"The history of density dependence: From Ricker to management and conservation"

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Outline

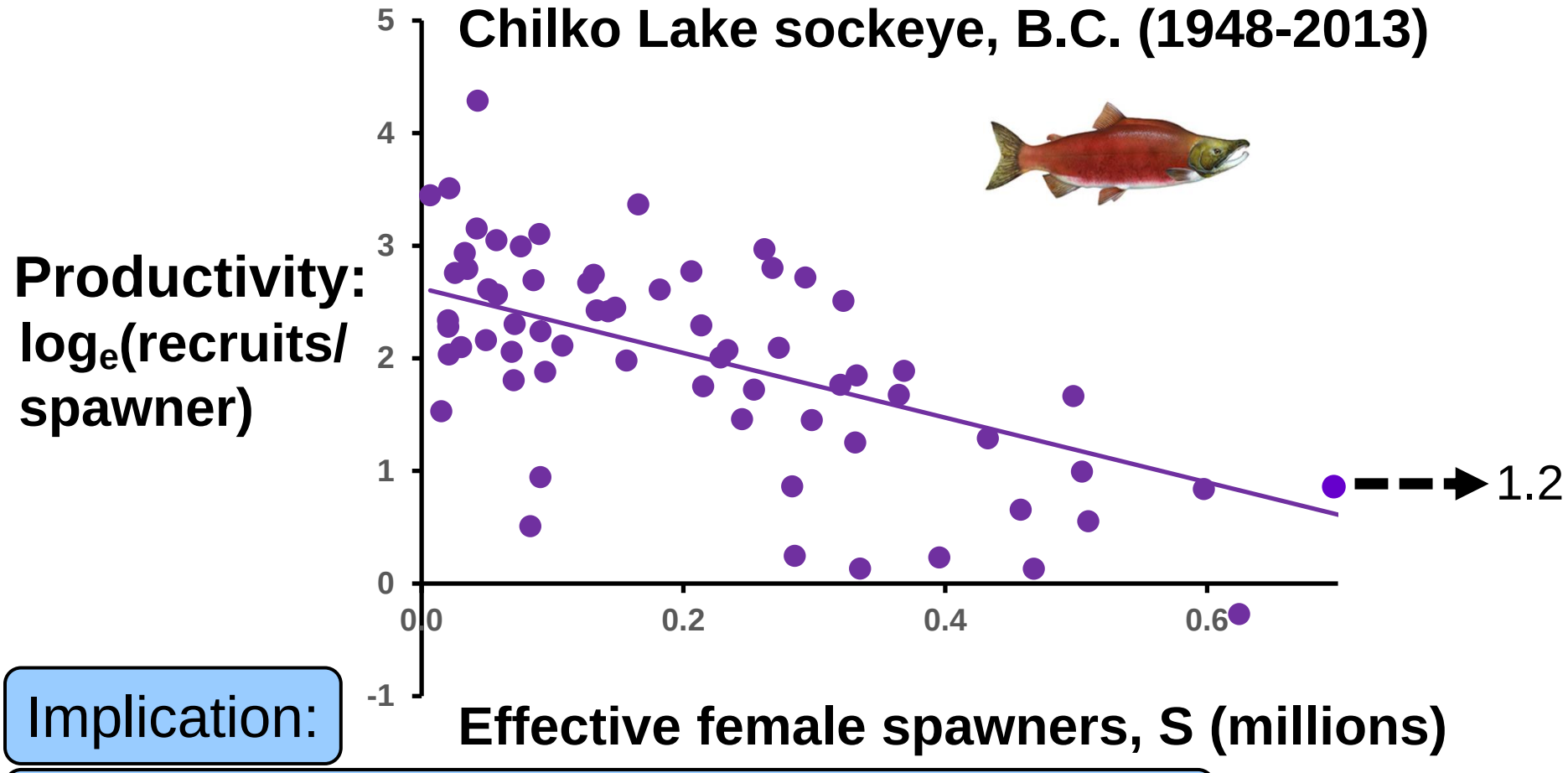
Fundamentals of density dependence in salmon

Types of density dependence

Implications for management and conservation

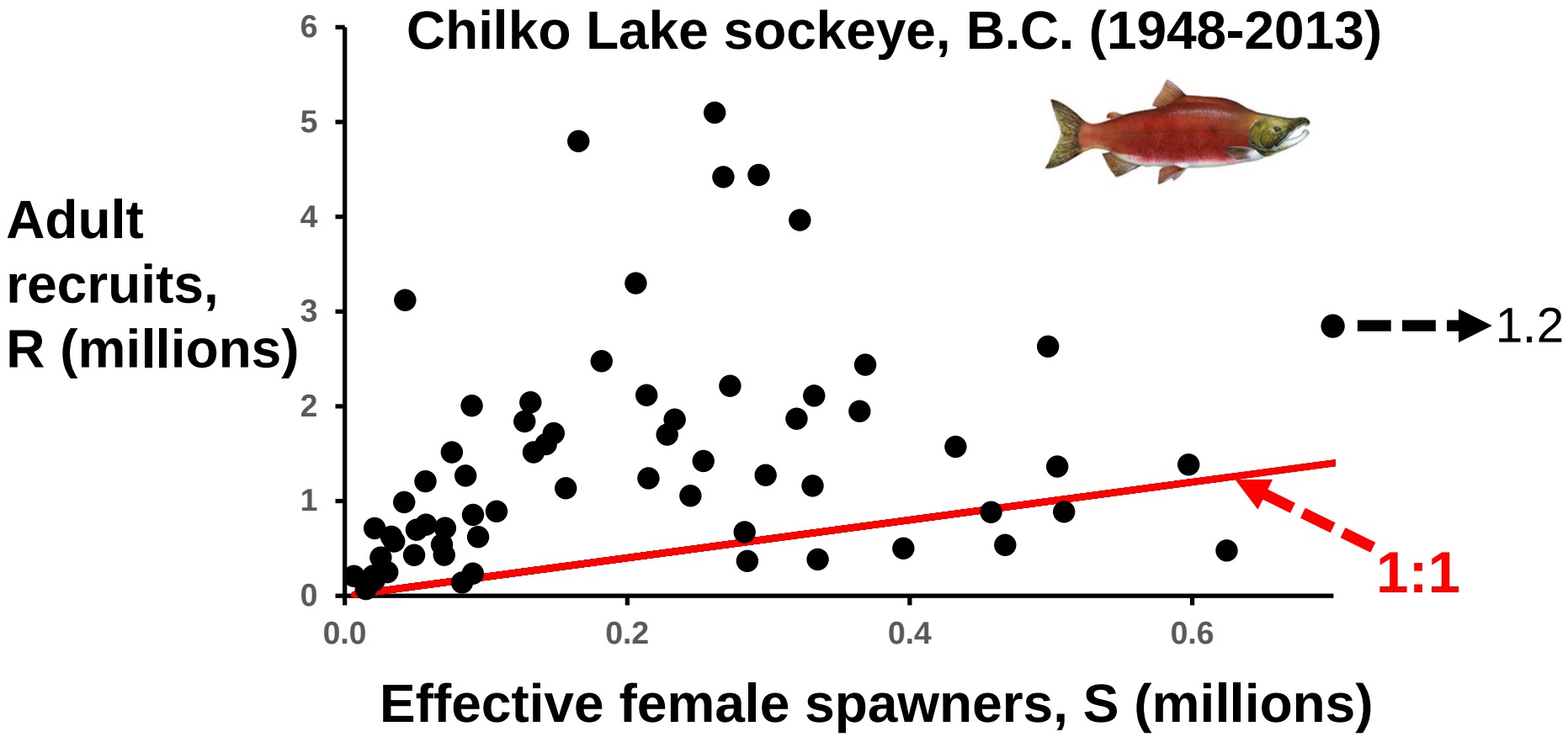
Only a review ...

