Exploring density dependence, delayed density dependence and time varying productivity to explain decreased productivity of Fraser sockeye salmon

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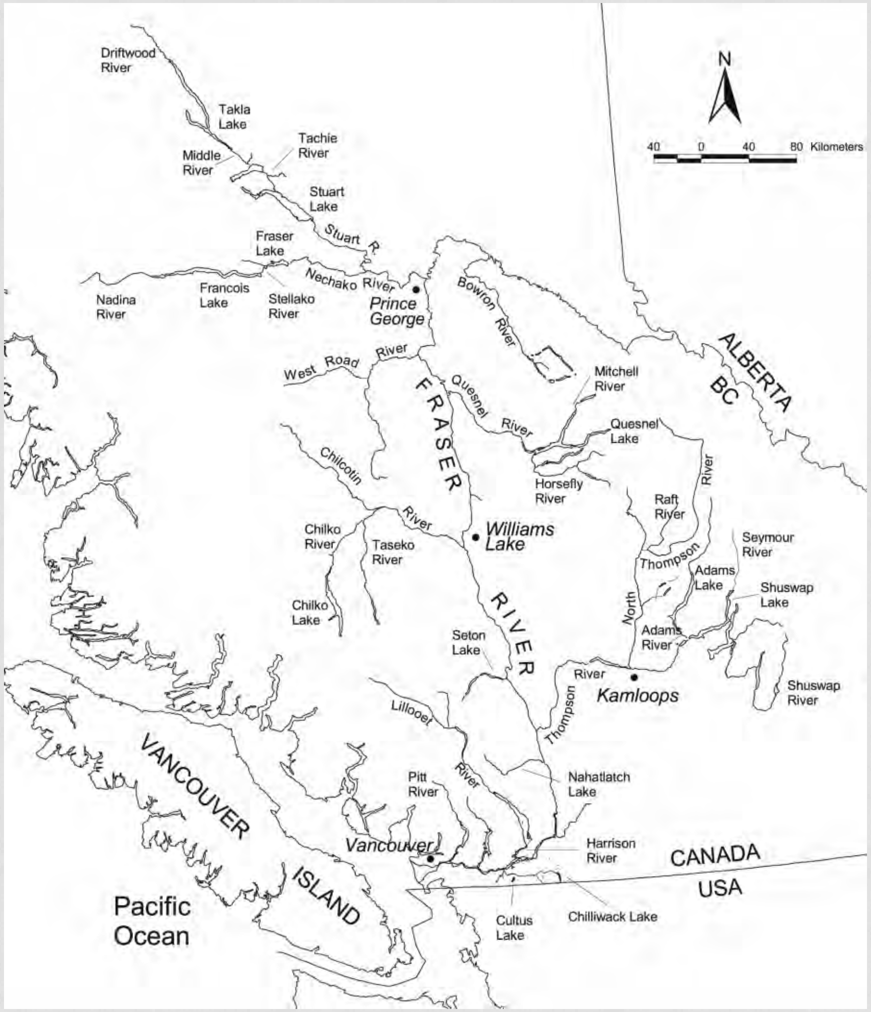
Fraser River sockeye stock-recruit data

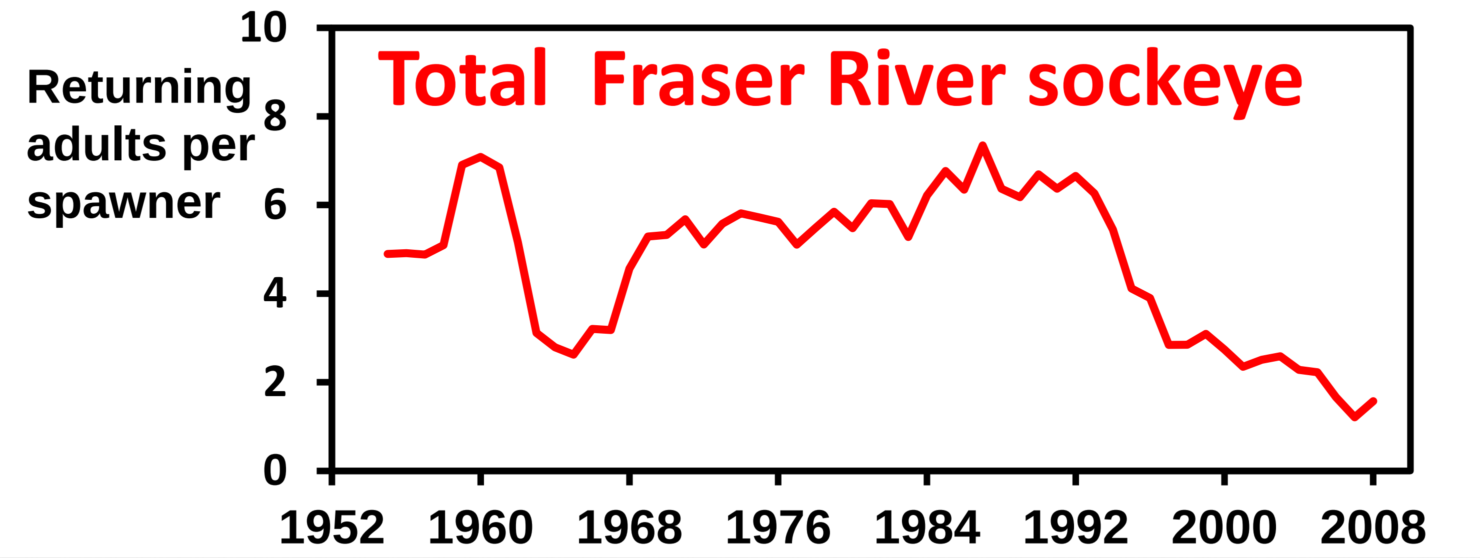
- Fraser River Sockeye stocks located in BC, Canada
- Long stock-recruit time series: 1948 – 2008 brood years
- 19 different stock groups modelled



