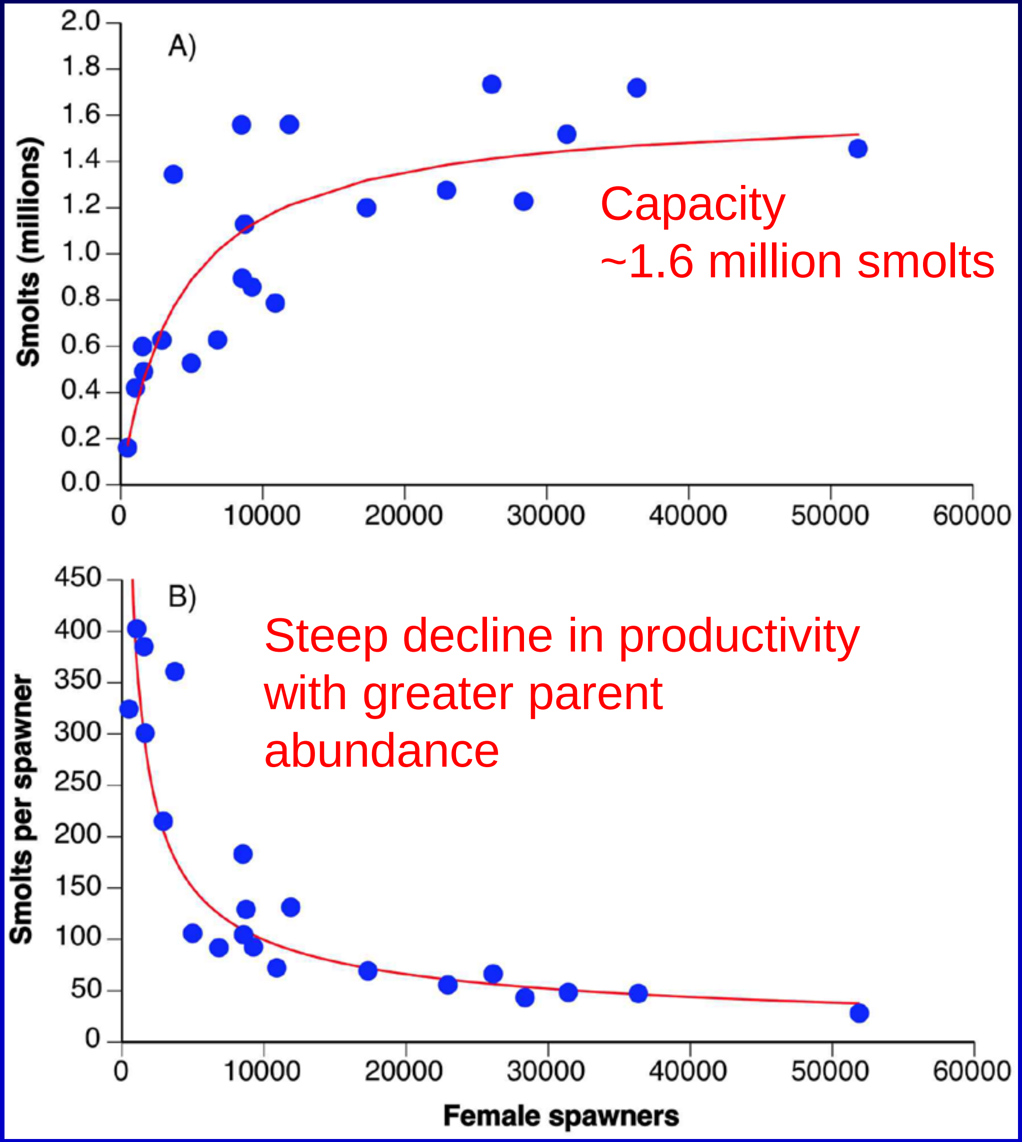
Density effects such as this can guide restoration actions



Walters et al. (2013a)

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



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

Key Finding

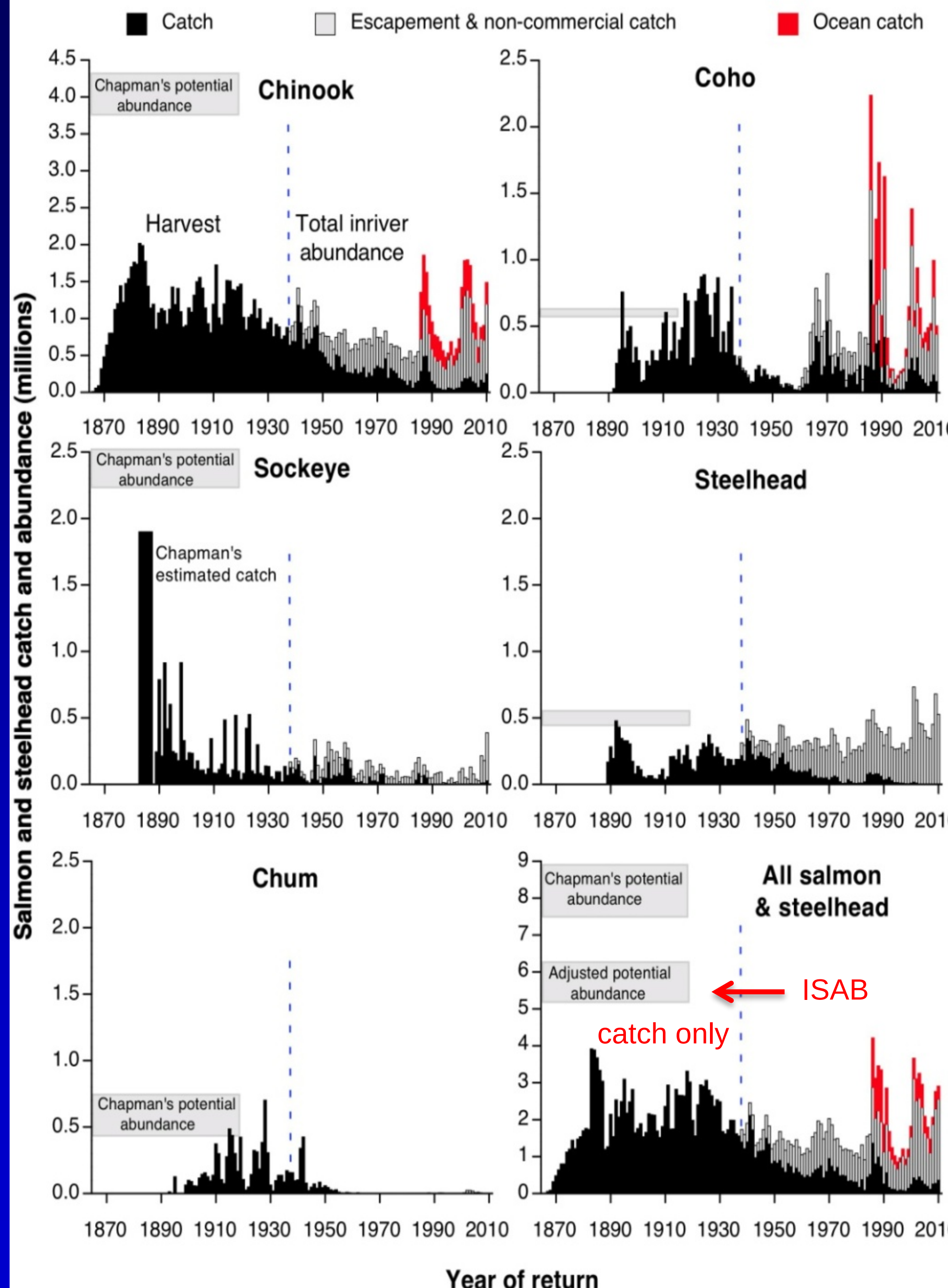
Density dependence is now evident in most of the ESA-listed populations examined and appears strong enough to constrain their recovery.

Why?   Aren't current abundances relatively low?

Pre-development Capacity of the Columbia River Basin

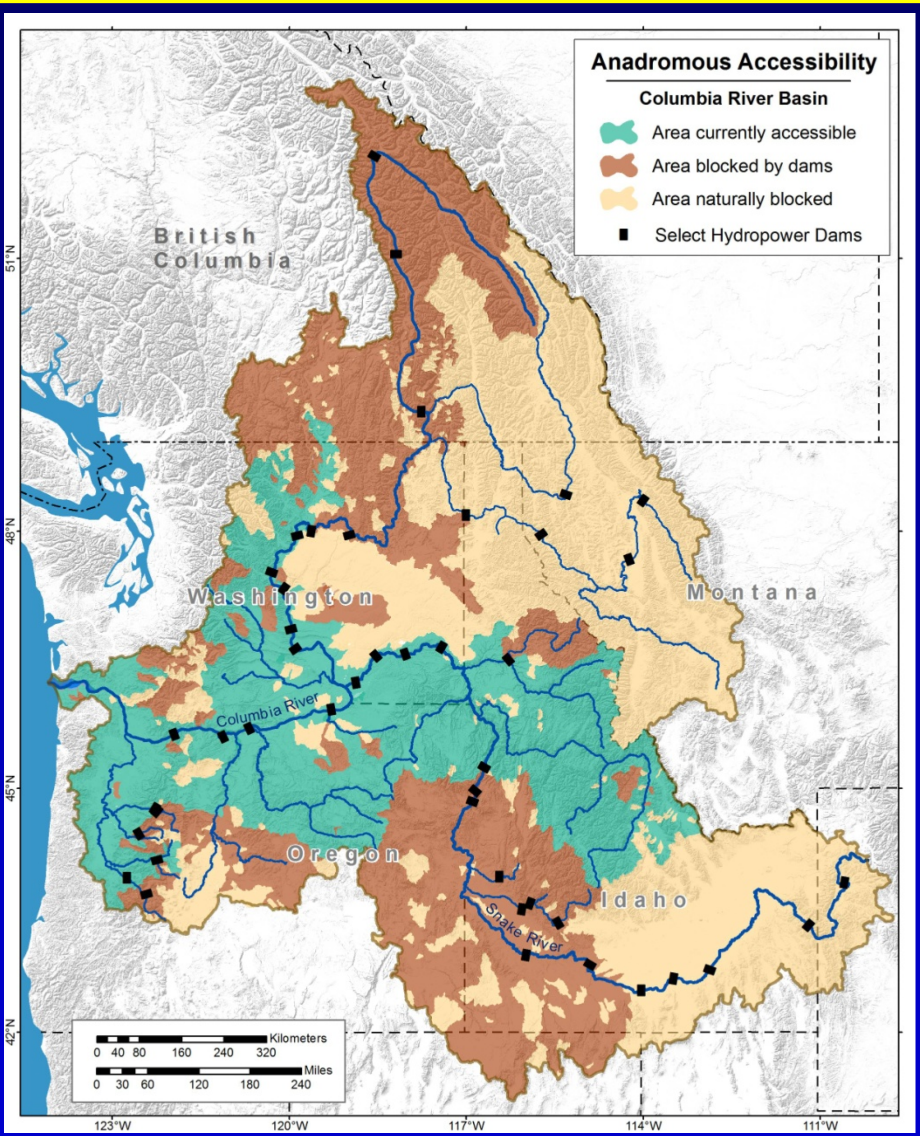
All Salmon & Steelhead

- Chapman (1986):
  7.5-8.9 million
- NPPC (1986): 9-16 million
- ISAB: ~~5-9 million
- Current abundance:
  2.3 million (2000-2012)