Compensation



Implication:

Helps to rebuild low-abundance populations



Allows for sustainable harvest

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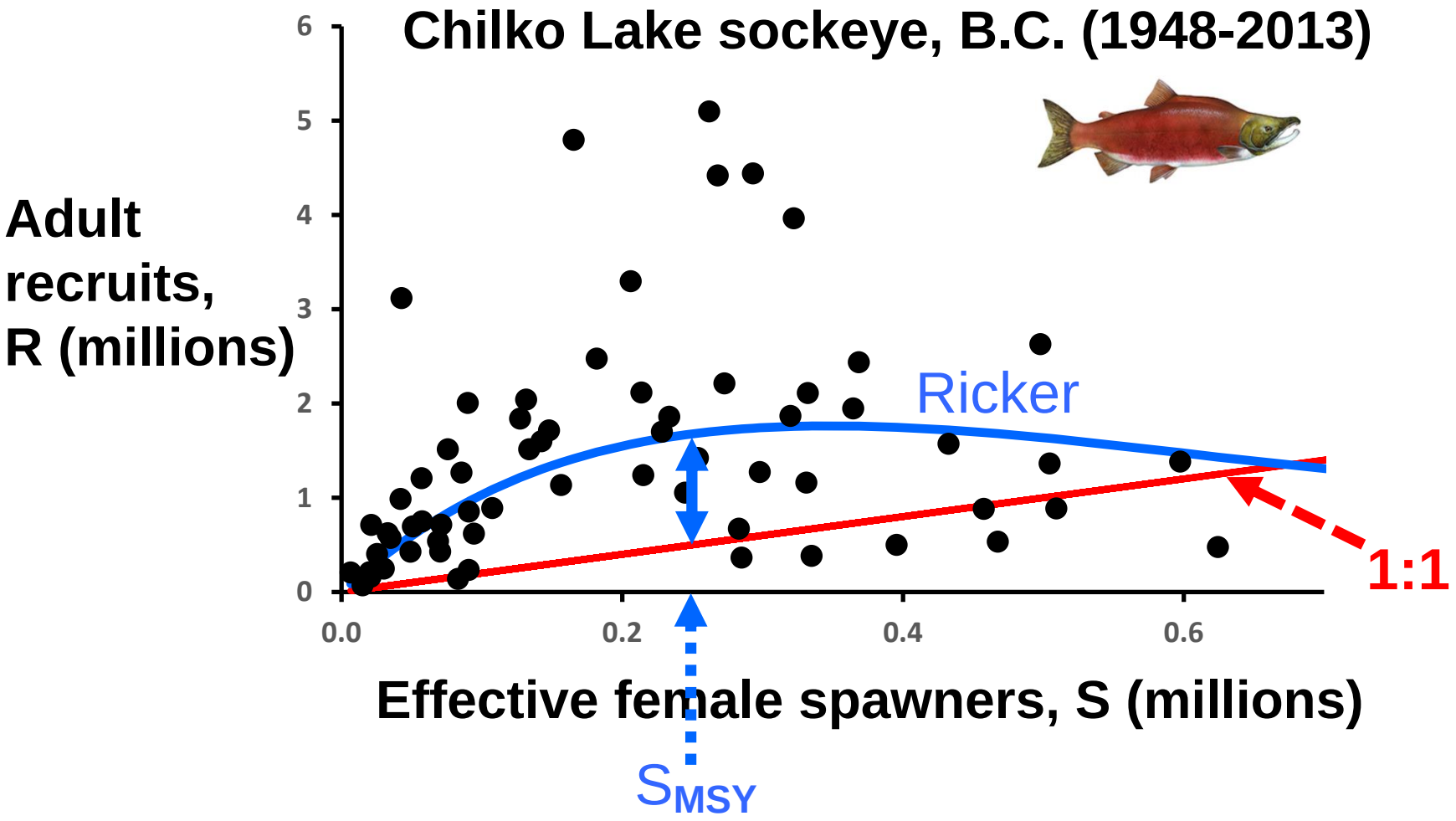
Michielsens, PSC, 2019



S_{MSY} depends on shape of function (parameters)

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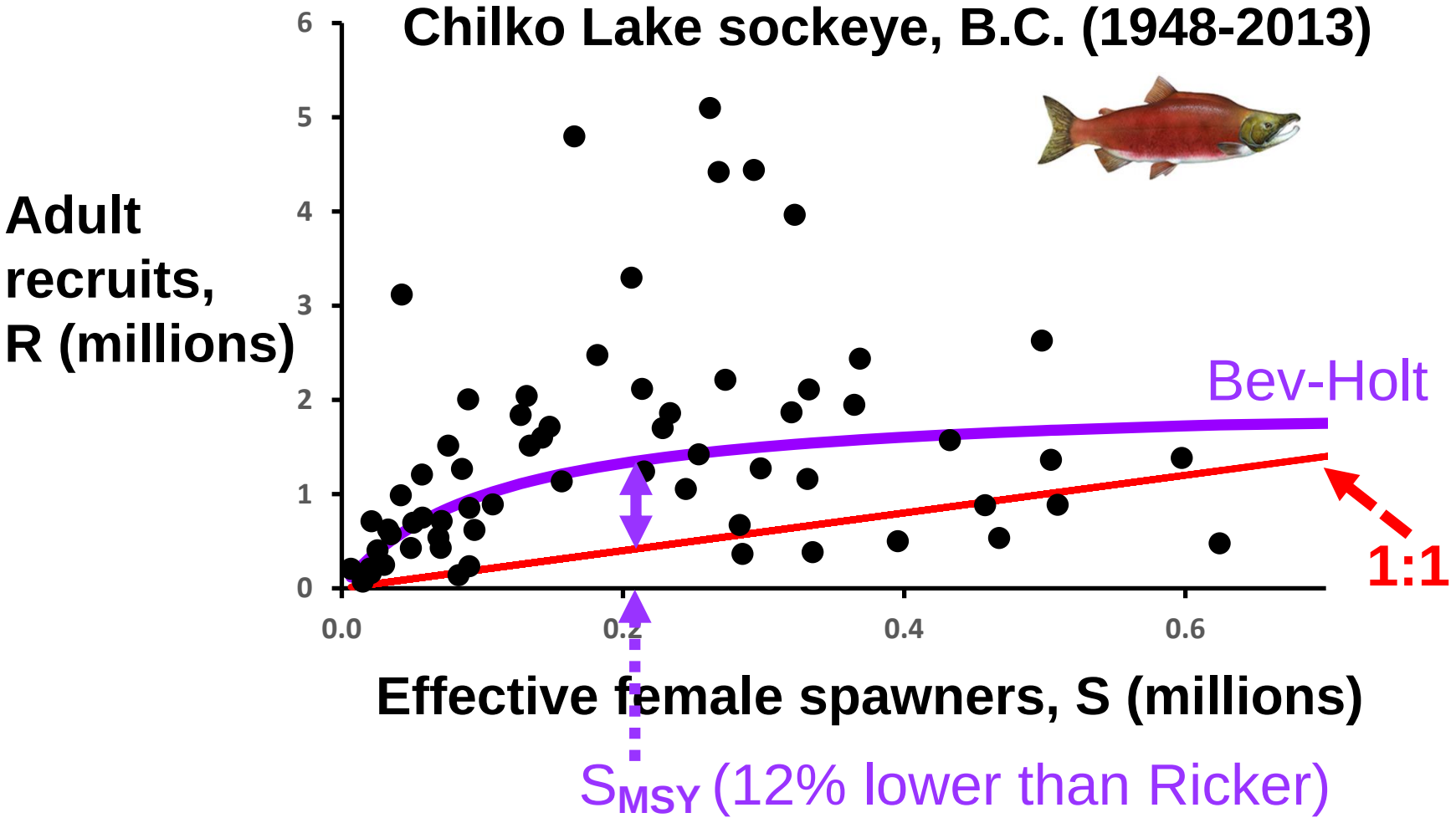
Michielsens, PSC, 2019



S_{MSY} also depends on which function is fit to the data; *Cunningham next.*

Target reference points for management

- S_{MSY} (spawners that produce MSY)
- % harvest rate that produces MSY
- ...

