"Kalman-filter reconstructions of temporal variation in productivity of Northeastern Pacific salmon"

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Acknowledgments

- Other collaborators
  - Chris Wood
  - Dan Ware
  - Carrie Holt
  - Mike Bradford
  - Zhenming Su
  - Steve Haeseker

- Agencies
  - Washington Dept. of Fish and Wildlife
  - Canada Dept. of Fisheries and Oceans
  - Pacific Salmon Commission
  - Alaska Department of Fish and Game

Outline

1. Research objective: Understand variation in productivity of Pacific salmon

2. Past results
   - Spatial scale of positive covariation in …
     -- Salmon productivity
     -- Environmental variables

3. New results
   - Do we get same conclusions when we account for observation error in salmon data using a Kalman filter?

1. Research objective

What are the key environmental sources of variation in salmon **productivity (~ recruits/spawner)?**

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Data on 120 salmon stocks

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Data on 120 salmon stocks

2nd step: Screening

Identify environmental variables with similar spatial scale to that of salmon productivity

Data on environmental variables: coastal SST, coastal salinity, upwelling

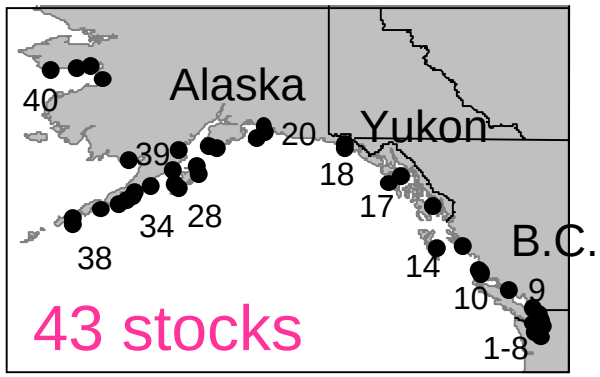
2. Results of past research

What is the spatial scale (extent) of positive correlation in productivity among salmon stocks?

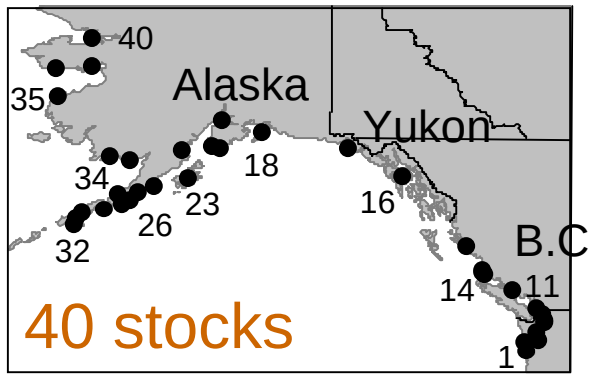
- Abundance data (1950s to 2001)
  - Spawners (S), catch, adult recruits (R)

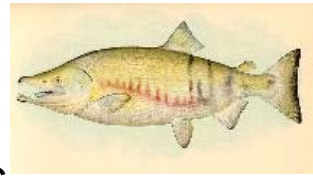
120 salmon stocks; averaging 31 years of S-R data