Area Blocked to Anadromous Salmon

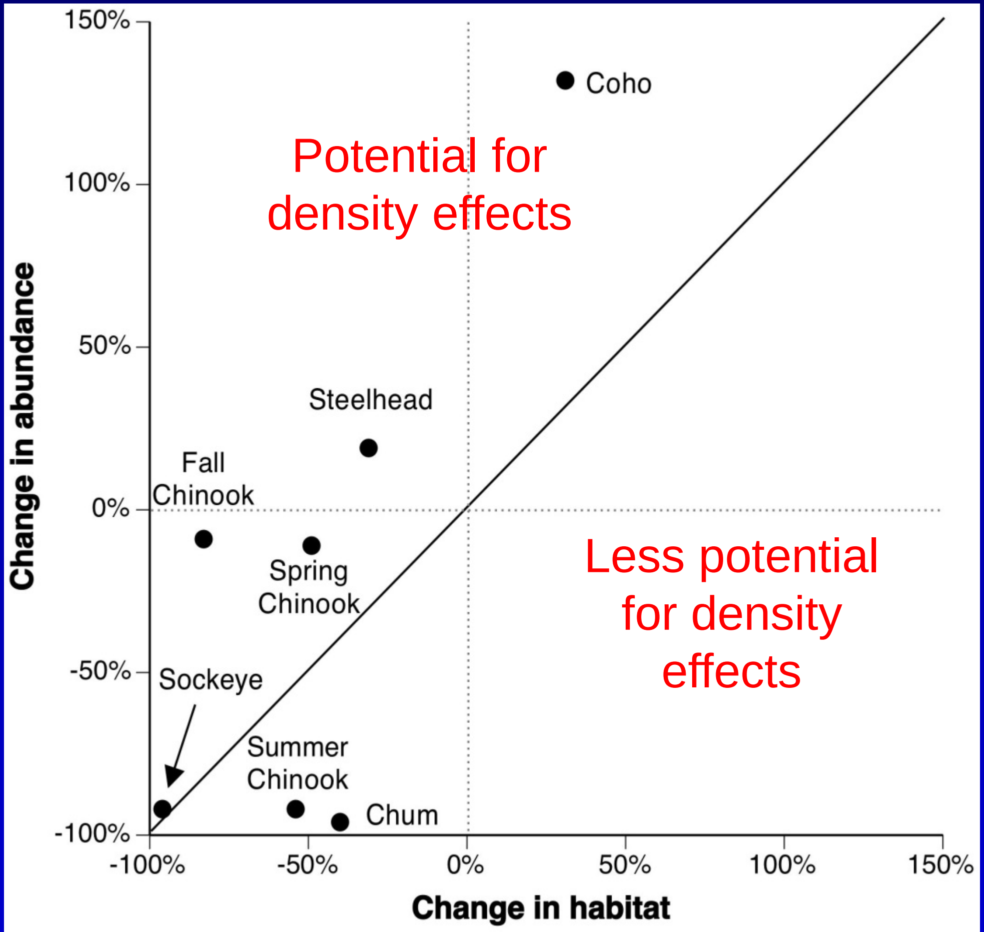
- 31% of previously accessible habitat now blocked.
- Impact varies by species.



Map produced for ISAB by Van C. Hare, PSMFC

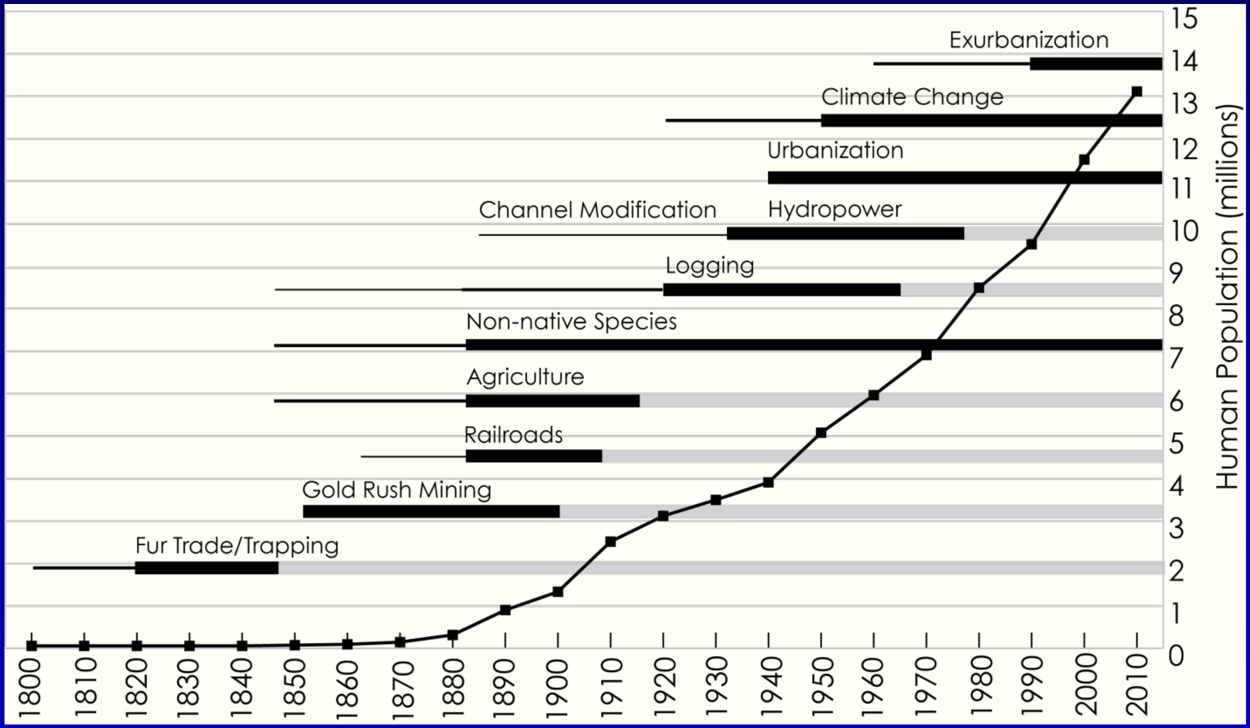
Could "density" (wild & hatchery salmon) be greater today?

- Initial evaluation of potential density effects.
- Change (%) in abundance versus accessible habitat: ~1850 to 1986-2010
- Spring & fall Chinook, coho, steelhead
- Caution!



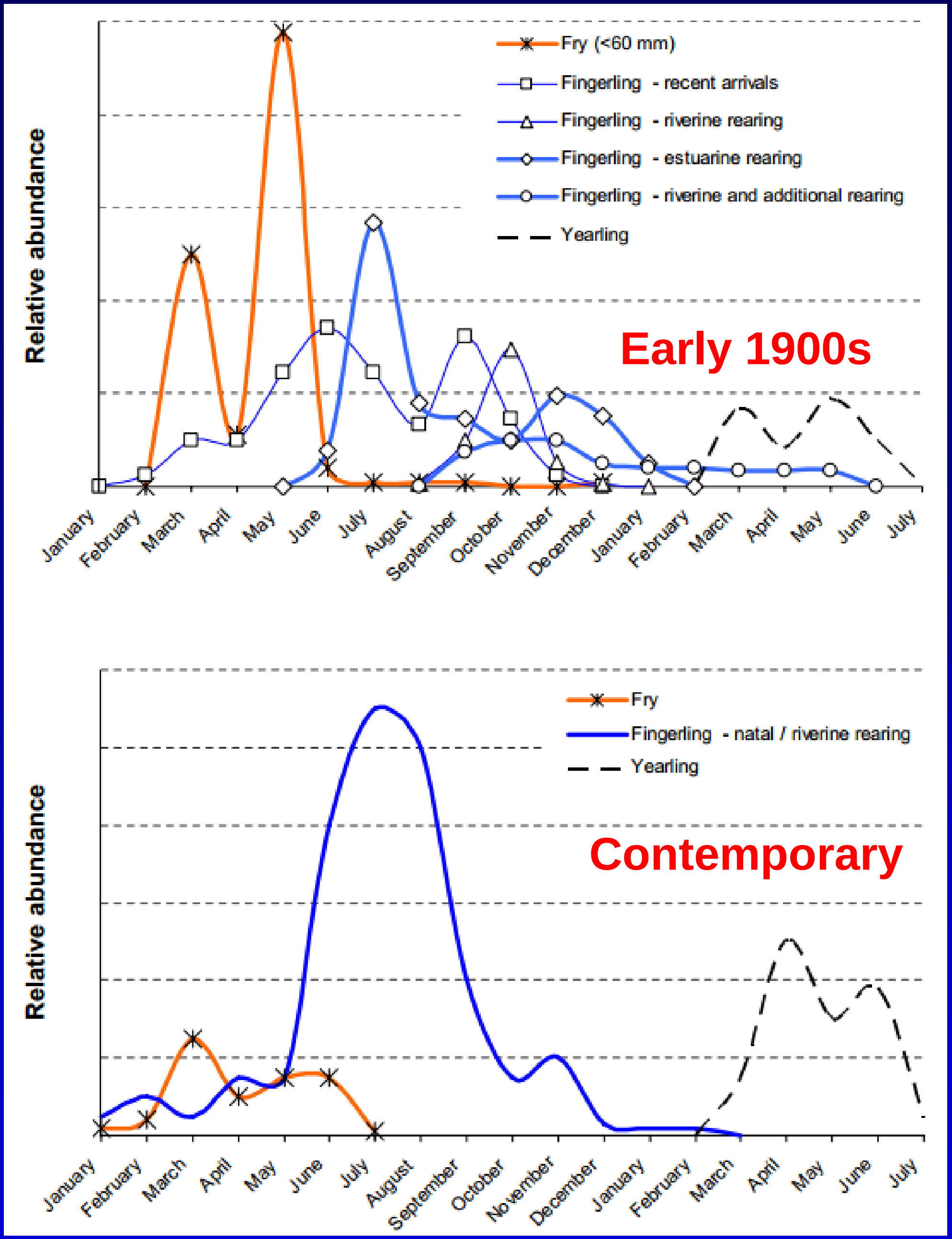
Columbia is Novel Ecosystem

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



Chinook life history diversity

- Loss of diversity concentrates fish in river and estuarine habitats, leading to potential density effects & lower overall capacity.
- Snake R spring/summer Chinook capacity decline: life history diversity?