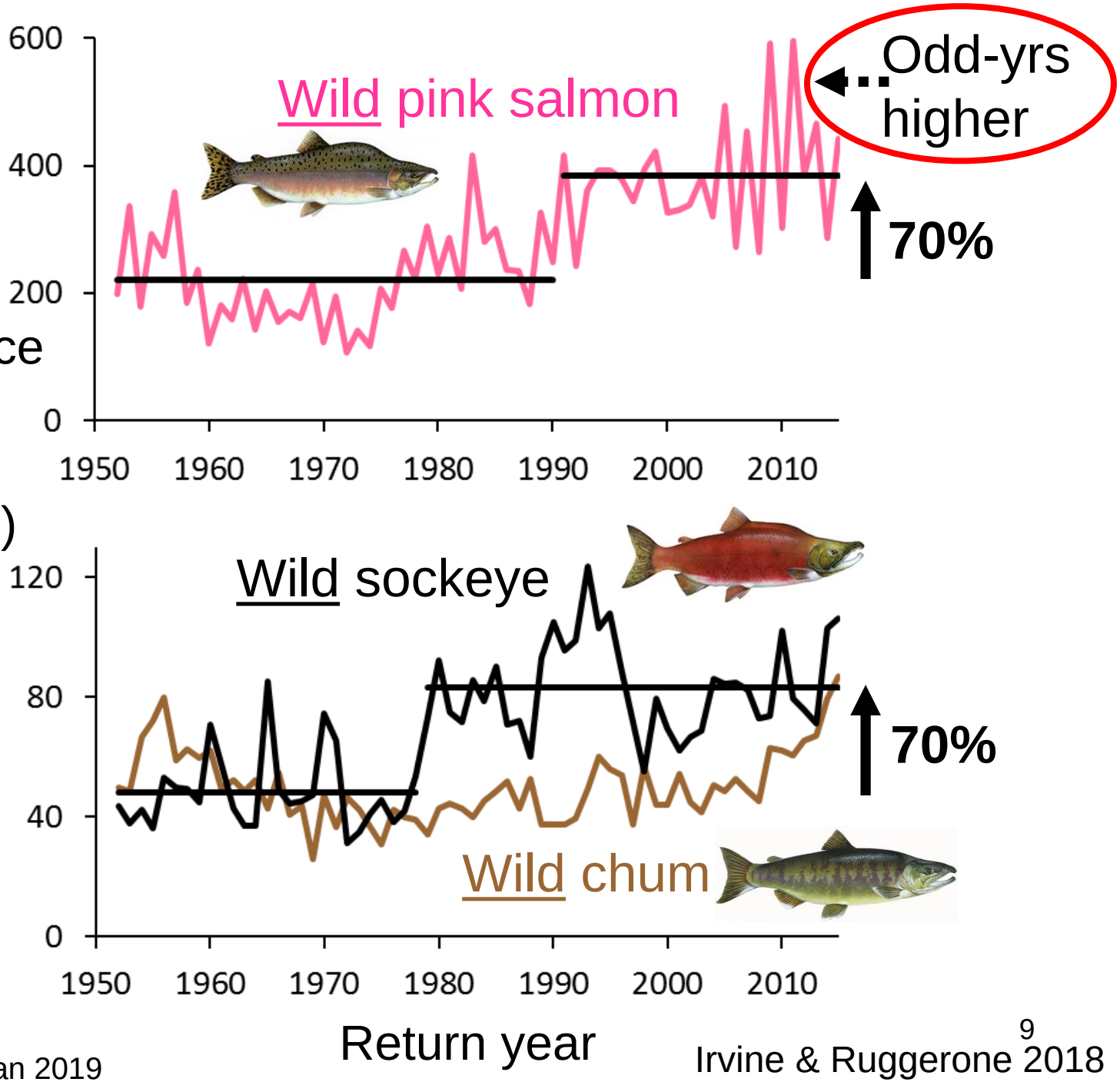
Limit reference points reflect conservation concerns

- Also derived from parameters of spawner-recruit model
- $0.4*S_{MSY}$
- S_{gen} (recovery to S_{MSY} in one generation)
- ...

Given conservation concerns, should we worry about density-dependent effects at high abundance?

Yes!

Adult abundance (catch+esc.) in North Pacific (millions of fish)



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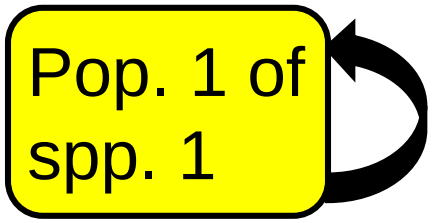
Irvine & Ruggerone 2018

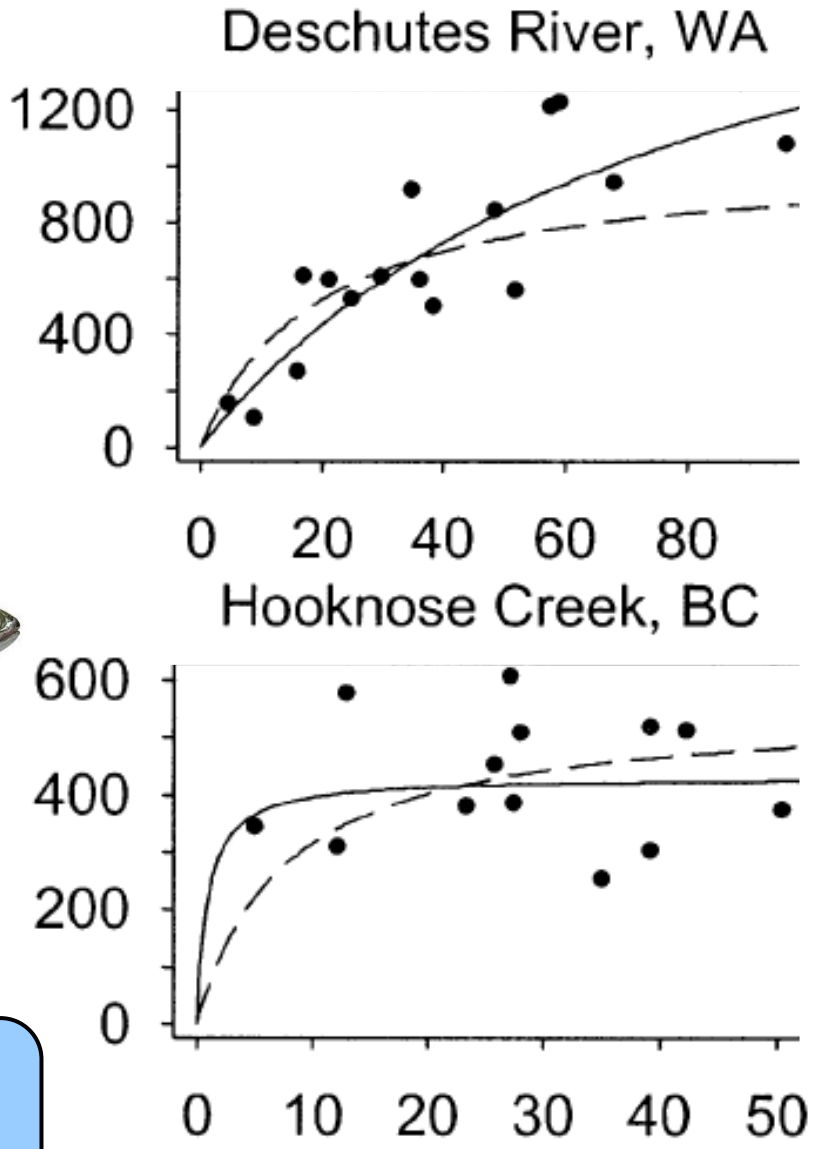
Four types of compensatory density dependence

1. Density dependence **within** a population



Density dependence in fresh water

Coho smolts per km of river

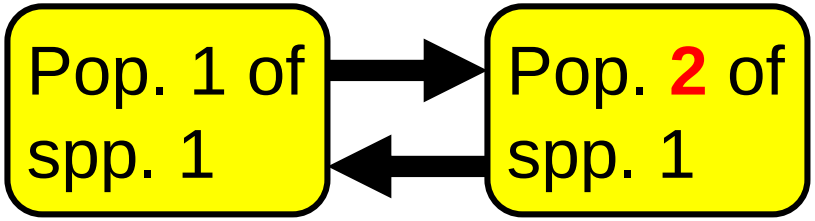


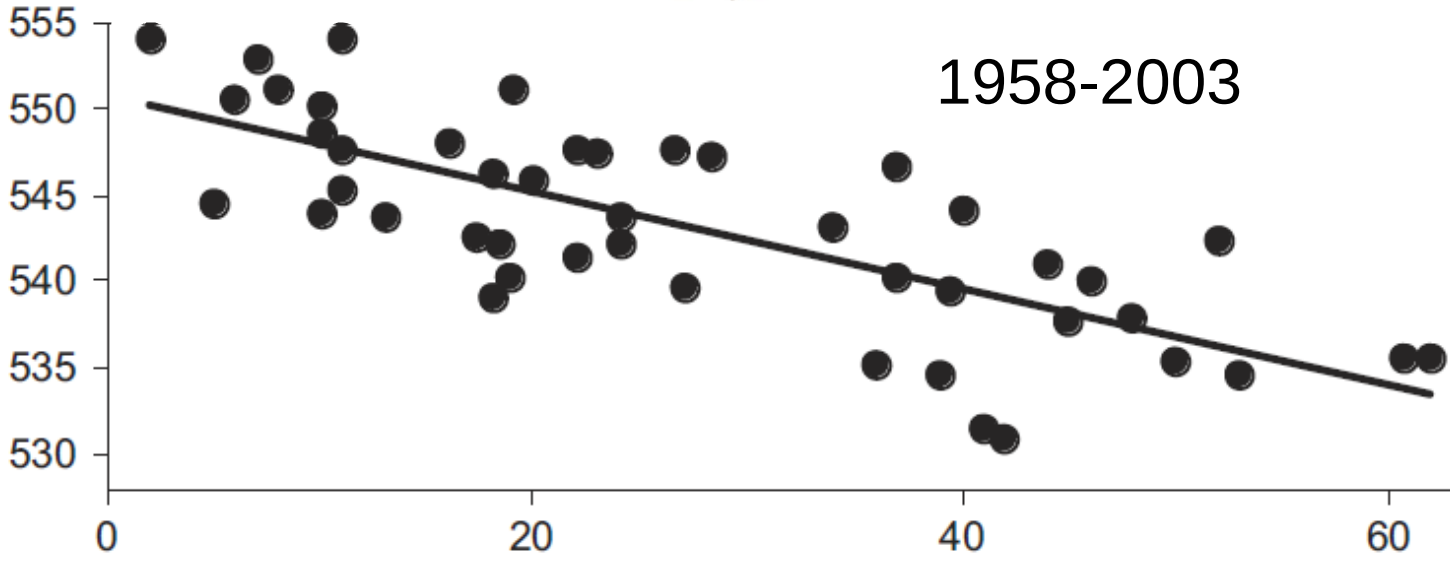
Female coho salmon spawners per km of river

Abundance of coho salmon smolts is limited by territoriality.