Pink salmon

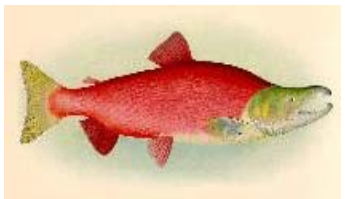


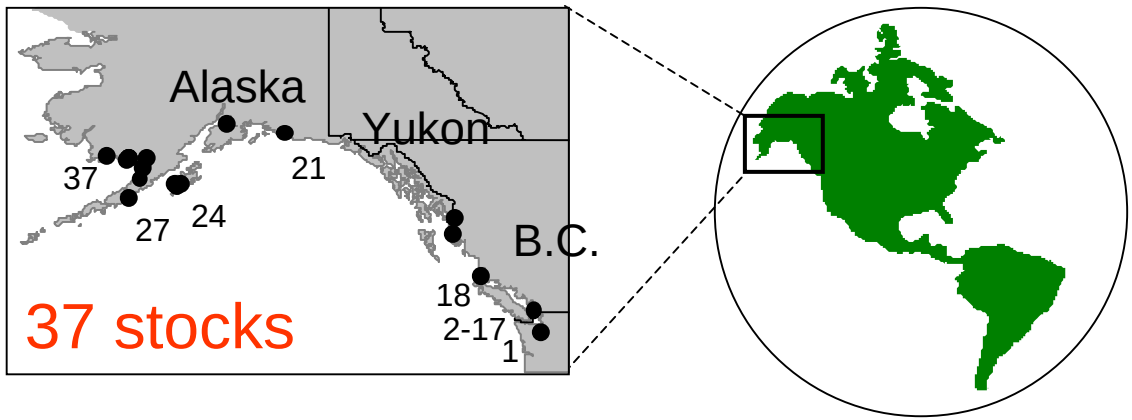