Decline in productivity of Fraser River Sockeye

2009 catastrophic return

Launch of $26 million Inquiry into the 'collapse of the salmon'



Part of the inquiry was stock-recruit analysis done by Peterman and Dorner[1]

[1]Peterman, R.M. and B. Dorner. 2011. Fraser River sockeye production dynamics. Cohen Commission Tech. Rept. 10:134p. Vancouver, B.C. www.cohencommission.ca

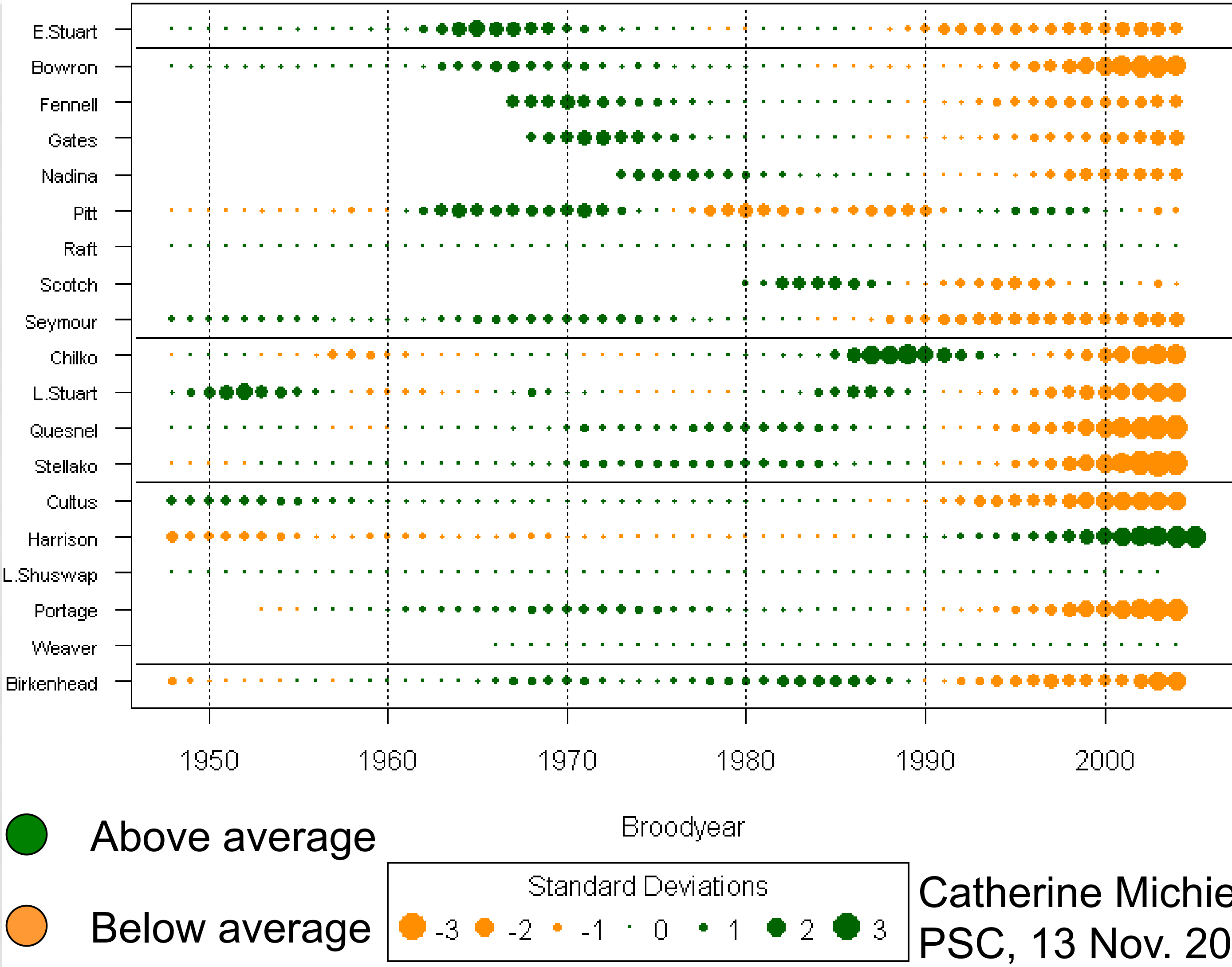
Decline in productivity of Fraser River Sockeye