Barrowman et al. 2003

2. Density dependence **between** populations **of same spp.**

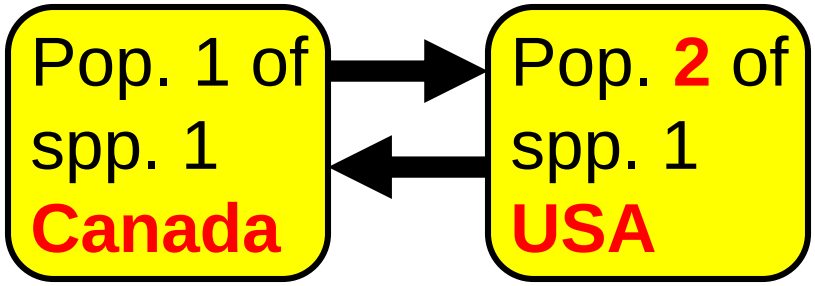




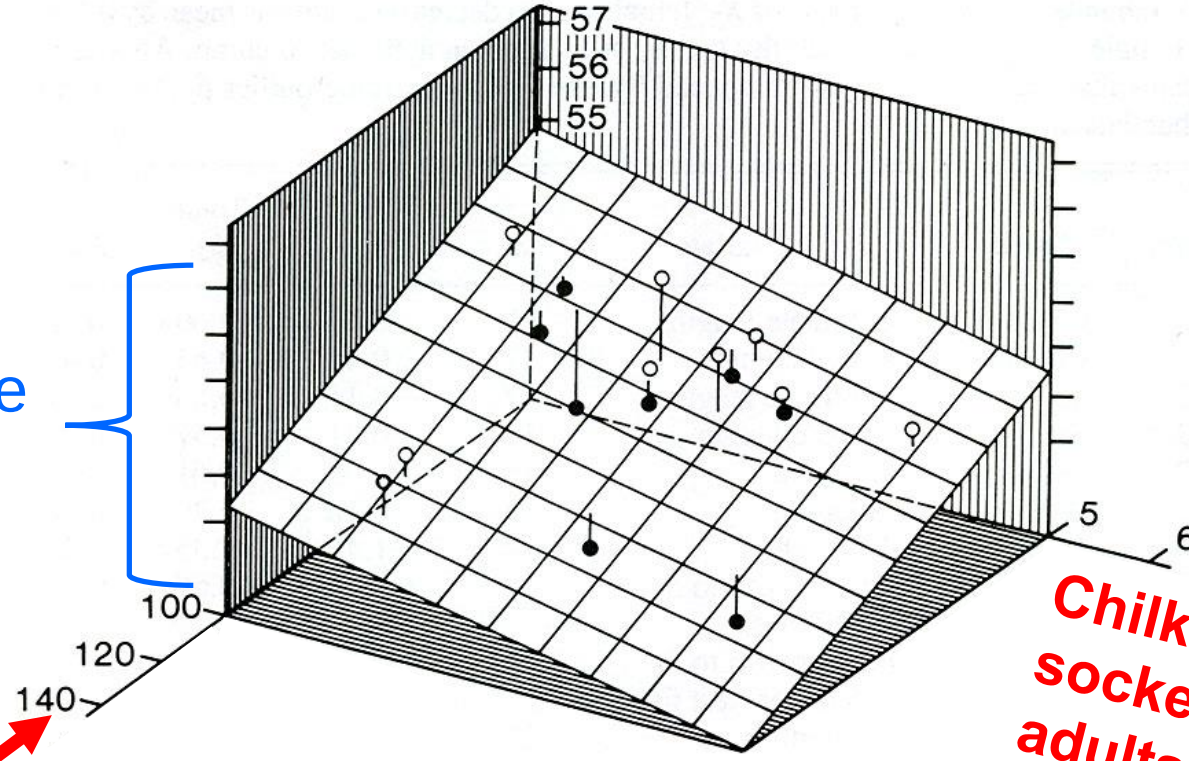
Reduced body length decreases biomass and fecundity.

Ruggerone et al. 2007;
first reported by Rogers 1980

3. Density dependence **between** populations of **same species** but **from different nations**



Chilko Lake, B.C. sockeye age-4 female length (cm)



22% decrease in mass per fish

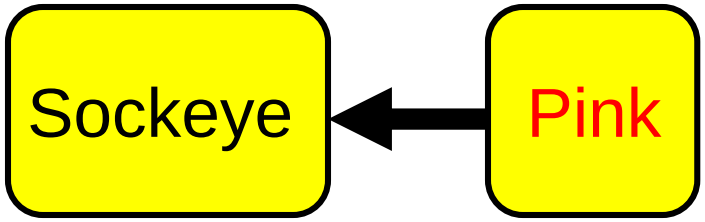
Chilko, B.C. sockeye adults (millions)

Total B.C. + Alaska sockeye adults (millions)

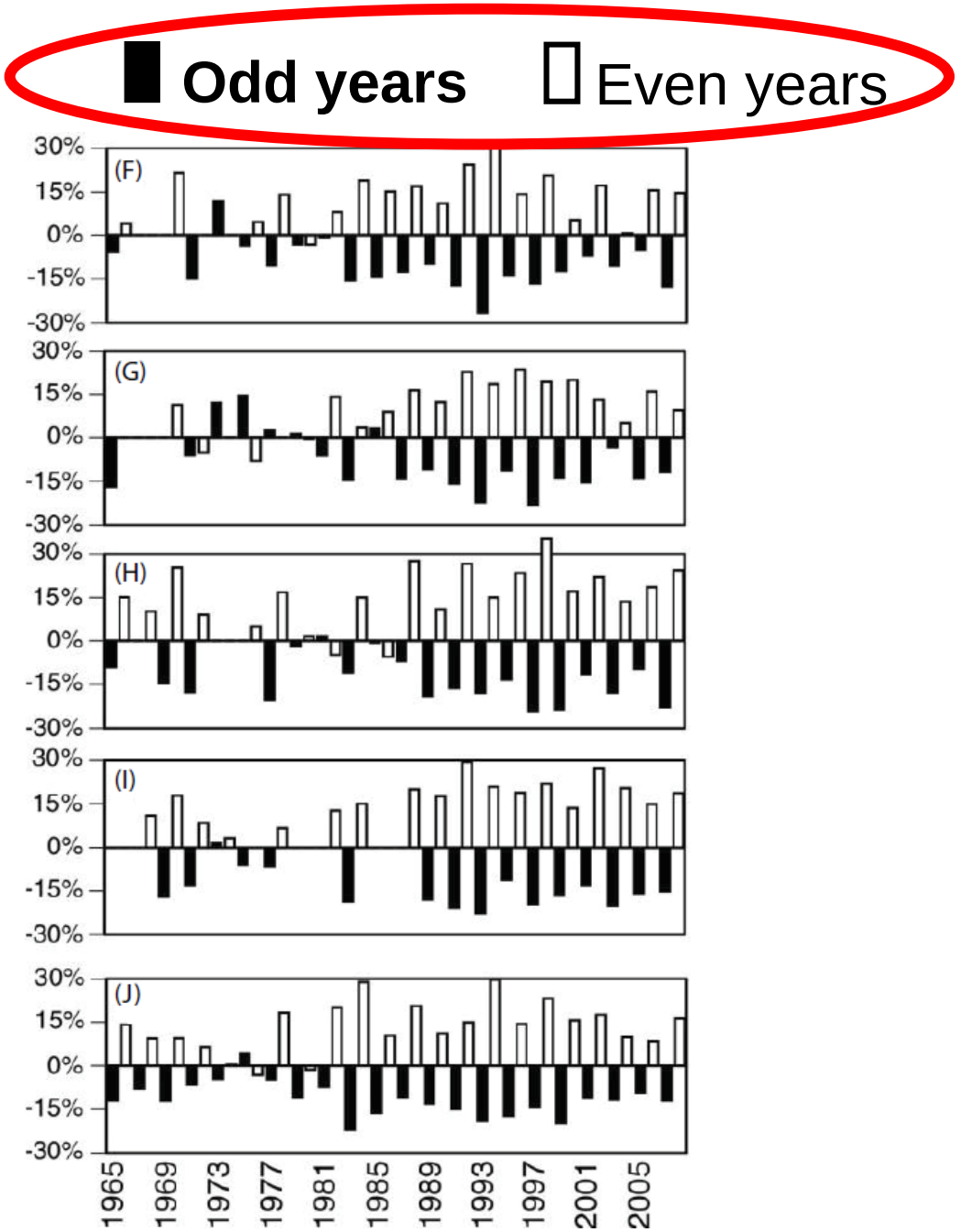
Sockeye from Alaska reduce body size of B.C. sockeye