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

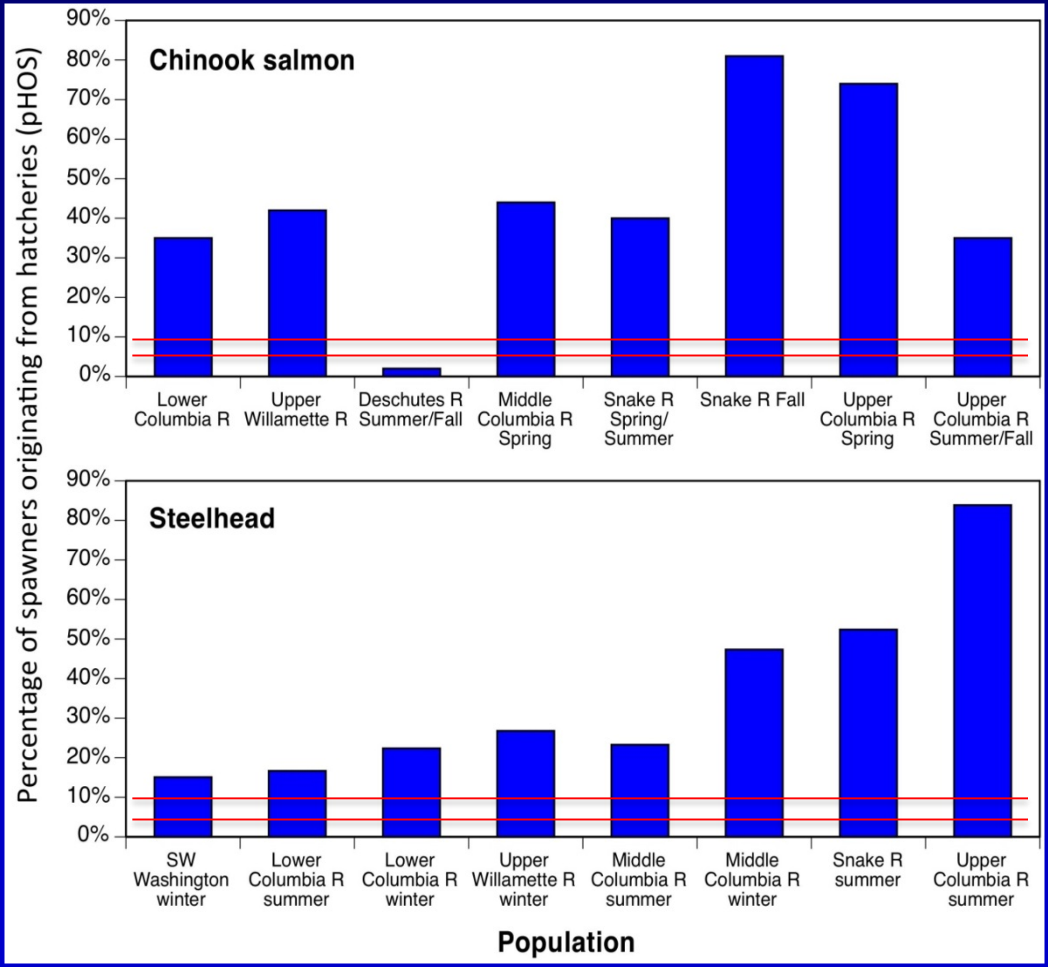
Key Findings (Anadromous) cont'd

Hatchery releases account for a large proportion of current salmon abundance

- Total smolt densities may be higher now than historically.
- But primary cause of strong density dependence at low abundance is altered habitat, including the hydrosystem.

Hatchery Contribution to Natural Spawners: Supplementation & Straying

- Supplementation & straying contribute to density effects
- Many spring/summer Chinook & steelhead not sustainable at higher densities
- Integrated hatchery approach not possible without sustainable natural population
- pHOS guidelines for segregated hatchery shown (red lines)



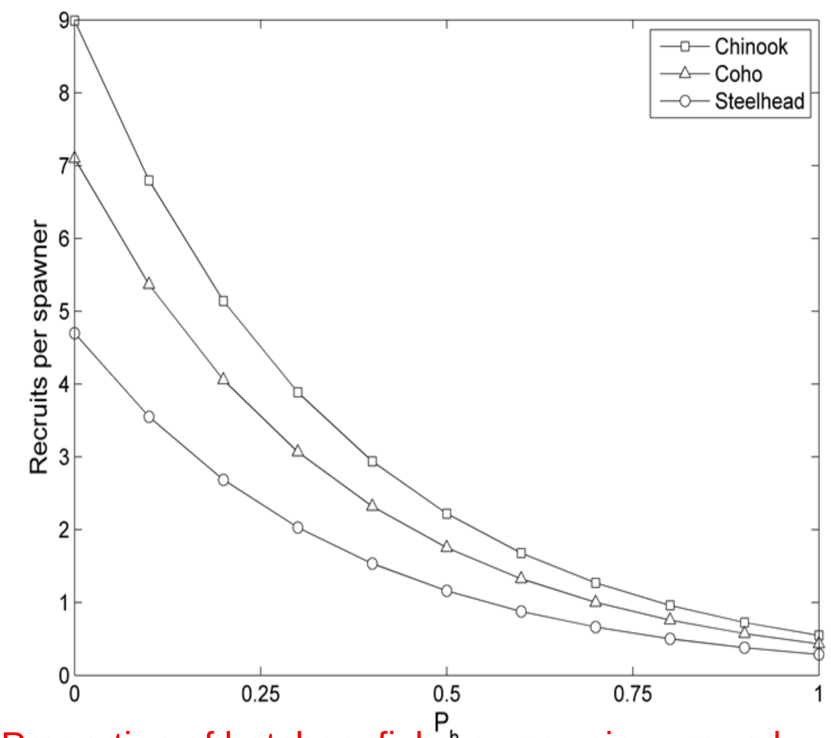
Modeled data provided by L. Mobrand, HSRG, February 2013.

“Supplementation” Effects on Recruitment

“Supplementation” lowers *intrinsic* productivity & resilience of Chinook, coho, steelhead

(20 yrs of data, 71 populations).

By creating unintended density effects on natural populations, supplementation may fail to boost natural origin returns despite its effectiveness at increasing total spawning abundance, e.g., Snake R spring/summer Chinook (Buhle et al. 2013, 2014).

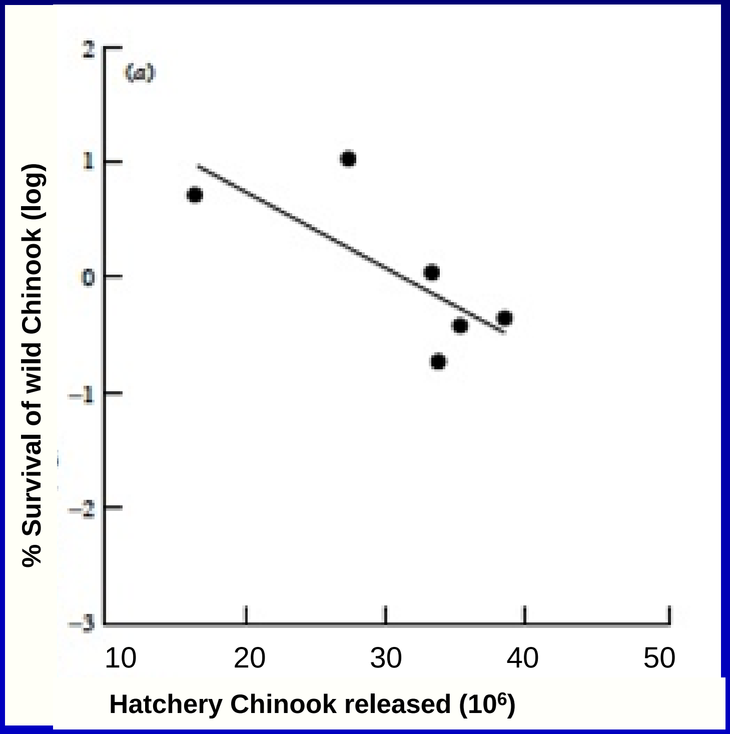


Proportion of hatchery fish on spawning grounds

Chilcote et al. (2013)

Estuary and Ocean Rearing

- Density dependence in estuary & ocean is a data gap for Columbia R species
- Evidence for density dependence in estuary and ocean found in other regions
- Estuarine habitat restoration in Columbia Basin focuses on habitat diversity and habitat capacity to support subyearling salmonids
- Spring Chinook survival at sea declined with hatchery Chinook releases but only with poor ocean conditions