Peterman and Dorner[1]

- Explored productivity time series, i.e. recruits per spawner
- Removed the density dependent effect in the recruits per spawner data by fitting the data to stock-recruit models
- Productivity is not stationary!
- Estimated a time-varying Ricker *a* parameter to evaluate productivity trends over time
- Evaluated if trends are consistent across stocks
- Concluded that there is a widespread decrease in productivity of sockeye salmon populations in western North America

[1]Peterman, R.M. and Dorner, B. 2012. A widespread decrease in productivity of sockeye salmon populations in western North America. Canadian Journal of Fisheries and Aquatic Sciences 69:1255-1260

Time series of time-varying Ricker *a* parameters as indicators of productivity



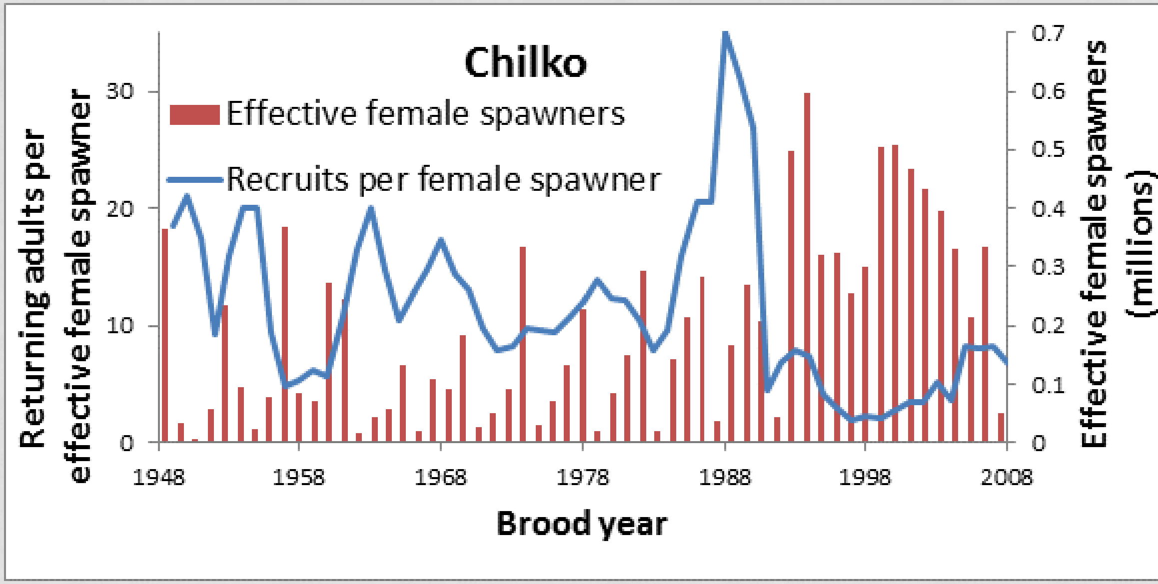
Above average

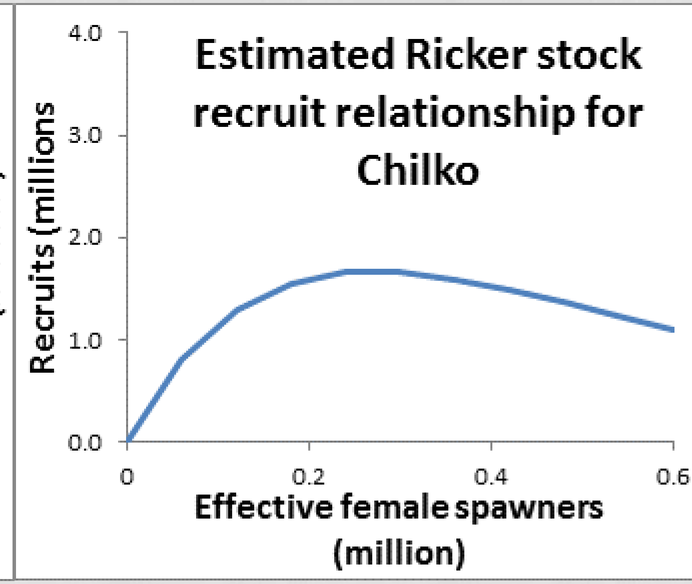
Below average

Catherine Michielsens, PSC, 13 Nov. 2009

Can we use these models for individual stocks?