Peterman 1984

4. Density dependence **between different species**



Relative sockeye growth in 3rd year



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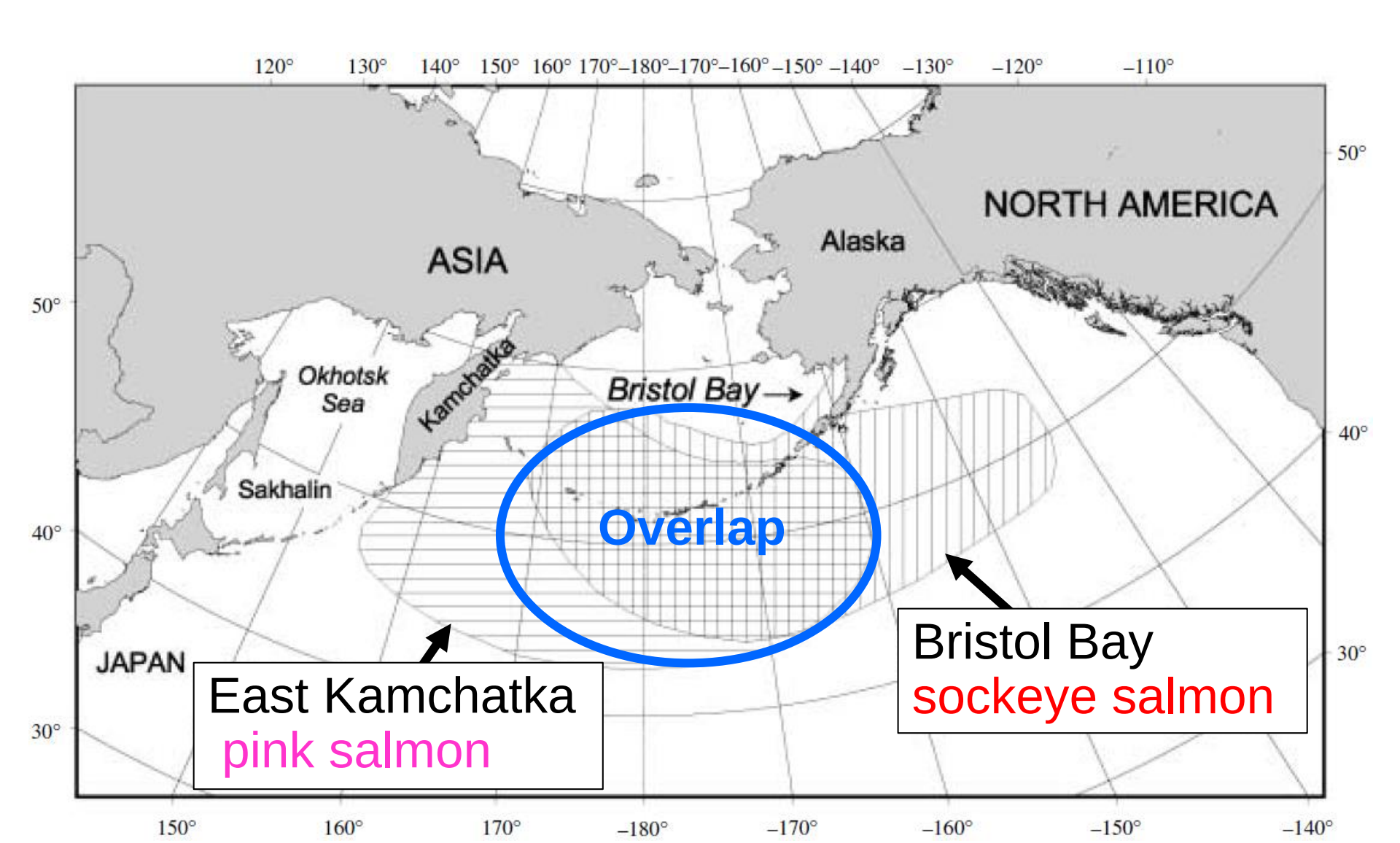
Ruggerone et al. 2016



Ruggerone et al. 2003

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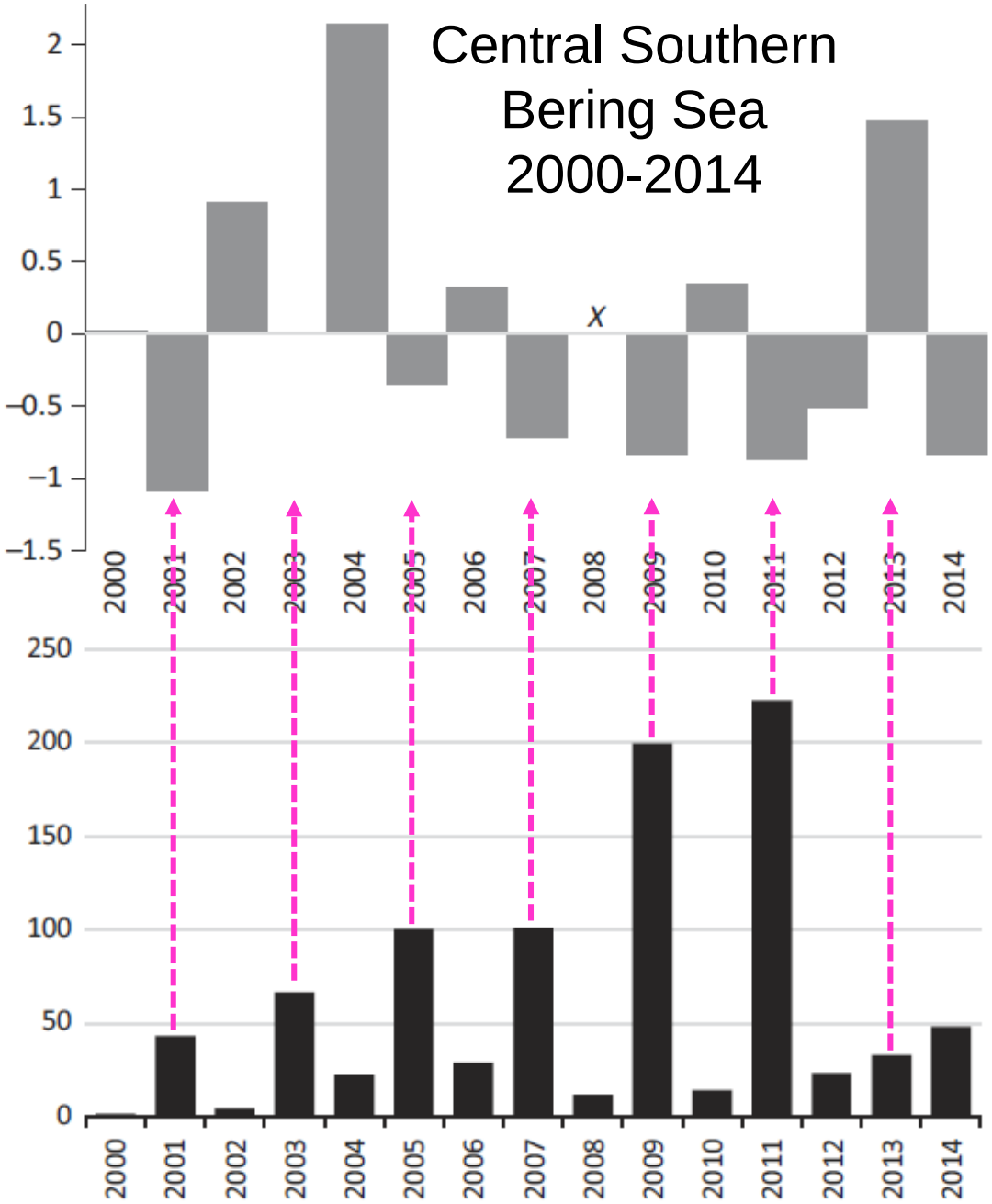
Normalized density of large copepods

r^2=0.32, P=0.04

East Kamchatka pink salmon (millions)