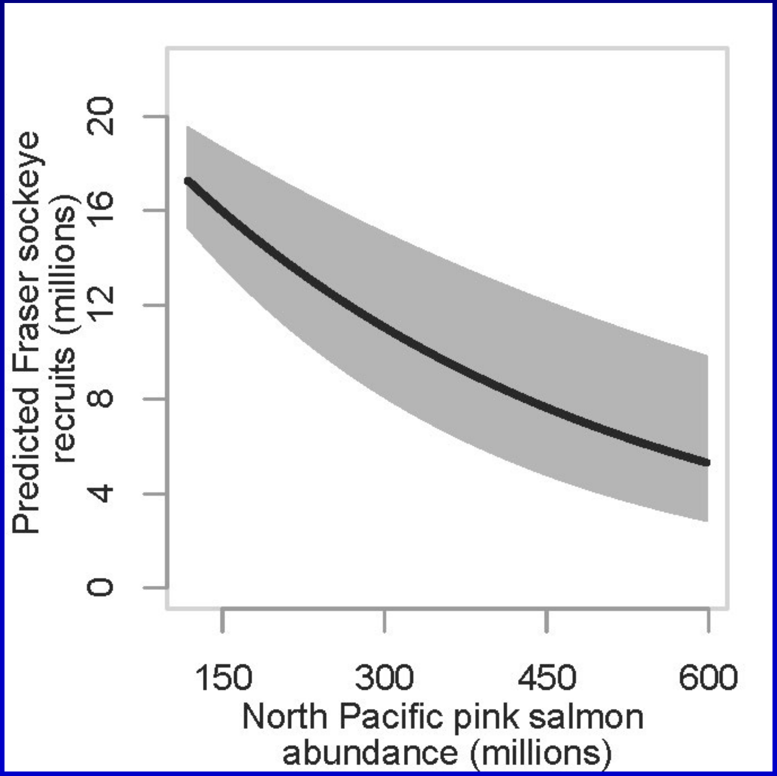


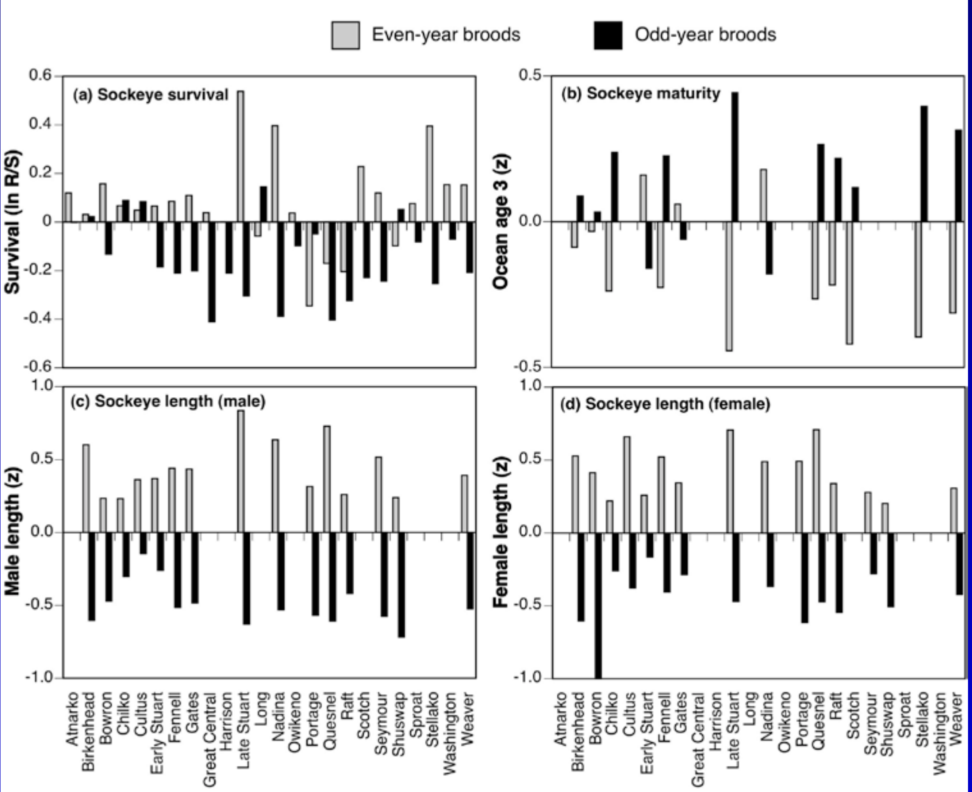
Source: Levin et al. 2001

Competition at Sea

Example: sockeye versus pink salmon

Fraser sockeye decline in relation to pink salmon abundance: abundance, growth, and age at maturation

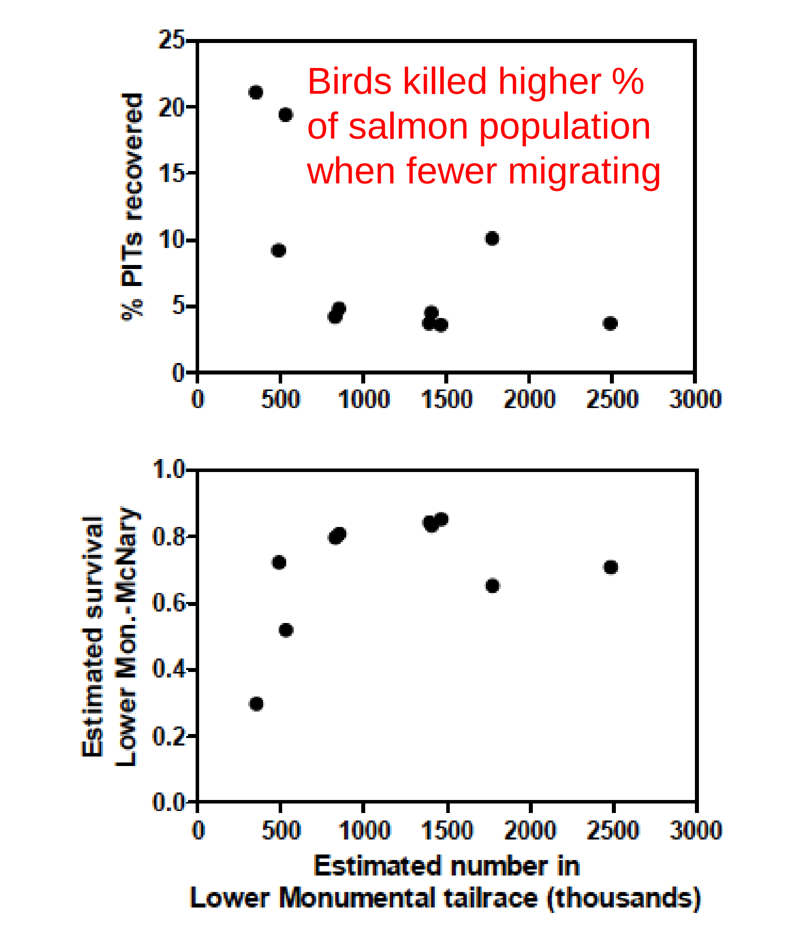




Source: Ruggerone and Connors 2015

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 management goal at Bonneville (115k) essentially met or exceeded each year since 2008. 2015??



Faulkner et al. (2008)

Habitat Restoration and Density Dependence: Improving Salmonid Populations Densities

- Quantify Carrying Capacity (e.g., Bioenergetic Models)
- Renewed Focus on Food Supplies, Phenology of Habitat Connectivity
- Understand Long-term Consequences of Hatcheries, Supplementation, and Harvest
- Eliminate Exposure to Harmful Chemicals
- Use Habitat Restoration to Support a Diversity of Salmon Life Histories

Naiman et al. 2012, Naiman 2013, Rieman et al. 2015

Habitat Restoration and Density Dependence: Improving Salmonid Populations Densities

- Attention to Social-Ecological Principles:
  - ✓ ecosystem perspective and resilience
  - ✓ broad public support
  - ✓ collaboration and integration
  - ✓ capacity for learning and adaptation

Naiman et al. 2012, Naiman 2013, Rieman et al. 2015

Recommendations Recap (All species)

- Understand why density dependence occurs in particular habitats and life stages of fish, such as limitations in spawning habitat, rearing habitat or food supply, or predator-prey interactions. This can help guide habitat restoration and population-recovery actions.
- Set biologically-based spawning escapement goals or harvest rates that sustain fisheries and also a resilient ecosystem & use goals as a reference points.

Recommendations Recap, cont'd (All species)

- Account for density effects when evaluating habitat restoration actions.
- Balance hatchery production with the Basin's capacity to support existing natural populations.
  - Anadromous salmonids
  - Trout
  - Sturgeon
  - Lamprey

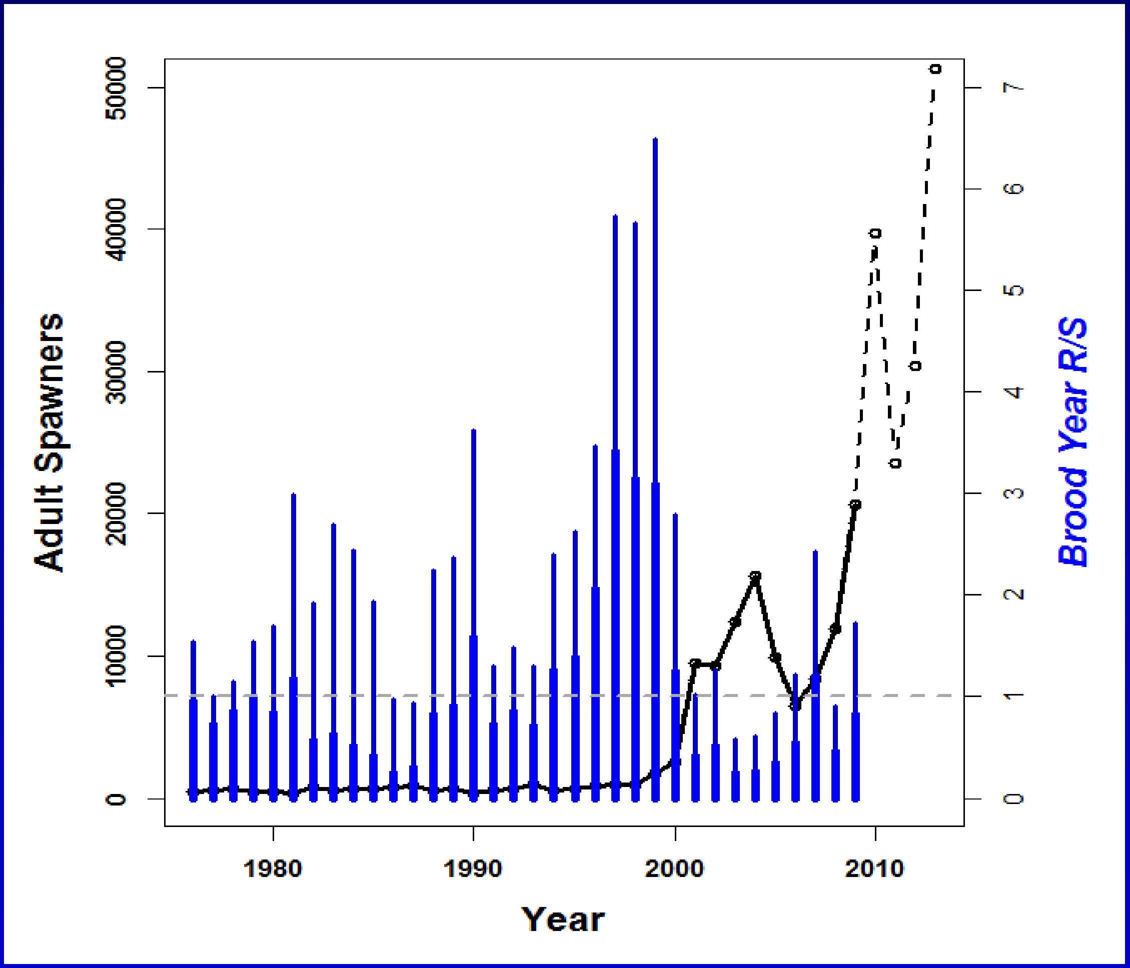
Questions?