Chum salmon



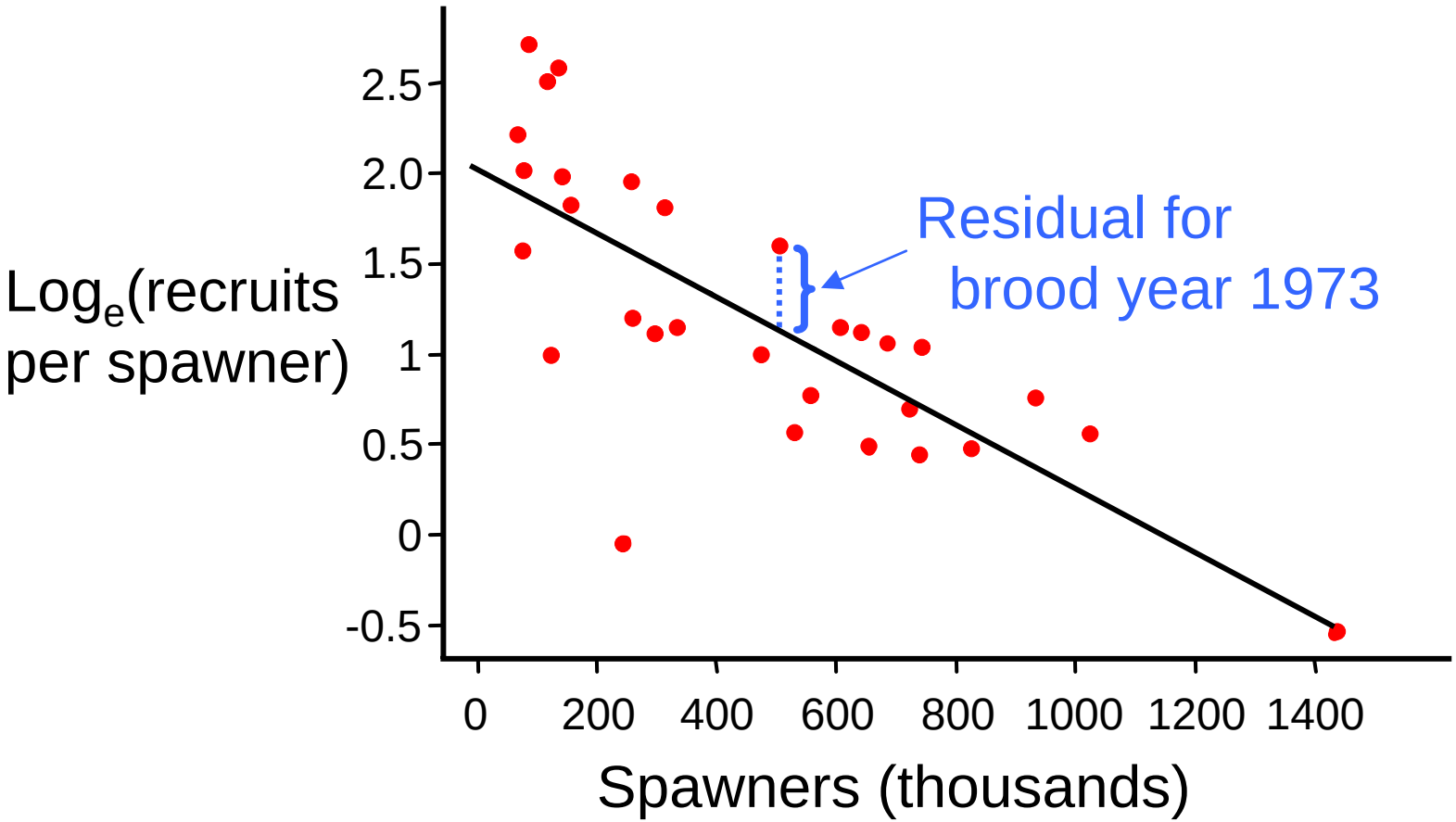


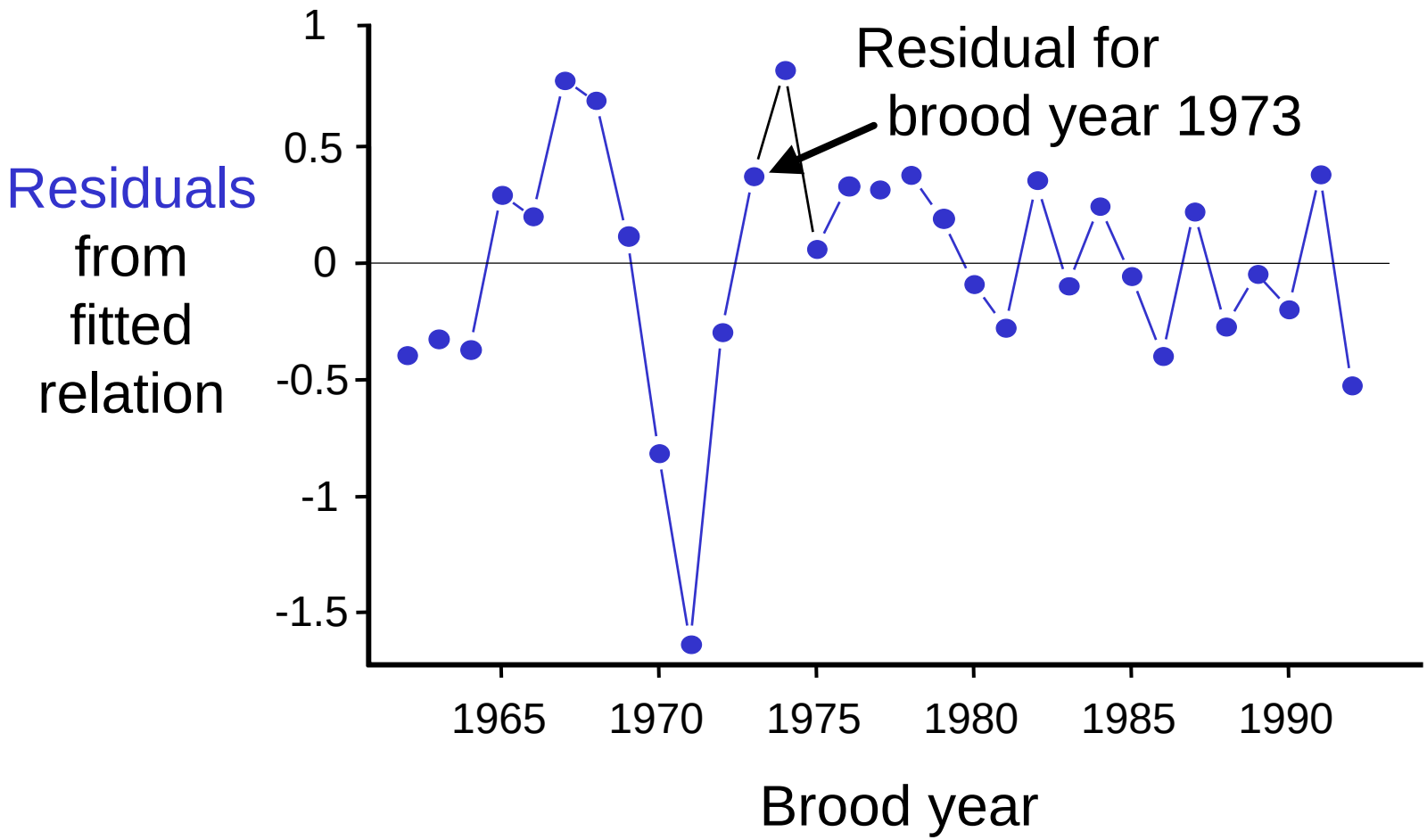