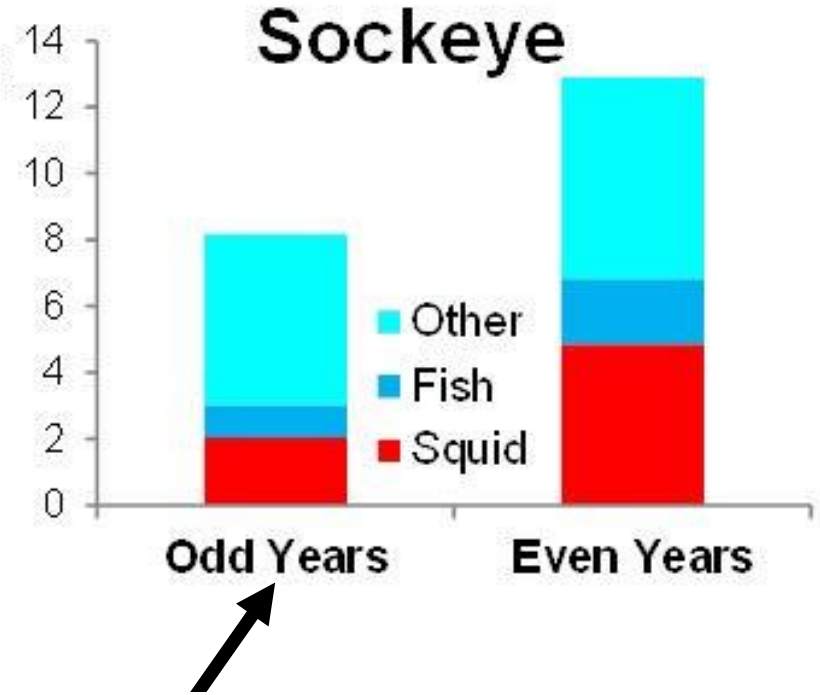
Batten et al. 2018

Pink and sockeye diets overlap in:

- Bering Sea (Davis 2003)
- Gulf of Alaska (Kaeriyama et al. 2004)

...

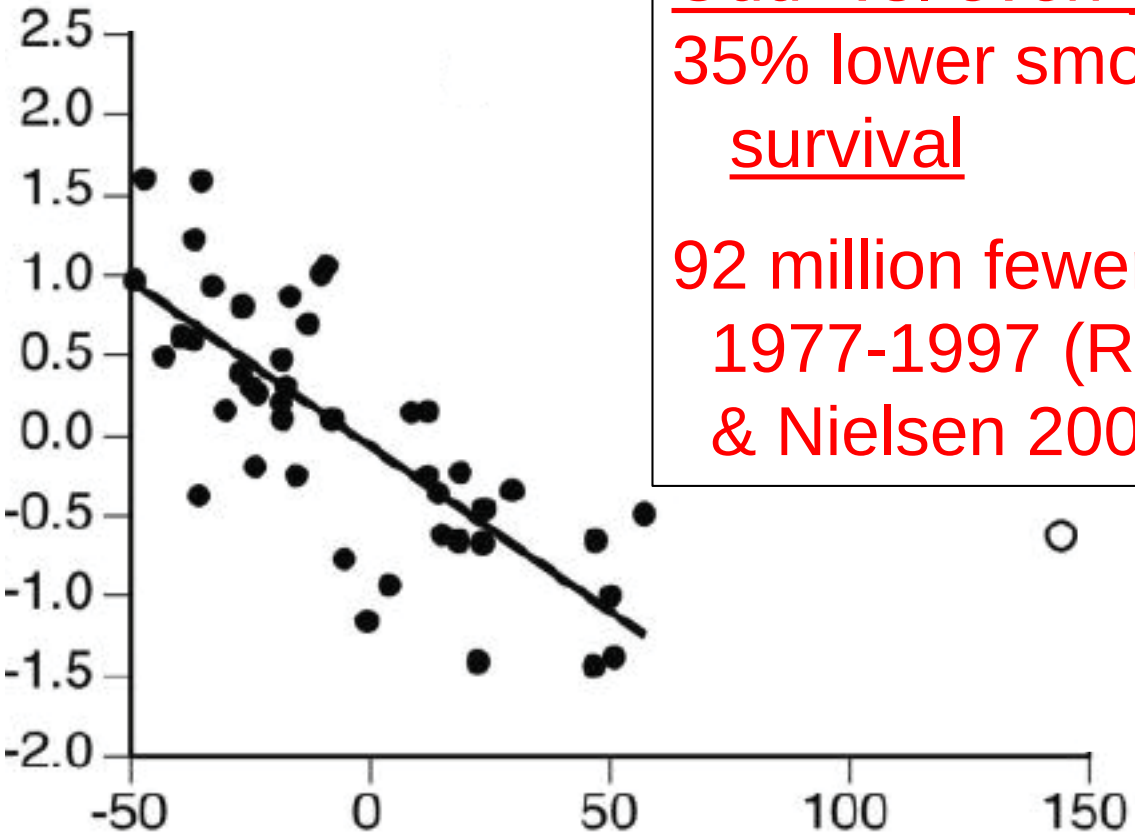
Stomach contents (g) 1991-2000



In odd years
38% decrease in fullness +
57% decrease in fish & squid

Davis 2003

Median Bristol Bay sockeye growth, z 1965-2009



East Kamchatka pink salmon abundance (millions), z

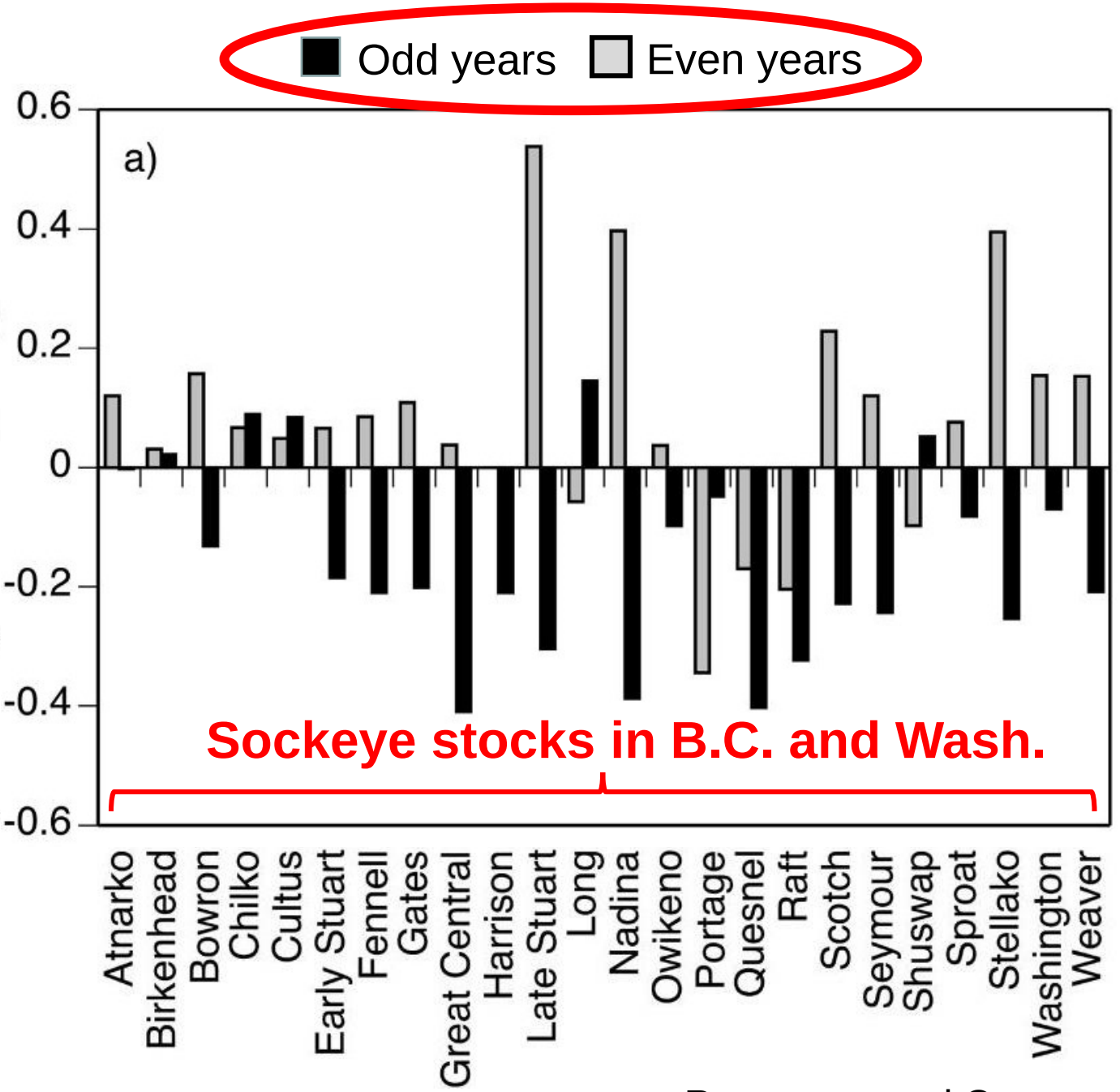
Odd- vs. even-yr sockeye

35% lower smolt-to-adult survival

92 million fewer adults in 1977-1997 (Ruggerone & Nielsen 2004)