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

Y. Berra 1998

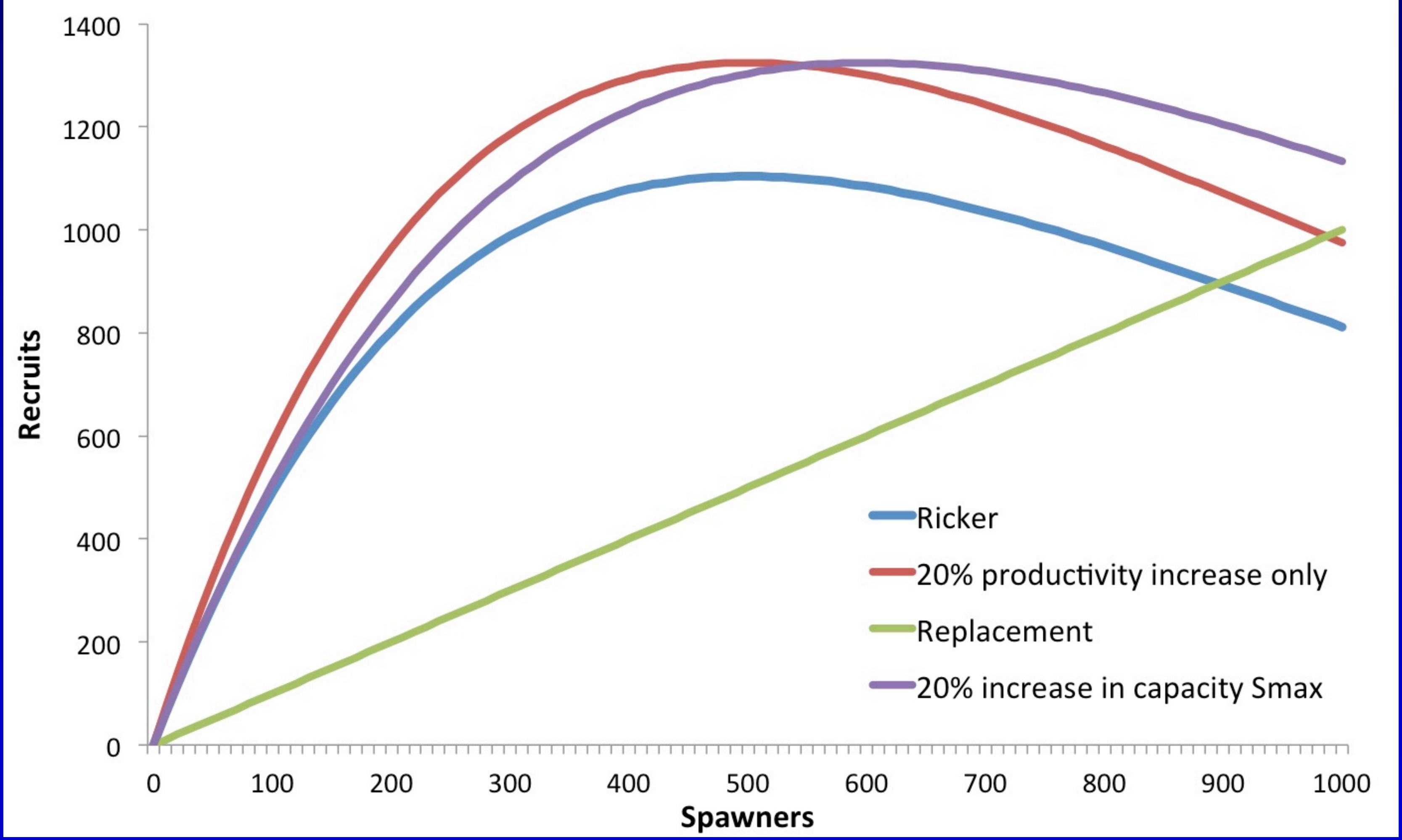
Status of Snake R Fall Chinook

- Increasing natural Chinook abundance since 2000, but pHOS ~75%.
- R/S often <1, recently.
- Large abundances not naturally sustainable.
- *“At what level of supplementation do genetic and ecological risks outweigh demographic benefits, such that hatchery supplementation should be scaled back?”*
- Would lower spawning abundance & lower pHOS enhance viability?
- Is all available habitat fully utilized?



T. Cooney, NOAA Fisheries

draft: How do changes in productivity and capacity affect salmon recruitment and sustainability?



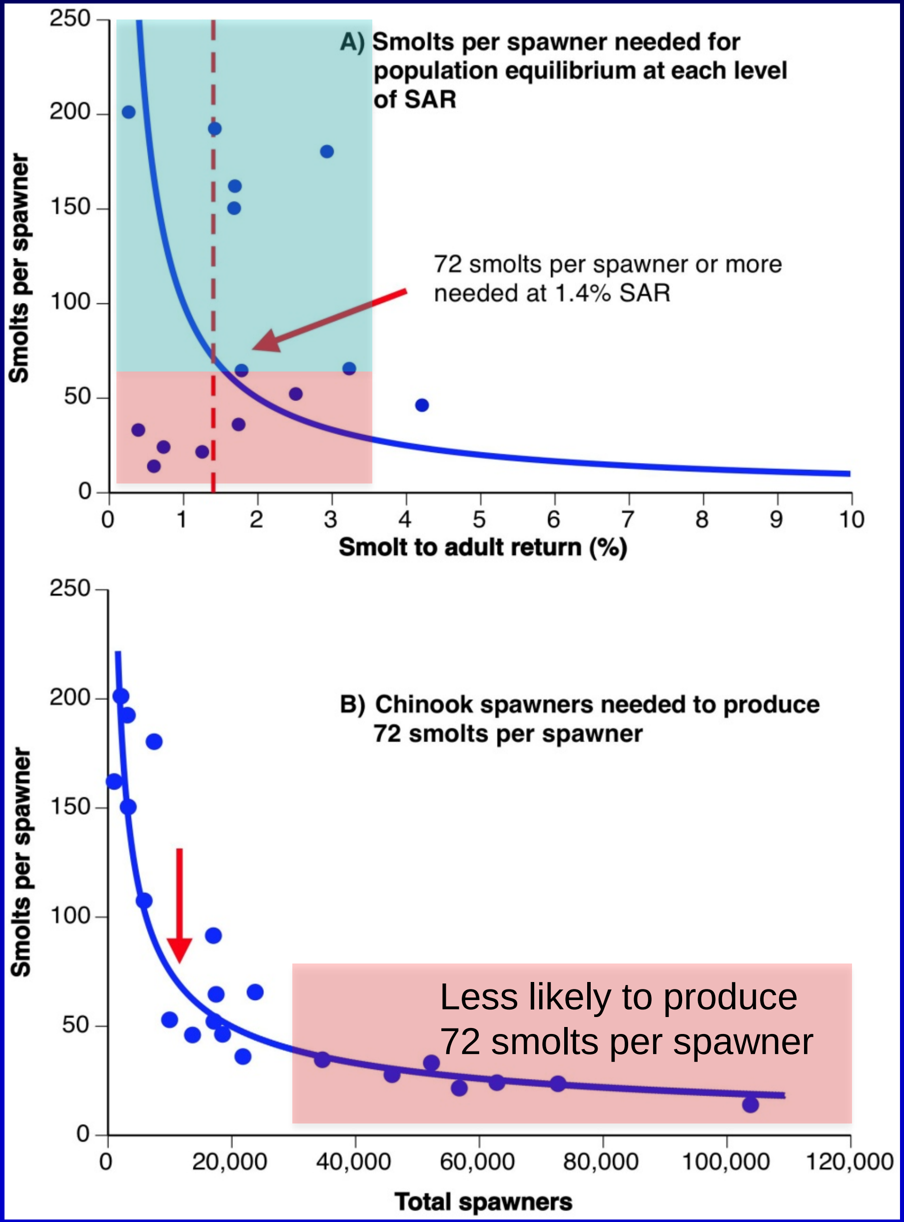
Draft: How many smolts per spawner are needed to support a viable population at current SAR (1.4%)?

Alternatives:

A) Increase smolts per spawner,

B) Increase survival thru hydrosystem & estuary,

C) Hope for better ocean conditions.