Sockeye salmon





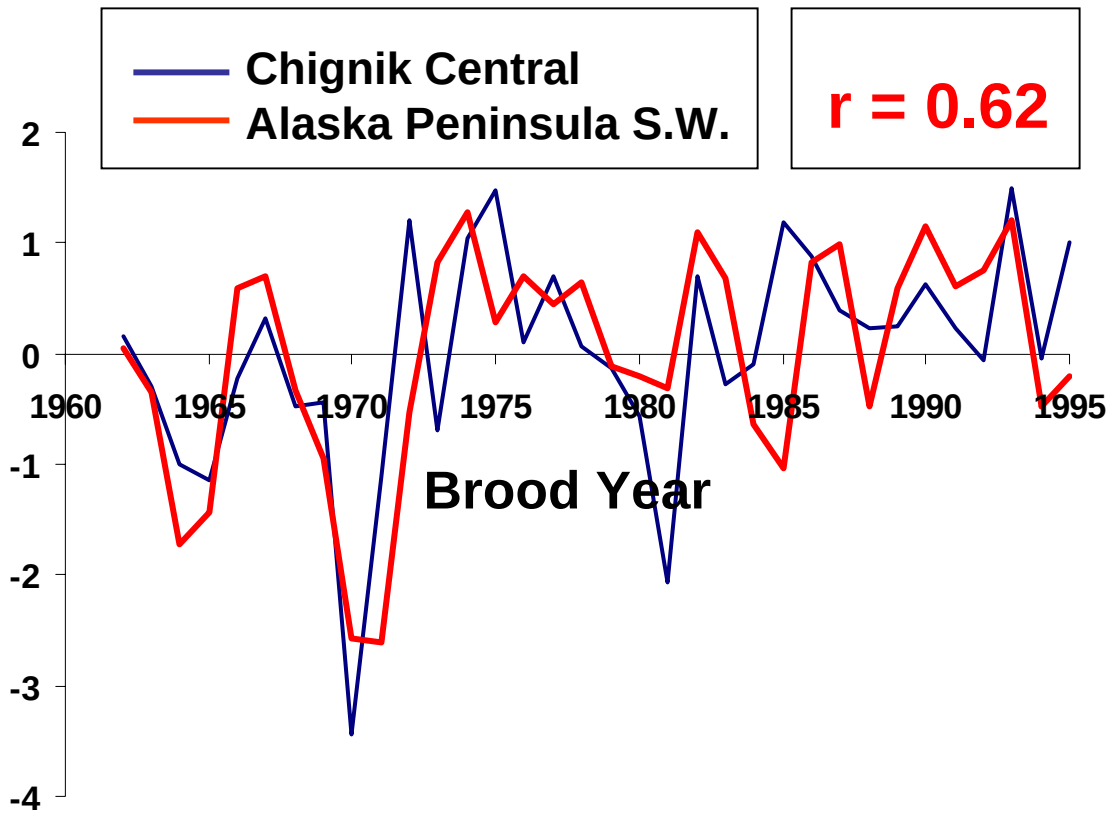
Removed within-stock density-dependent effect