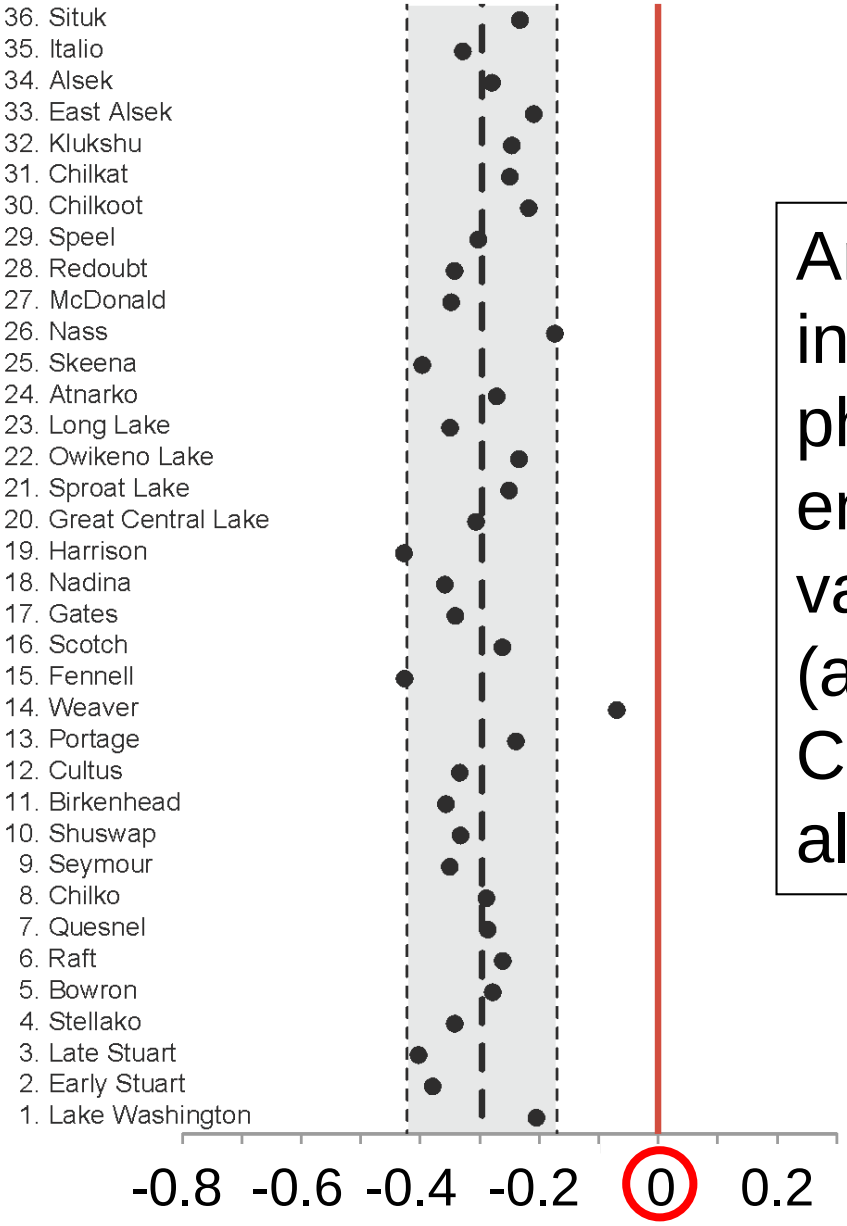
Ruggerone et al. 2016

Average <u>productivity residuals</u> from Ricker S-R curve 1978-2005



Ruggerone and Connors 2015

Sockeye stocks from S.E. Alaska to B.C. and Wash.

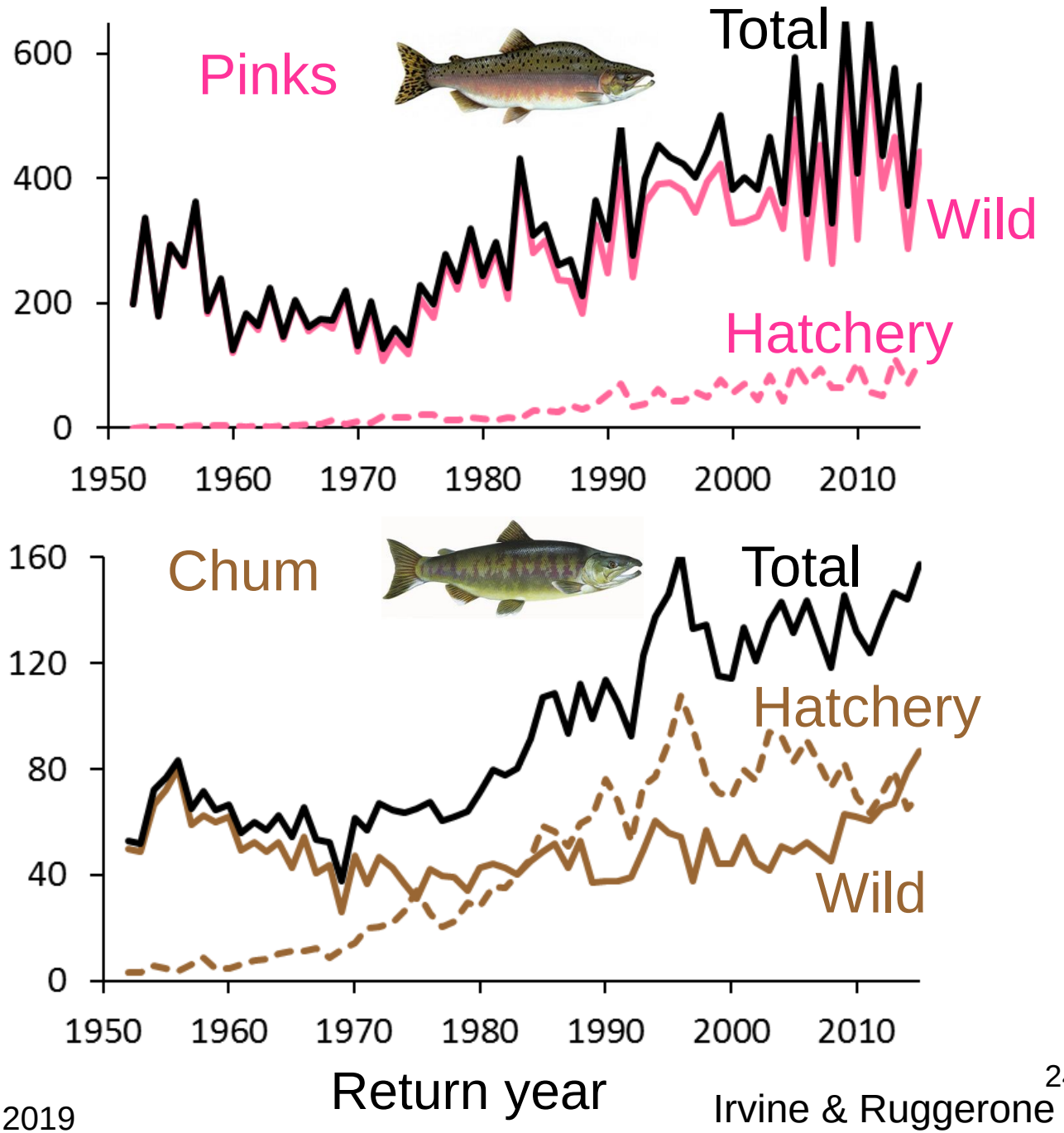


Analysis took into account physical environmental variables (as did Cunningham et al. 2018, etc.)

Ruggerone and Connors 2015

Change in sockeye <u>productivity</u> [$\log_e$(R/S)] per SDU change in pink salmon abundance

Adult abundance in North Pacific (millions of fish)



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Irvine & Ruggerone 2018

Abundant odd-year pink salmon reduce growth and/or survival rates of sockeye in ocean.