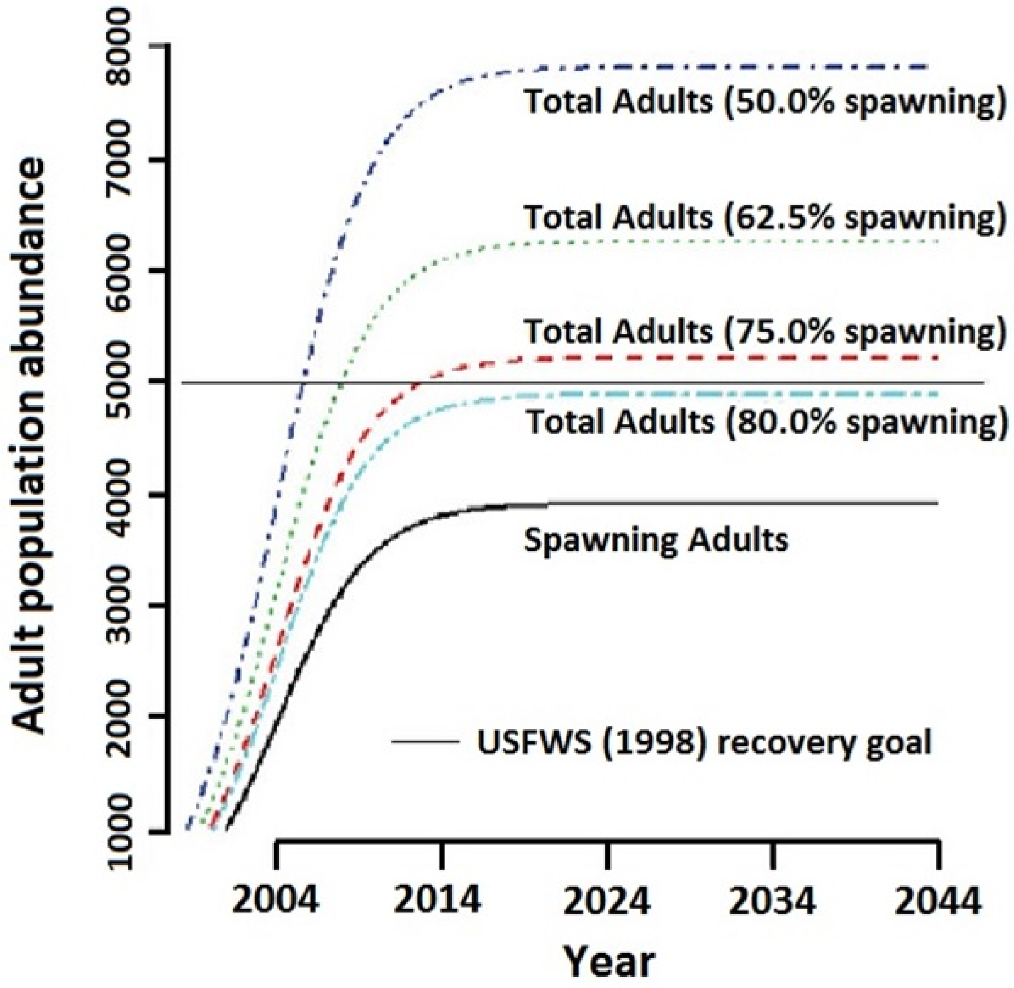


Part II: “Resident” trout, kokanee, sturgeon, and lamprey

- Different animals, different questions
- Trout: Four questions re: DD and carrying capacity (CC)
  - Habitat restoration ***Complicated***
  - Hatchery stocking ***Clear***
  - Nonnative trout invasions ***Relatively clear***
  - Angling regulations/closures ***Relatively clear***

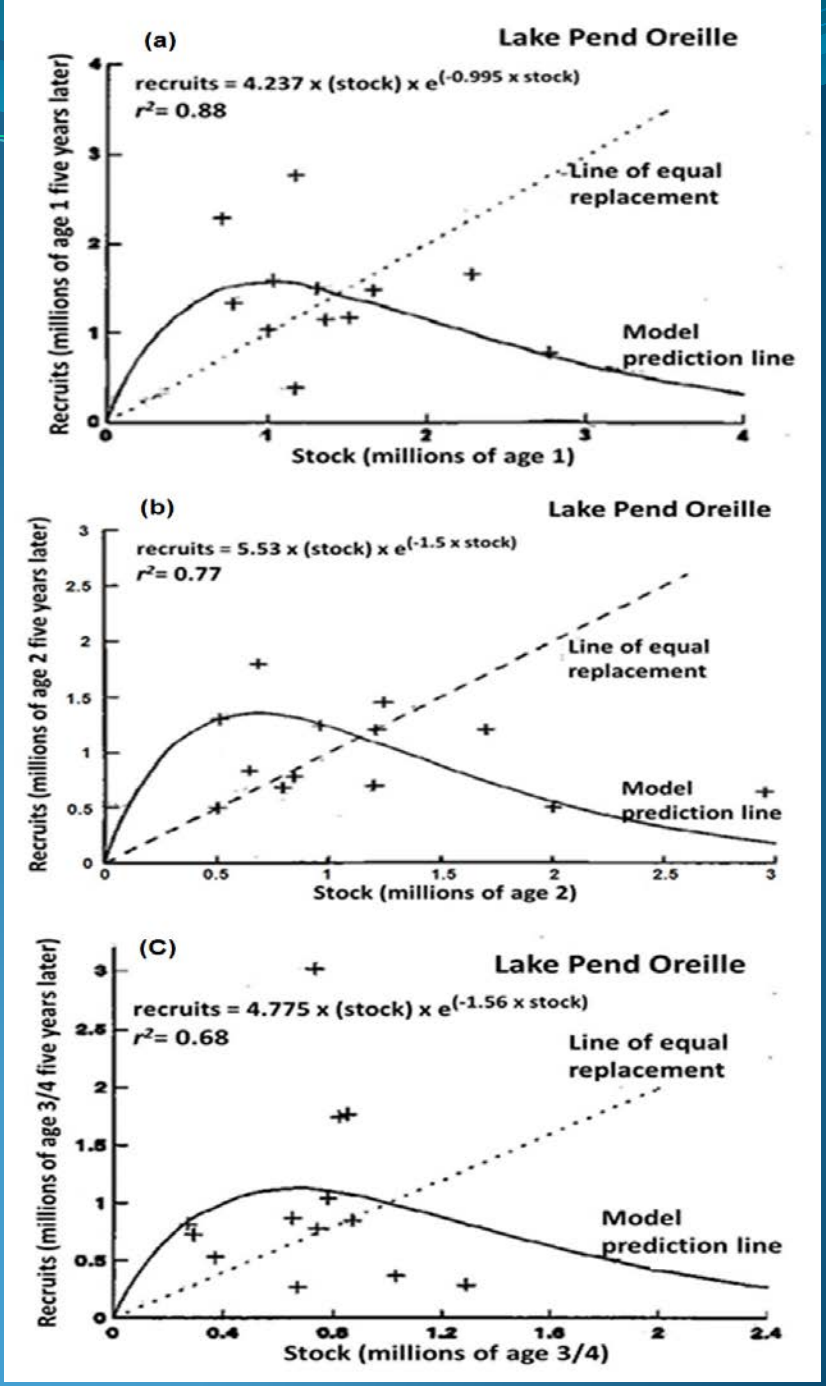
- Does habitat restoration increase CC, and trout density?
  - Trout move in and stay
  - Survive better first year
- Does stocking reduce CC for wild trout?
  - Modest effects on growth and none on survival
  - Comprehensive study in ID detected no effects
  - Hybridization and disease are common

- Do nonnative trout ruin the neighborhood for natives?
  - Removal increased native trout 10 times
  - Brook trout pack in more tightly
    - Greater load on ecosystem; can reduce spiders and birds
- Can native trout populations rebound when fishing is reduced?
  - Slow-growing bull trout can
  - Reach new limits

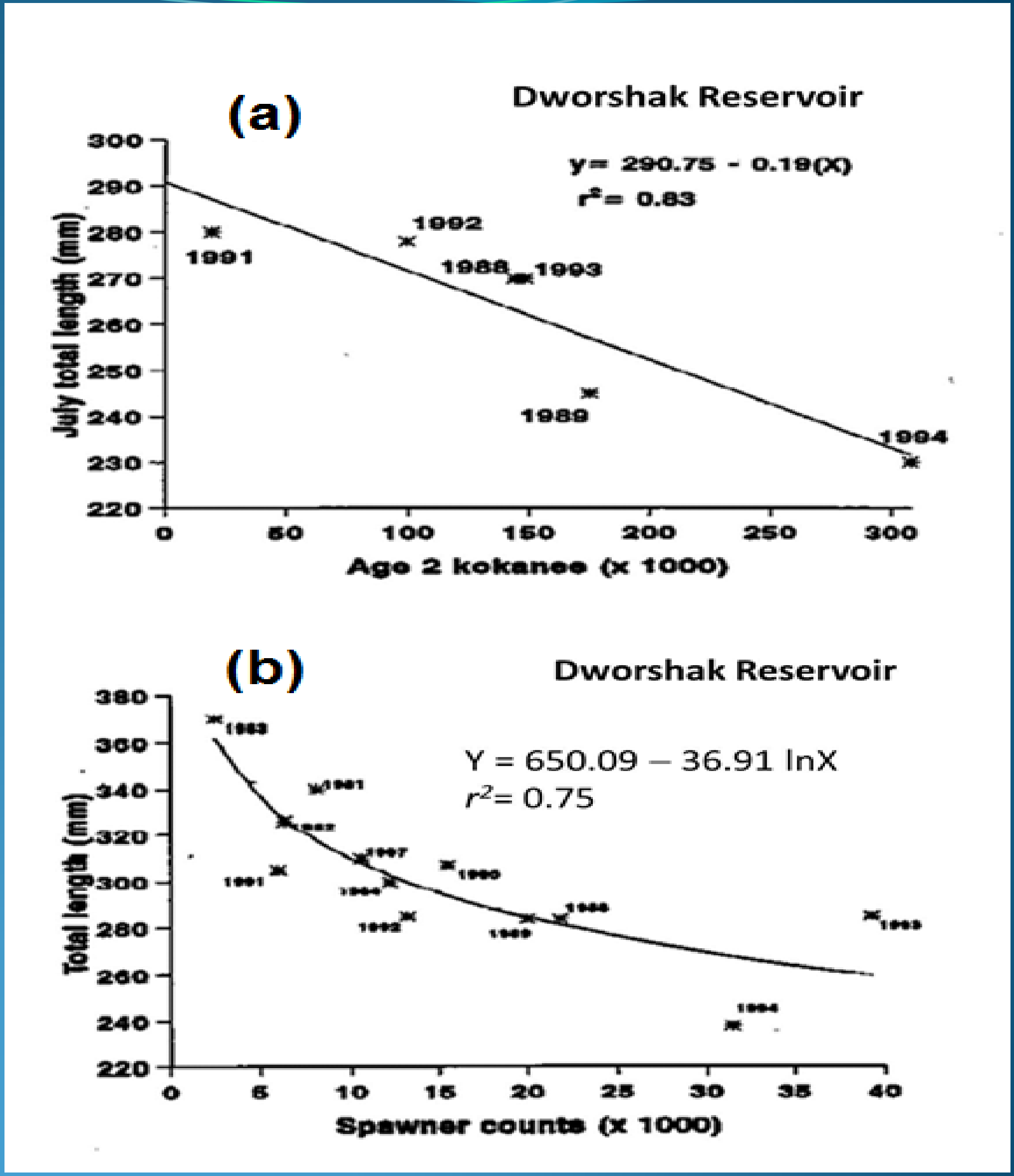


Logistic model estimates of the adult population of North Fork migratory Bull Trout compared with the U.S. Fish and Wildlife Service recovery goal of 5,000 adults. The intrinsic rate of growth was derived from redd counts from 1994 to 2008. The population estimate in 2004 was based on estimates from Hanson et al. (2006). Total adult abundances were estimated from the spawning frequency findings (80%) reported by Hanson et al. (2006), and additional frequencies were added for comparison. From Erhardt and Scarnecchia (2014).