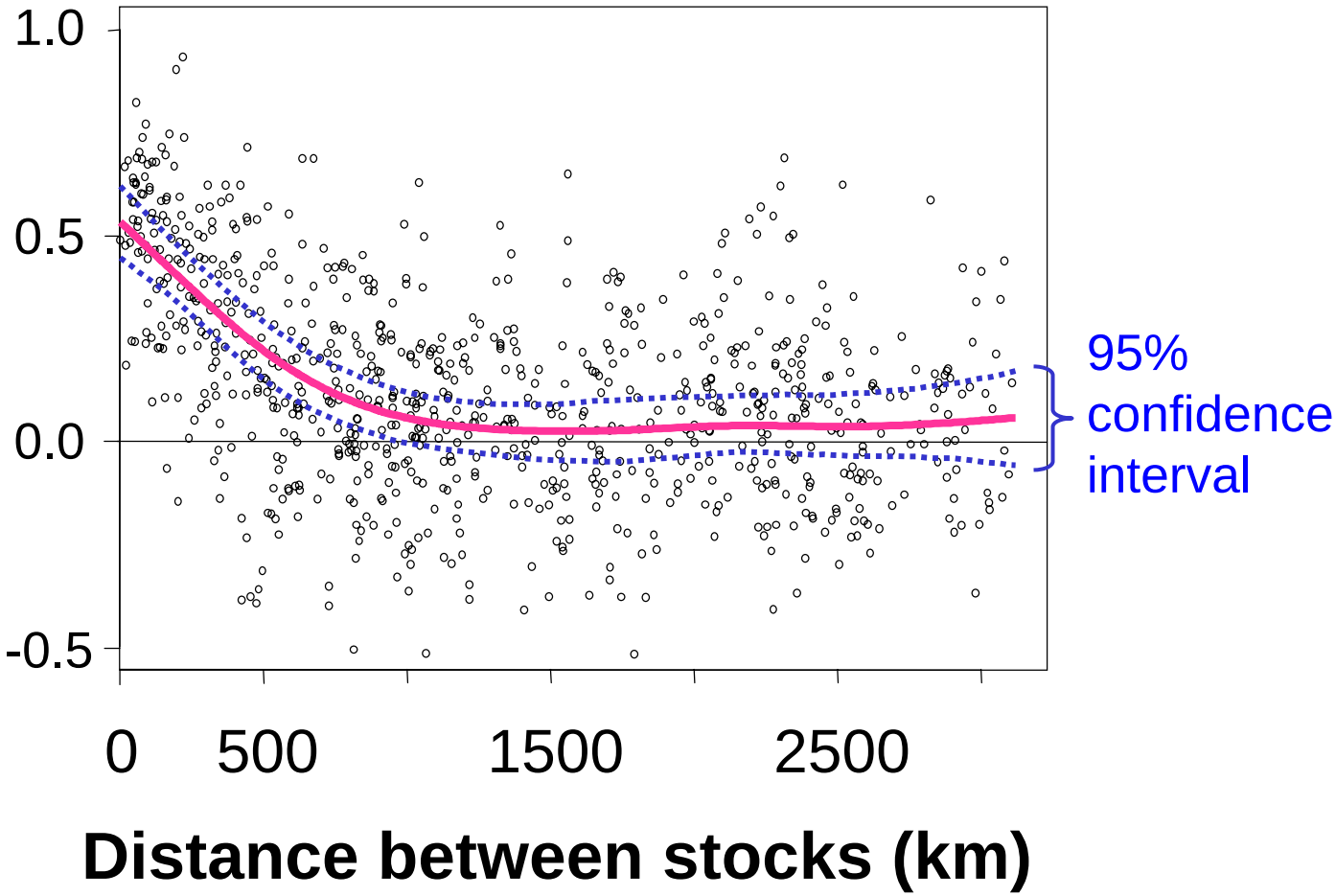

Residuals from fitted relation
1
0.5
0
-0.5
-1
-1.5
Residual for brood year 1973
1965
1970
1975
1980
1985
1990
Brood year

Pink salmon

Standardized residuals (mean=0, SD =1)