Decline in productivity of individual stocks





Large spawner abundances can cause the number of recruits to be low due to the limited amount of resources available

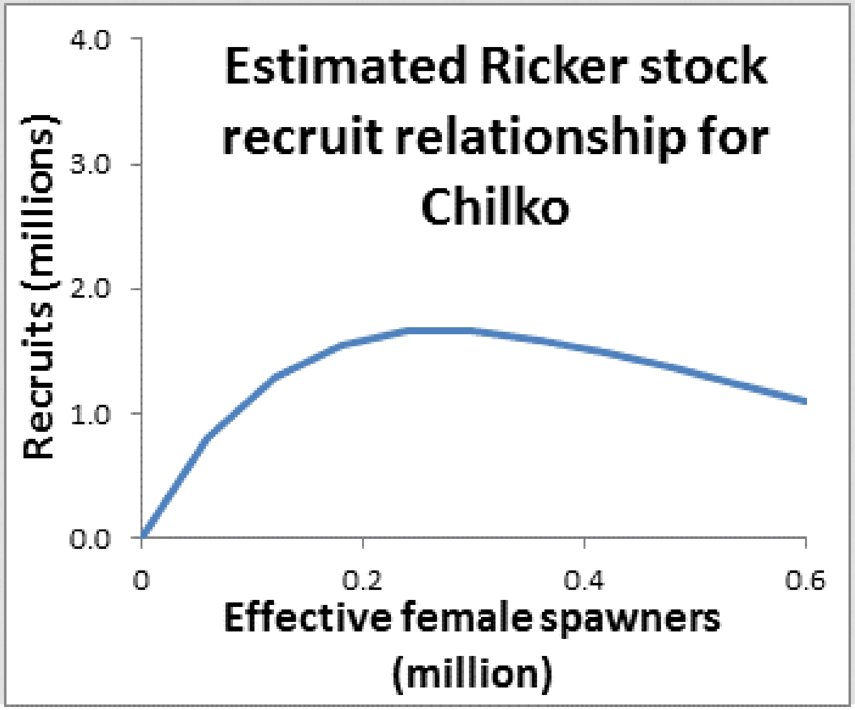
Ricker stock-recruit relationship accounts for density dependence

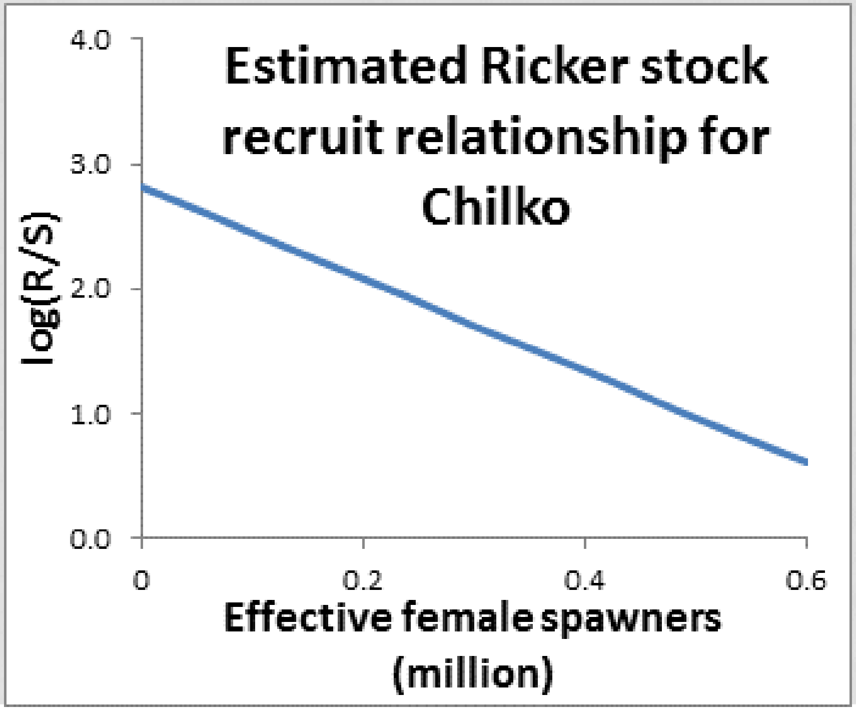
Density dependence (Ricker model)

Ricker stock-recruit relationship can be reformulated in terms of a linear relationship:

$$log_e(R_t/S_t) = a + bS_t + v_t \qquad v_t \sim N(0, \sigma^2)$$

Density dependence can be tested through correlation analyses



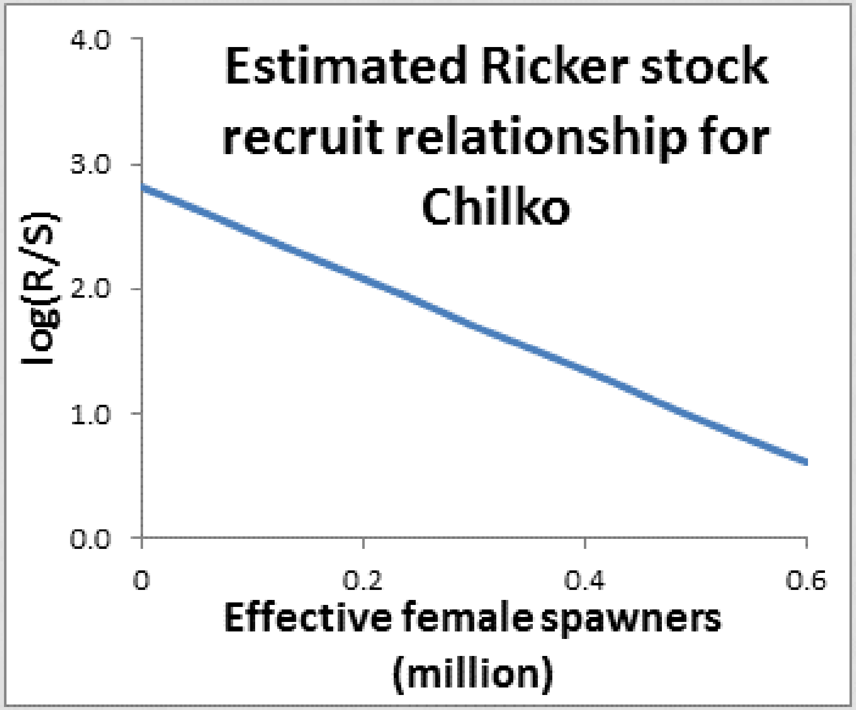


Density dependence

Stock	Correlation
Early Stuart	-0.41 *
Late Stuart	-0.53 ***
Stellako	-0.46 **
Bowron	-0.5 ***
Quesnel	-0.39 *
Chilko	-0.56 ***
Seymour	-0.27
L.Shuswap	-0.26
Birkenhead	-0.6 ***
Weaver	-0.57 **
Fennel	-0.74 ***
Gates	-0.52 **
Harrison	-0.66 ***

P-value: * < 0.01, ** < 0.001, *** < 0.0001

- Density dependence apparent for many but not all stocks
- More complex interactions are possible

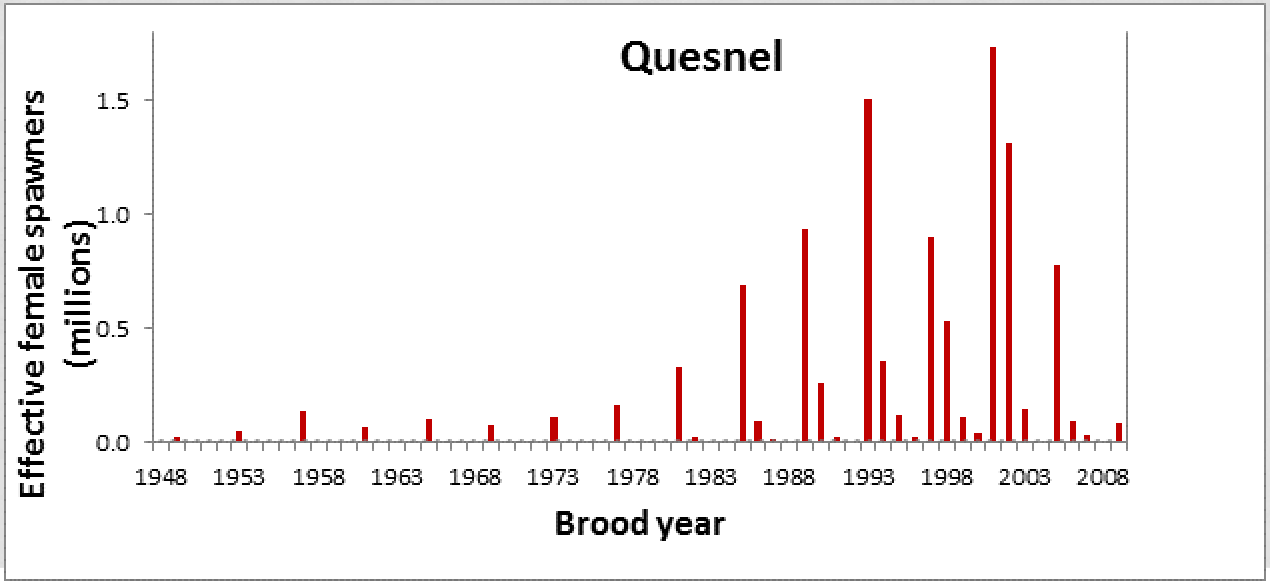


Delayed density dependence (Larkin model)

Large spawner abundances not only affect the number of recruits produced by these spawners but also the number of recruits in subsequent years

This can occur due to depletion of food supplies, increased survival of predators or increased incidence of diseases at high densities