- Creates errors in pre-season forecasts of sockeye

- Pink and chum hatchery plans must consider negative effects on other populations, species, and regions
- "Tragedy of the Commons" in ocean
- Need international cooperation/regulations on hatcheries (cap-and-trade, other regulations)
- Economic evaluations (Kishi et al. 2012; Kitada 2018)
- Possibly harvest wild pinks to below S_{MSY}

Compensation (all examples above)

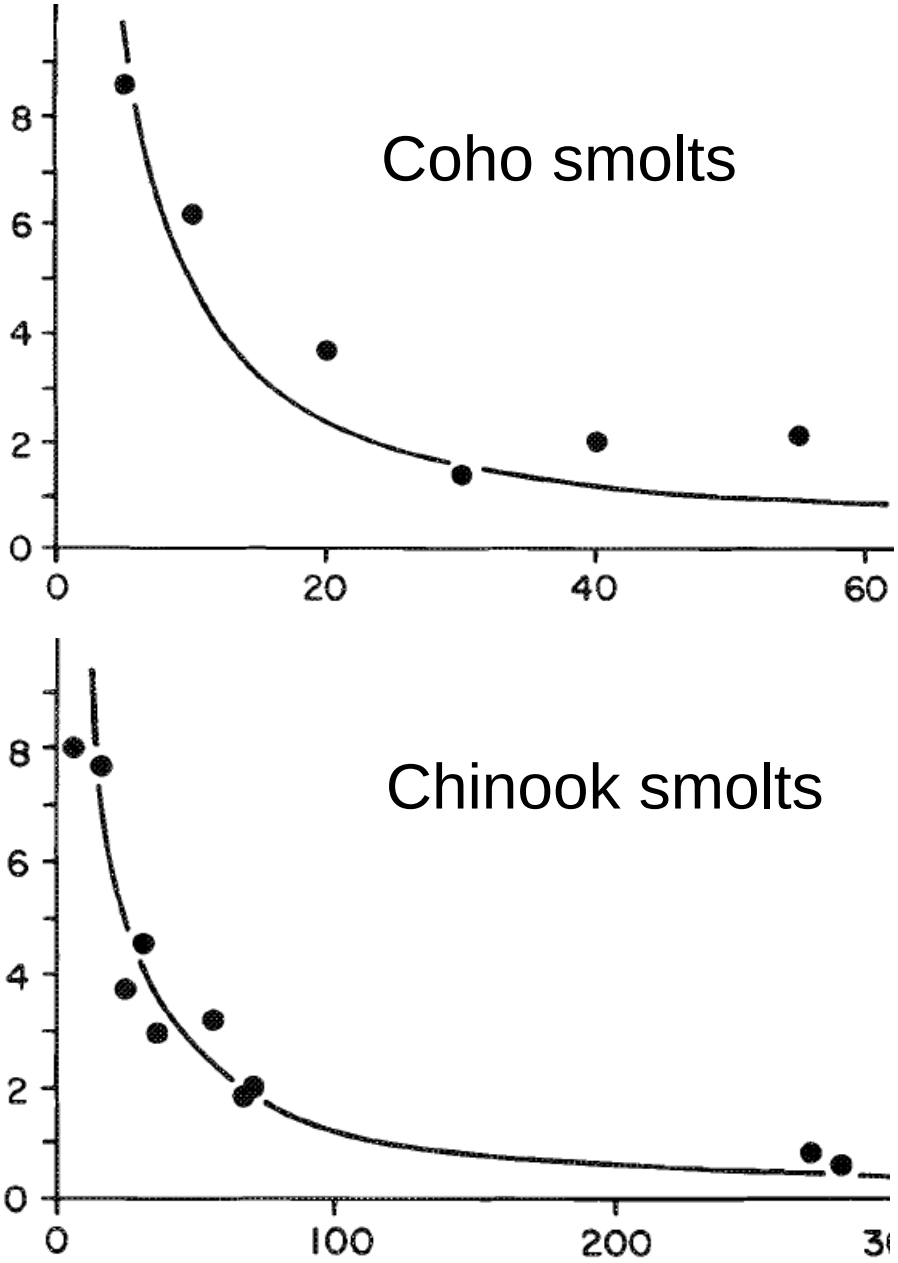
- Productivity **increased** at low abundance and **decreased** at high abundance

Depensation

- Productivity **decreases** at low abundance because of higher predation mortality

Depensation

Max. daily % mortality due to mergansers



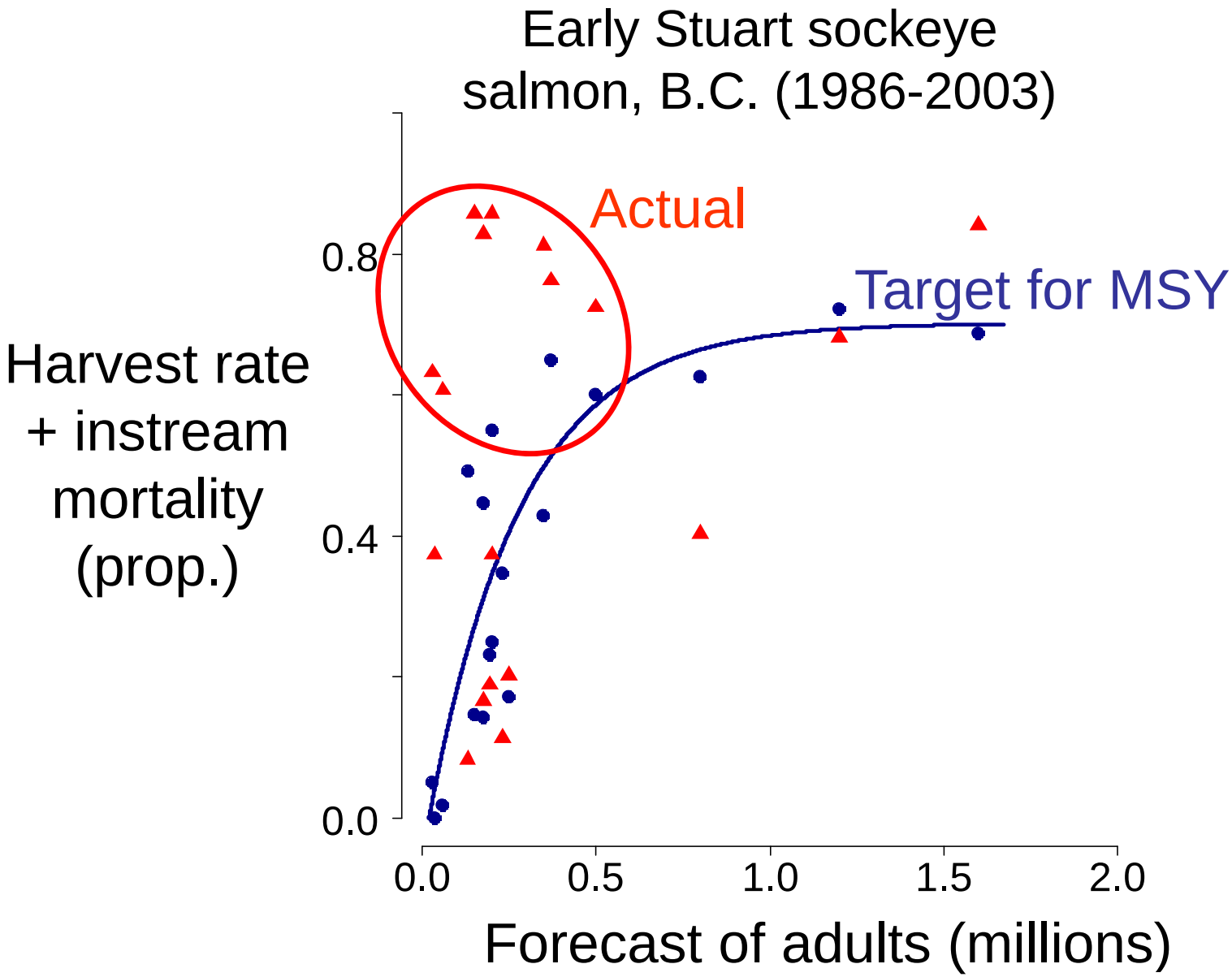
Wood 1987

Predation by marine mammals

Steller sea lions along coast of B.C. and Southeast Alaska

Olesiuk 2018

Depensatory fishing



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Holt and Peterman (2006)

Depensation

- Decrease in abundance of some salmon populations may continue due to predation
- Depensation may prevent rebuilding

Conclusion

Density dependence
Affects growth and/or survival
and occurs ...
- In fresh water and ocean
- Within and between species
- Within and between nations

Management, conservation, and hatchery actions must take these density-dependent effects into account.