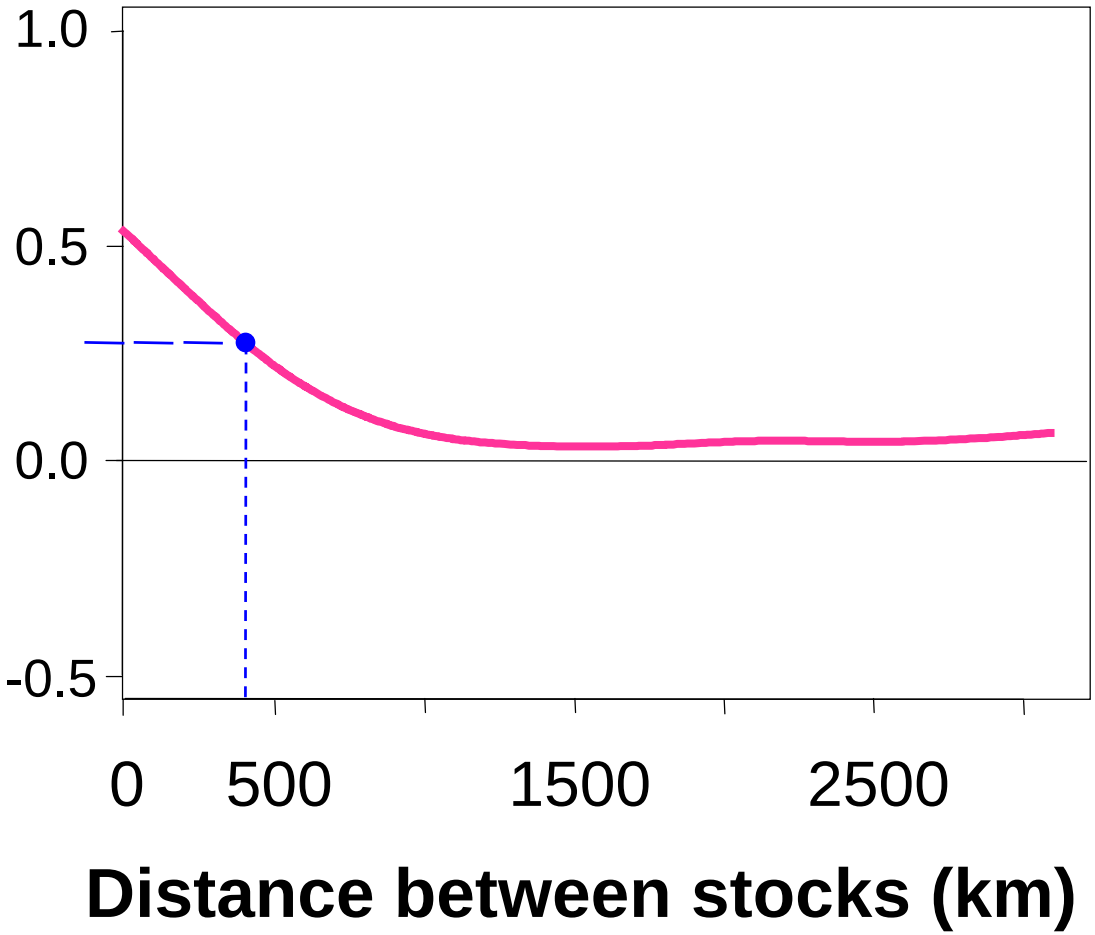


Pairwise correlations in productivities among 43 **pink** salmon stocks



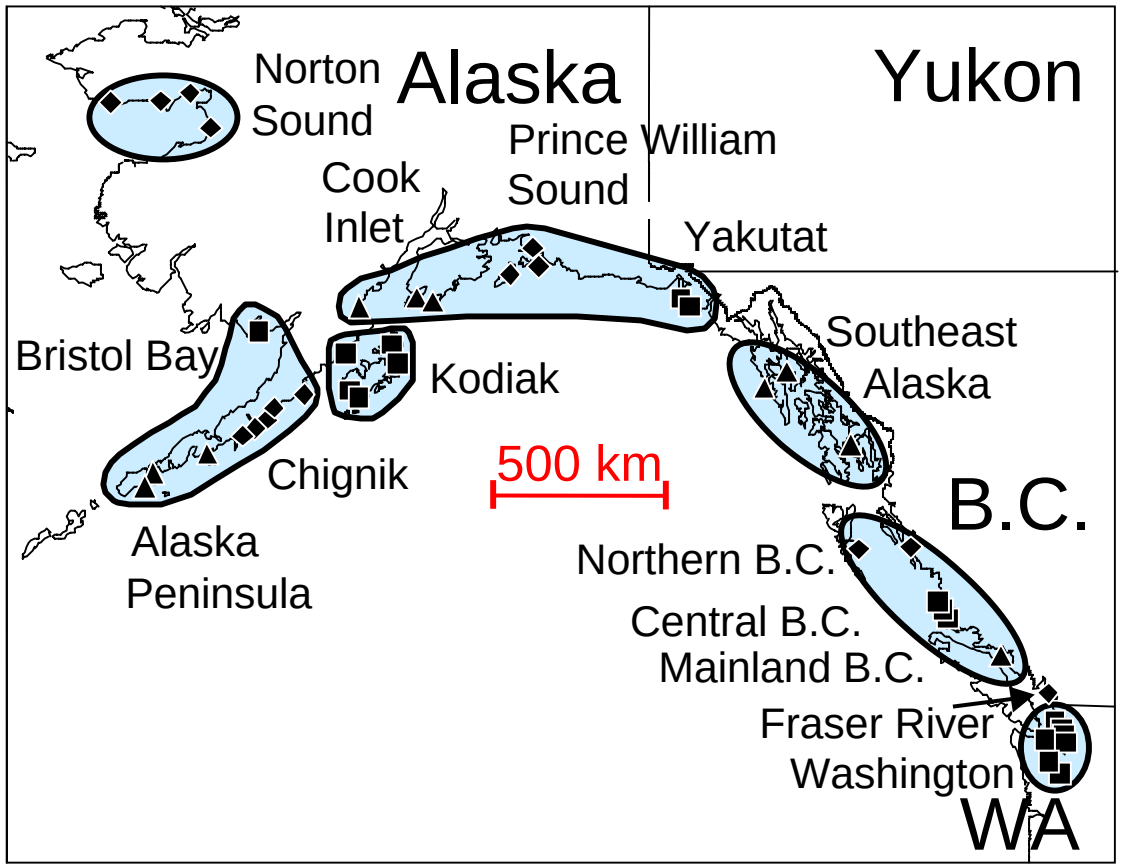
Mueter et al. 2002 *Fish. Oceanog.*