$$log_e(R_t/S_t) = a + bS_t + b_1 S_{t-1} + b_2 S_{t-2} + b_3 S_{t-3} + v_t$$



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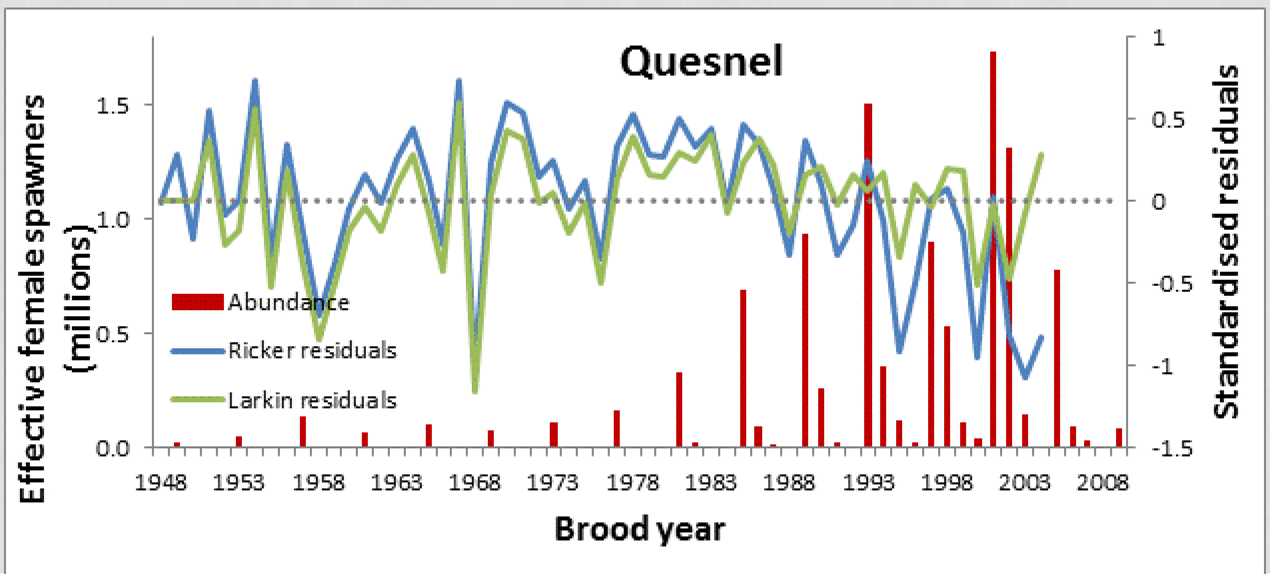


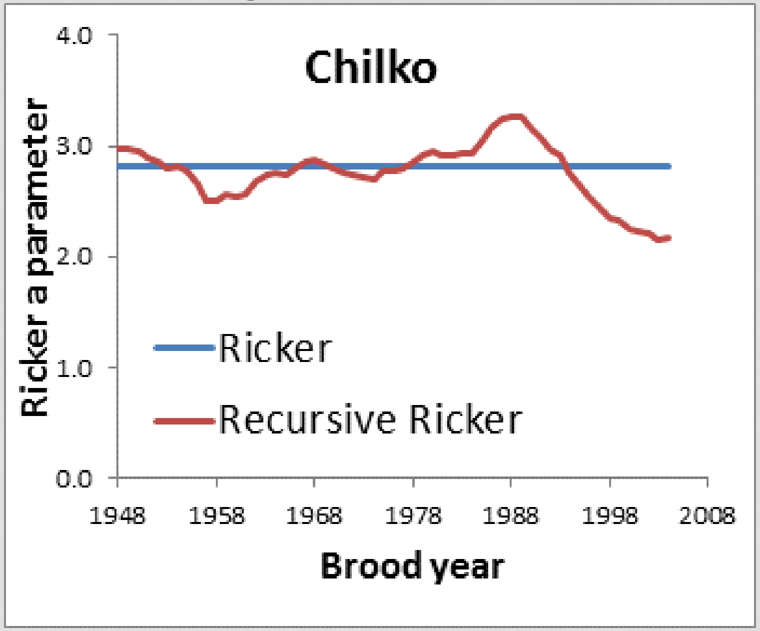
Trends in productivity: Time-varying Ricker *a* parameter

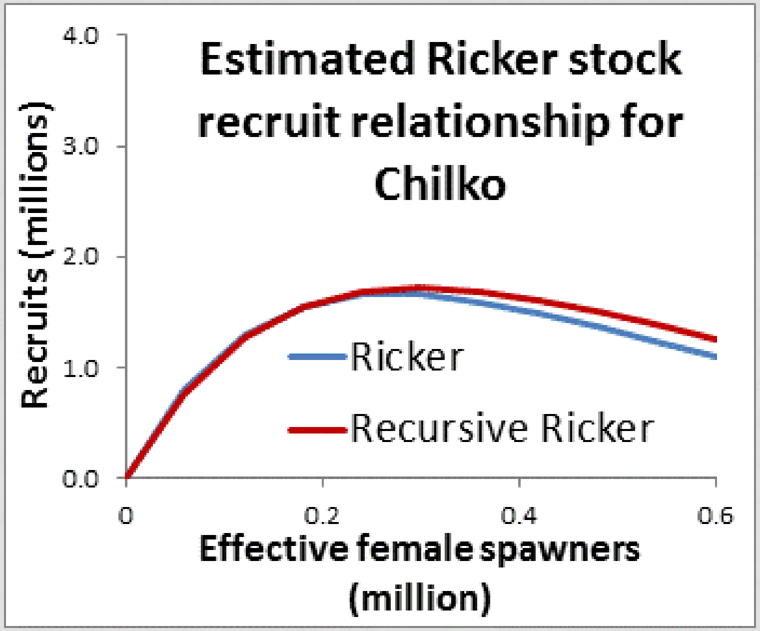
Kalman filter or recursive Ricker model allows us to estimate trends in productivity (Ricker *a* parameter)

$$log_e(R_t/S_t) = a_t + bS_t + v_t \qquad a_t = a_{t-1} + w_t \qquad w_t \sim N(0, \sigma^2)$$