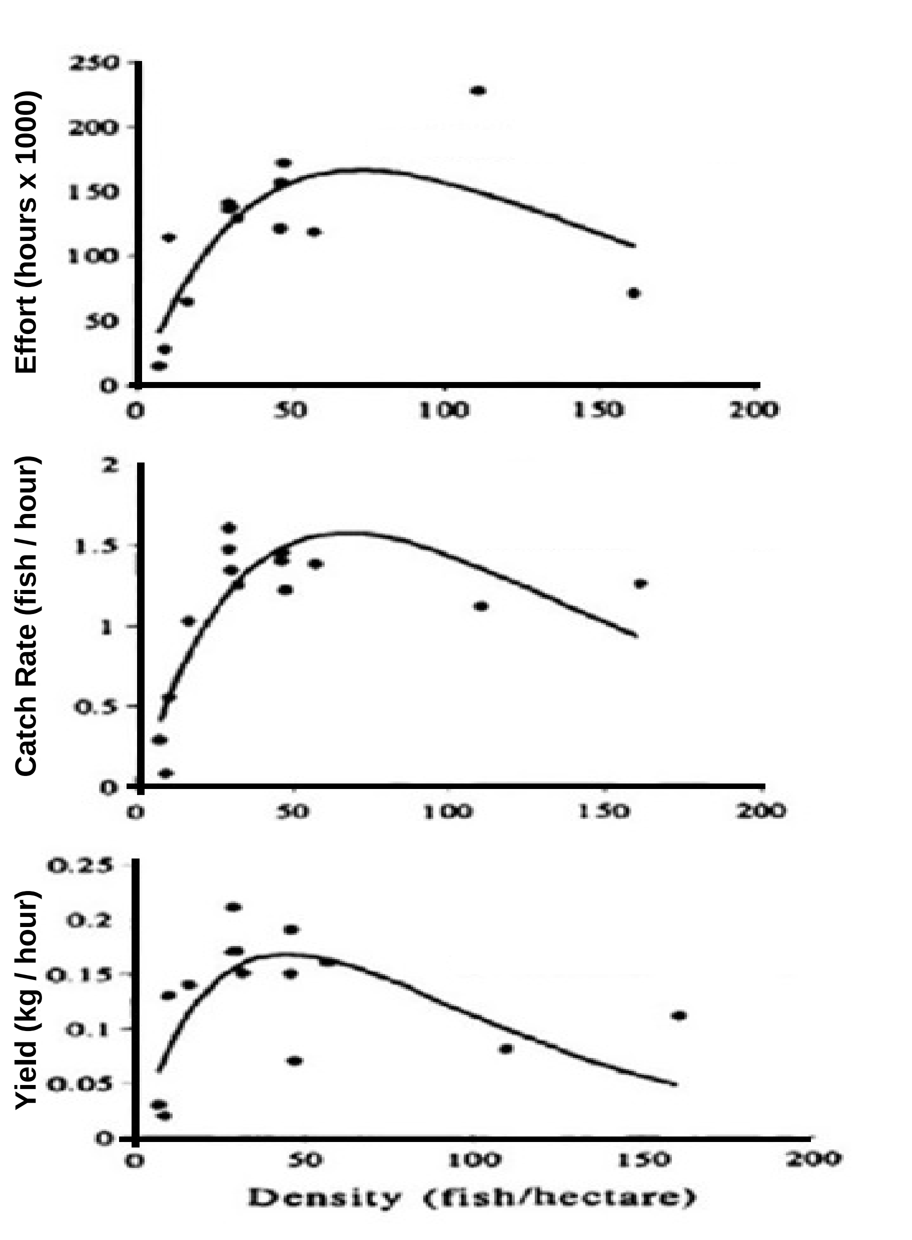
(a) Abundance of age1+ kokanee (recruits) as a function of age1+ kokanee five years prior (stock). (b) Abundance of age2+ kokanee (recruits) as a function of age2+ kokanee five years prior (stock). (c) Abundance of age3+/4+ kokanee (recruits) as a function of age3+/4+ kokanee five years prior (stock). From Fredericks et al. 1995b.

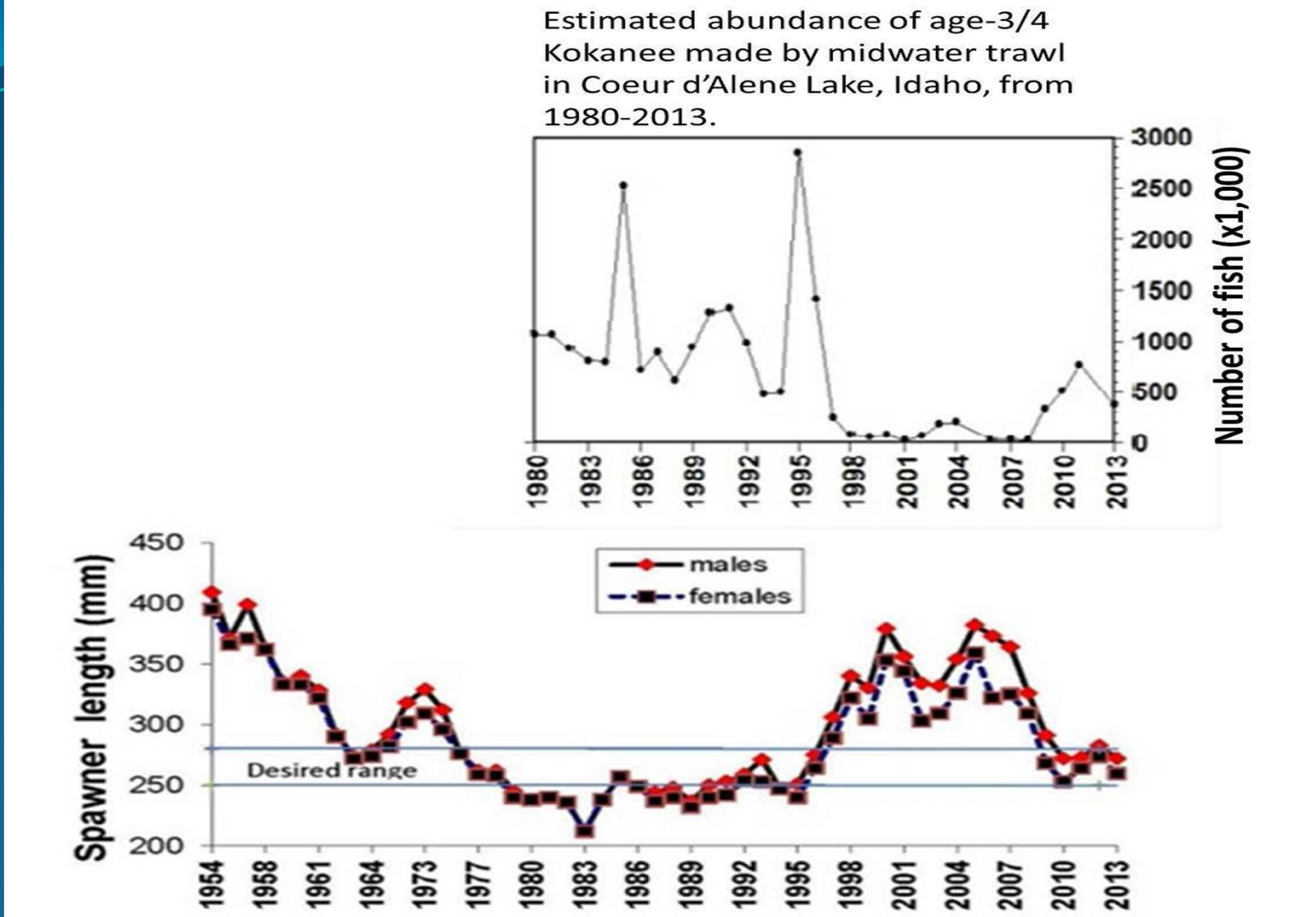


(a) Abundance of age 2+ and 3+ kokanee and their modal length estimated from the July trawling effort. (b) The number of spawning kokanee in Isabella, Quartz, and Skull creeks since 1981 and their modal length. From Fredericks et al. 1995a.



Relationships of estimated angler effort (thousands of hours), catch rate, and yield against kokanee density for fisheries in Idaho and Oregon. From Rieman and Maiolie 1995.



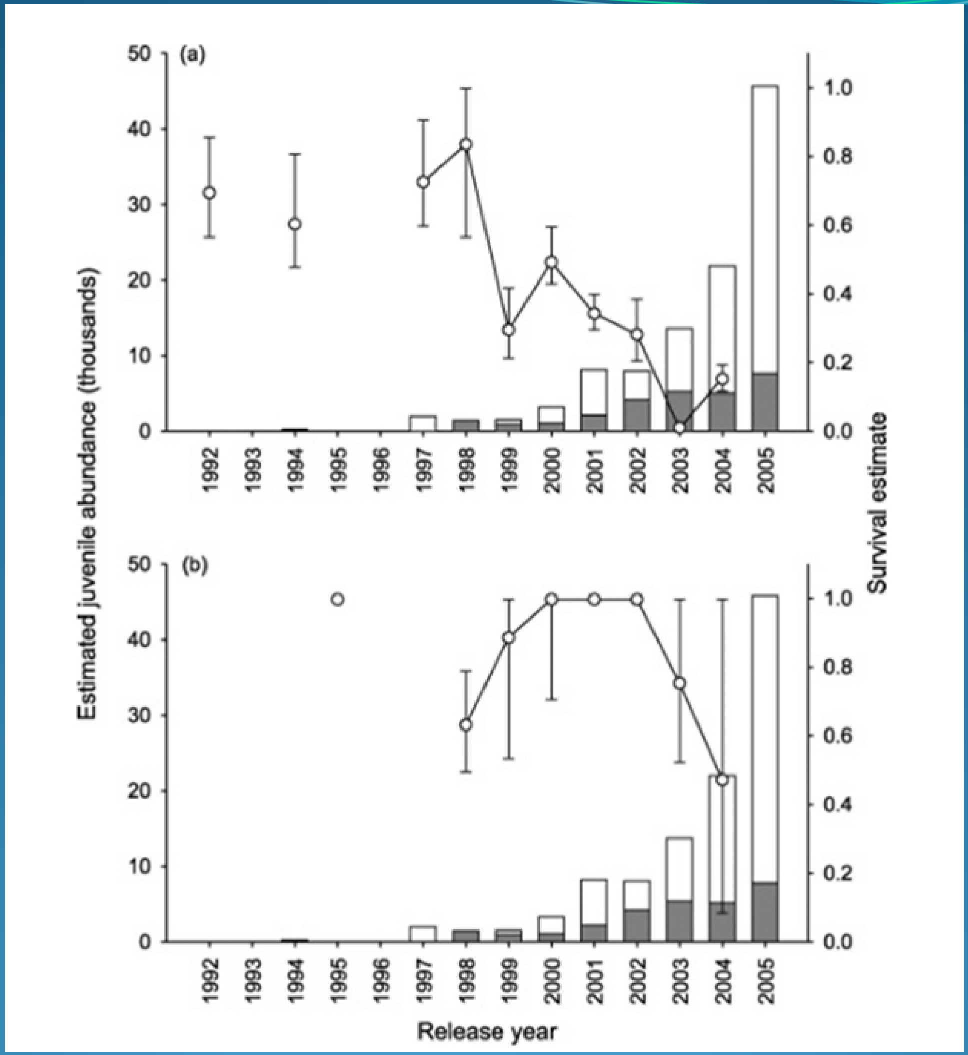


Mean total length of mature male and female Kokanee in Coeur d'Alene Lake, Idaho, from 1954 to 2013. Years where mean lengths were identical between sexes were a result of averaging male and female lengths together. The horizontal line depicts a desired range between 250 mm and 280 mm. Source: Fishery Management Annual Report (IDFG 14-102), Idaho Dept. of Fish and Game (2014).