Average correlations in productivities among 43 **pink** salmon stocks

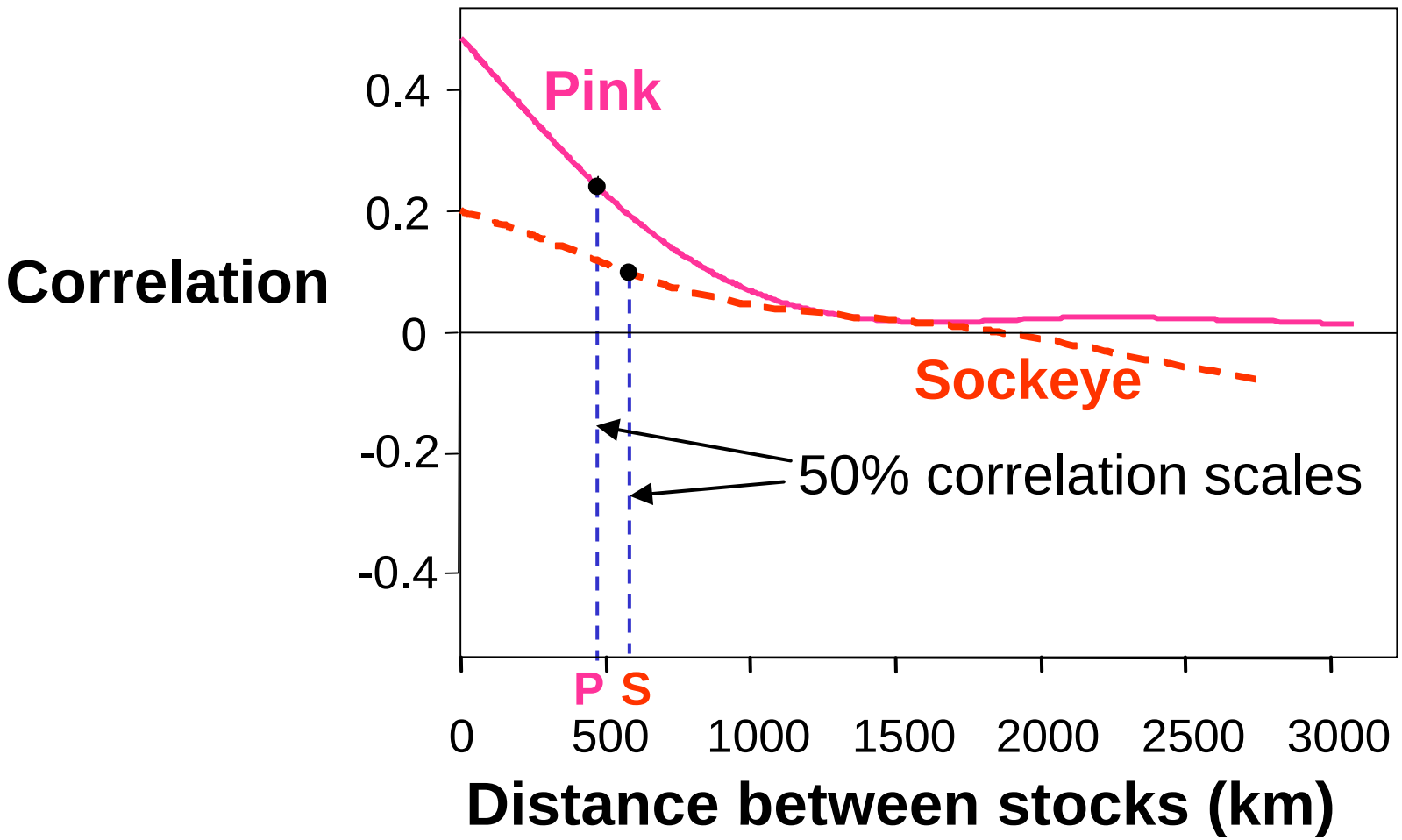


Mueter et al. 2002 *Fish. Oceanog.*