Recursive Ricker model explains the trend in residuals once density dependence has been taken into account

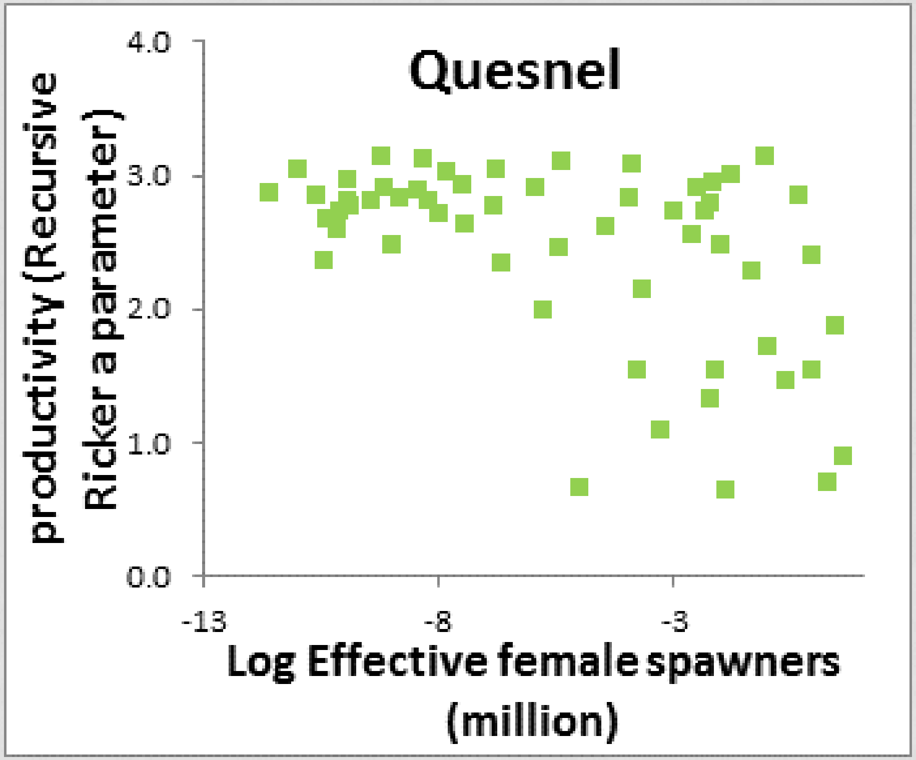
On average, stock-recruit relationships would look the same

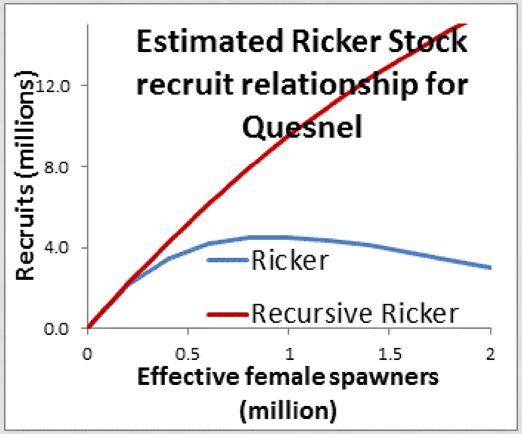


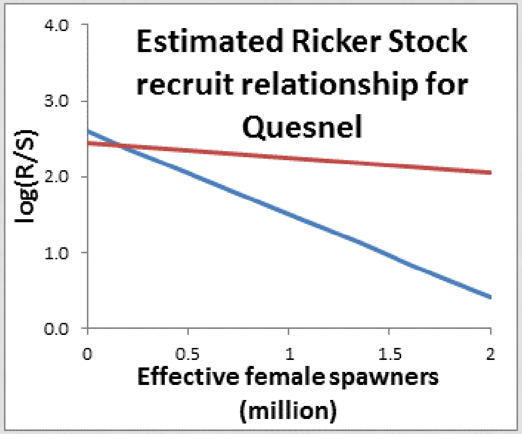


Trends in productivity

Correlation between Spawner numbers and the time varying Ricker *a* parameter would indicate that density dependence is no longer properly accounted for







Kalman or recursive Ricker models may not properly account for density dependence

Correlation	Spawner vs. log (R/S)	Spawner vs. recursive Ricker *a* parameter
Early Stuart	-0.41 *	-0.33
Late Stuart	-0.53 ***	-0.42 *
Stellako	-0.46 **	-0.44 **
Bowron	-0.5 ***	0.08
Quesnel	-0.39 *	-0.51 ***
Chilko	-0.56 ***	-0.16
Seymour	-0.27	-0.26
L.Shuswap	-0.26	0
Birkenhead	-0.6 ***	-0.24
Weaver	-0.57 **	-0.45 *
Fennel	-0.74 ***	-0.7 ***
Gates	-0.52 **	-0.57 **
Harrison	-0.66 ***	0