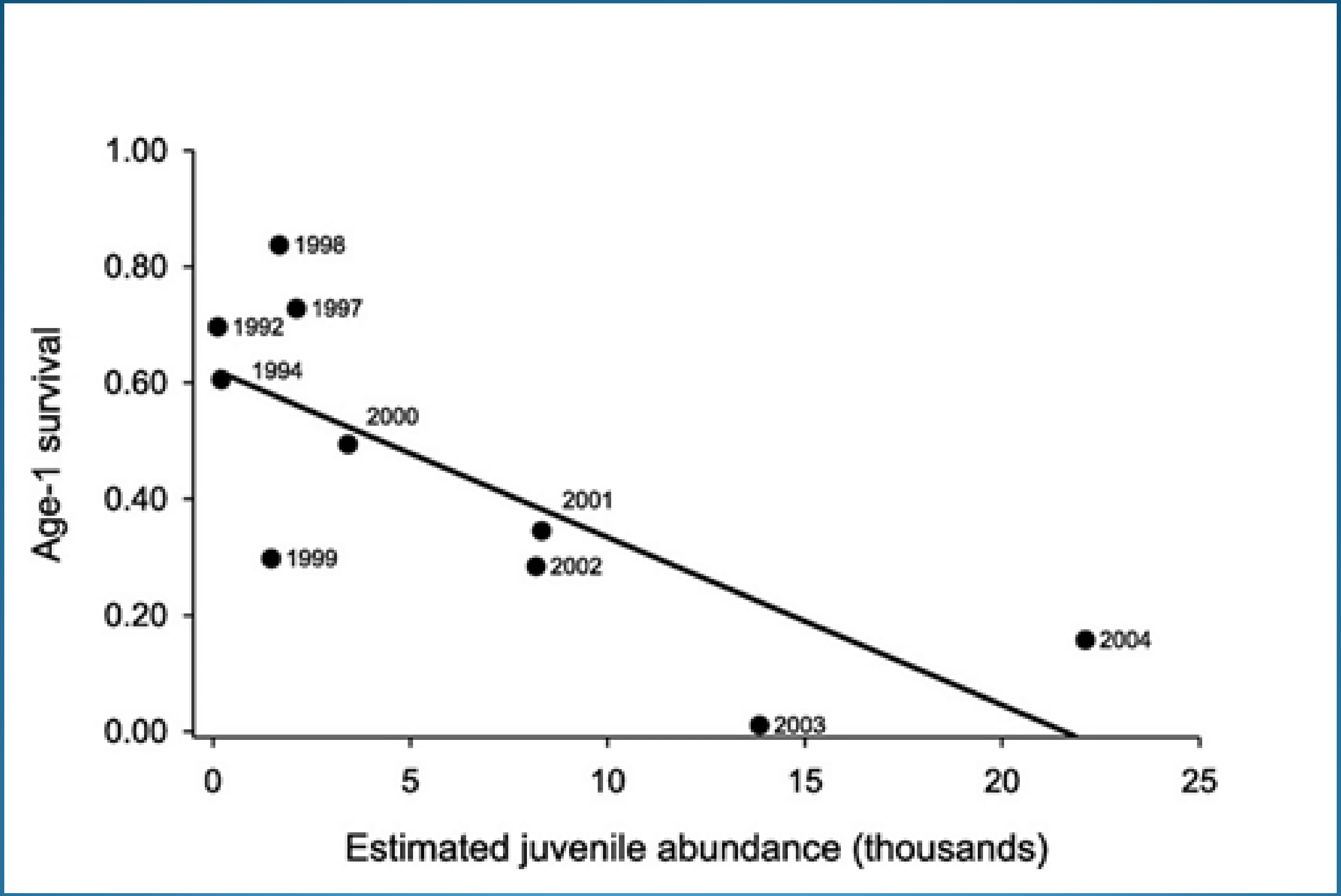
Kokanee

- Kokanee widely stocked, with widely fluctuating populations
  - Limited plankton food in unproductive reservoirs
  - Fluctuating flows kill eggs/fry, but increase growth
  - Manage for the middle (Goldilocks)

www.fishwithjd.com



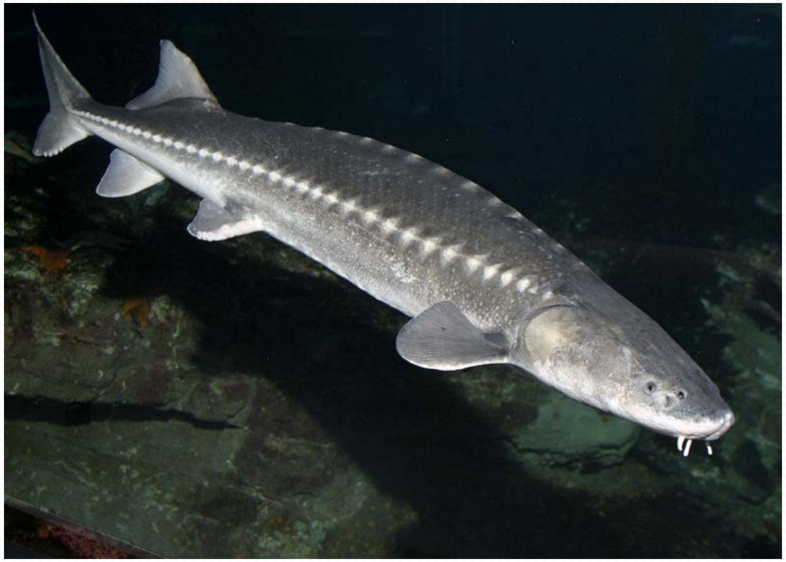
Estimated abundance (total releases + residual population) of hatchery-reared juvenile white sturgeon compared with (a) age-1 survival rates and (b) age-2 survival rates for release years 1992-2005. New releases, residual population, and survival rates are denoted by open bars, solid bars, and circles, respectively. Survival estimates were derived from the best-fitting noncovariate (Model 6). From Justice et al. 2009.



Relationship between annual estimates of juvenile sturgeon abundance and age-1 survival rates. Survival estimates were derived from the best-fitting noncovariate model (Model 6). From Justice et al. 2009.

Sturgeon

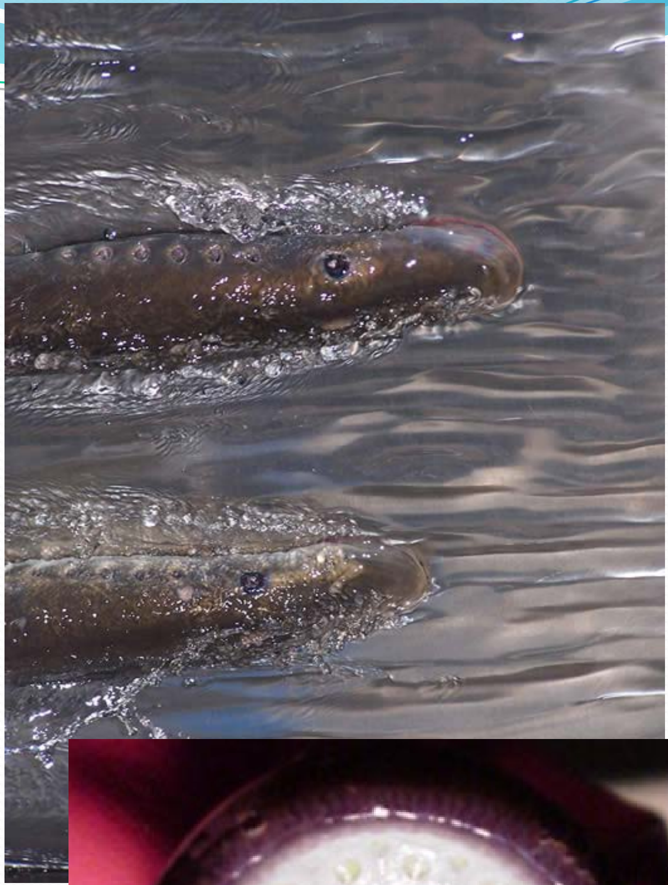
- Declined basin-wide, esp. above Bonneville
  - Low reproduction and juvenile survival
- Endangered Kootenai River population
  - Stocking for conservation
  - Lower growth and survival with more stocking
  - Lower temperature and fewer nutrients with Libby Dam
  - Realistic goals in "novel ecosystems"

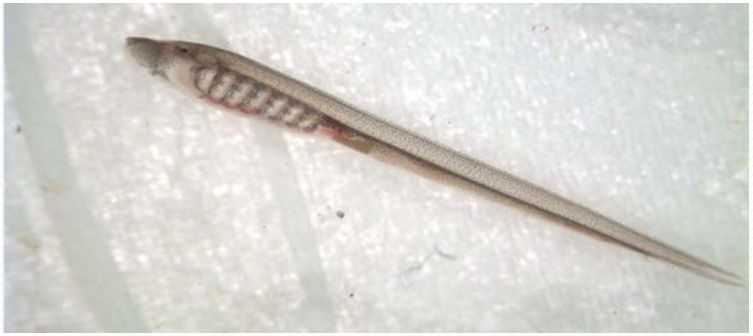


www.montereybayaquarium.com;
www.buffalopost.net

Lamprey

- Density has declined sharply in last 40 years
- Some hints that crowding affects repro/growth/survival
- Numbers rise/fall with host fish in ocean





Images courtesy A. Maule, L. Weiland