P-value: * < 0.01, ** < 0.001, *** < 0.0001

Cyclic stocks

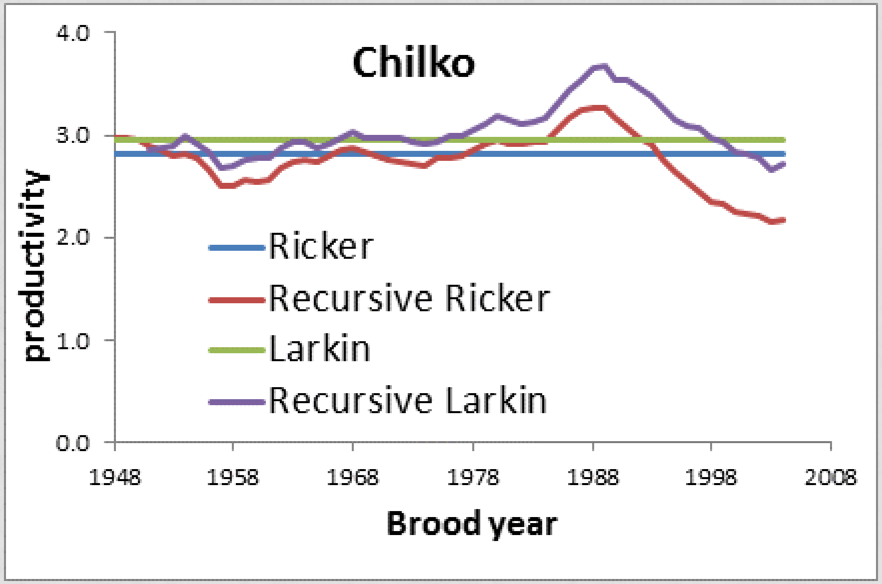
The Kalman filter or recursive Ricker model will attribute the lower recruits per spawner on the dominant cycle to lower overall productivity

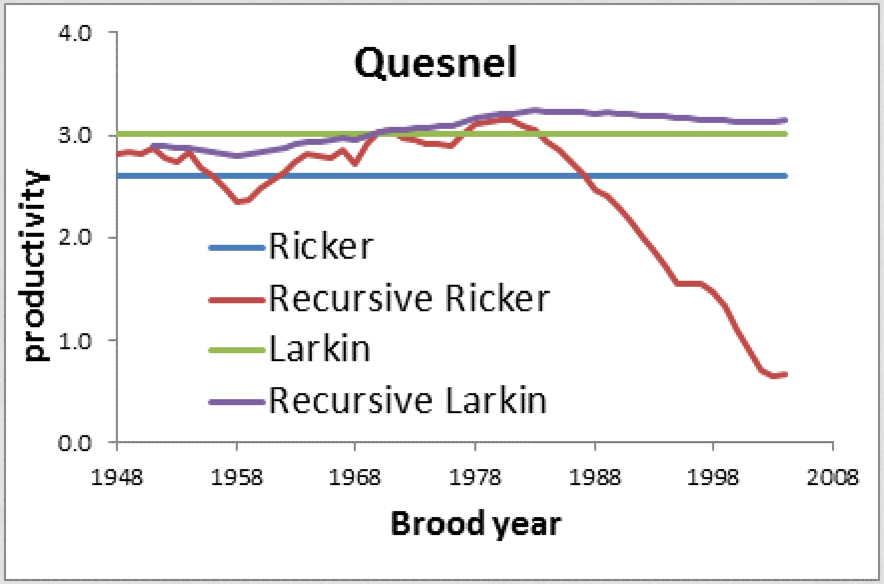
Recursive Larkin model with time varying *a* parameter

Recursive Larkin models account for cycle line interactions

$$log_e(R_t/S_t) = a_t + bS_t + b_1 S_{t-1} + b_2 S_{t-2} + b_3 S_{t-3} + v_t$$

$$a_t = a_{t-1} + w_t \qquad w_t \sim N(0, \sigma^2)$$





Recursive Larkin models may be more appropriate for cyclic stocks

Conclusion

- Kalman filter or recursive Ricker models are excellent for evaluating productivity trends over time across a wide range of stocks
- But may not be the most appropriate for particular stocks e.g. stocks displaying cyclic dominance
- The Kalman filter or recursive Ricker model will attribute the lower recruits per spawner on the dominant cycle to lower overall productivity
- Recursive versions of alternative models may be more appropriate e.g. Recursive Larkin model
- Easy to derive benchmarks based on recursive Ricker models but difficult to do the same for recursive Larkin models
- Using recursive Ricker models to derive benchmarks may not be appropriate for some of the stocks

General conclusion

- Meta analyses of data from a wide range of populations or stocks covering large geographical areas are useful to find general patterns in the data
- General conclusions are easier to communicate
- But particularities of individual stocks or populations are easily brushed aside
- Care should be taken when using results from those broad scale analyses to draw conclusions about individual populations or stocks

Thank you!

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