Regions of positive correlation in productivity of pink salmon stocks



Pyper et al. (2001) *CJFAS*



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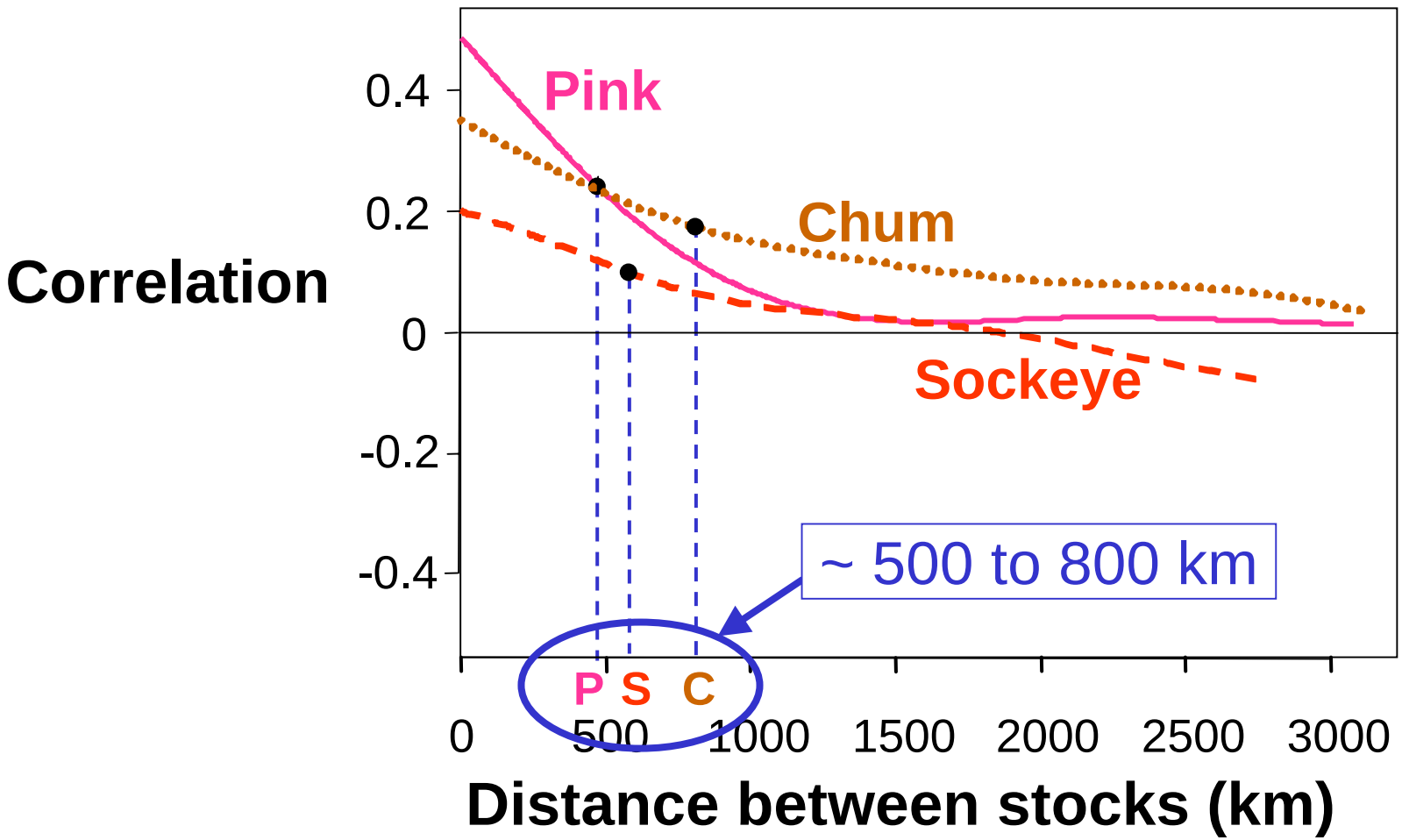
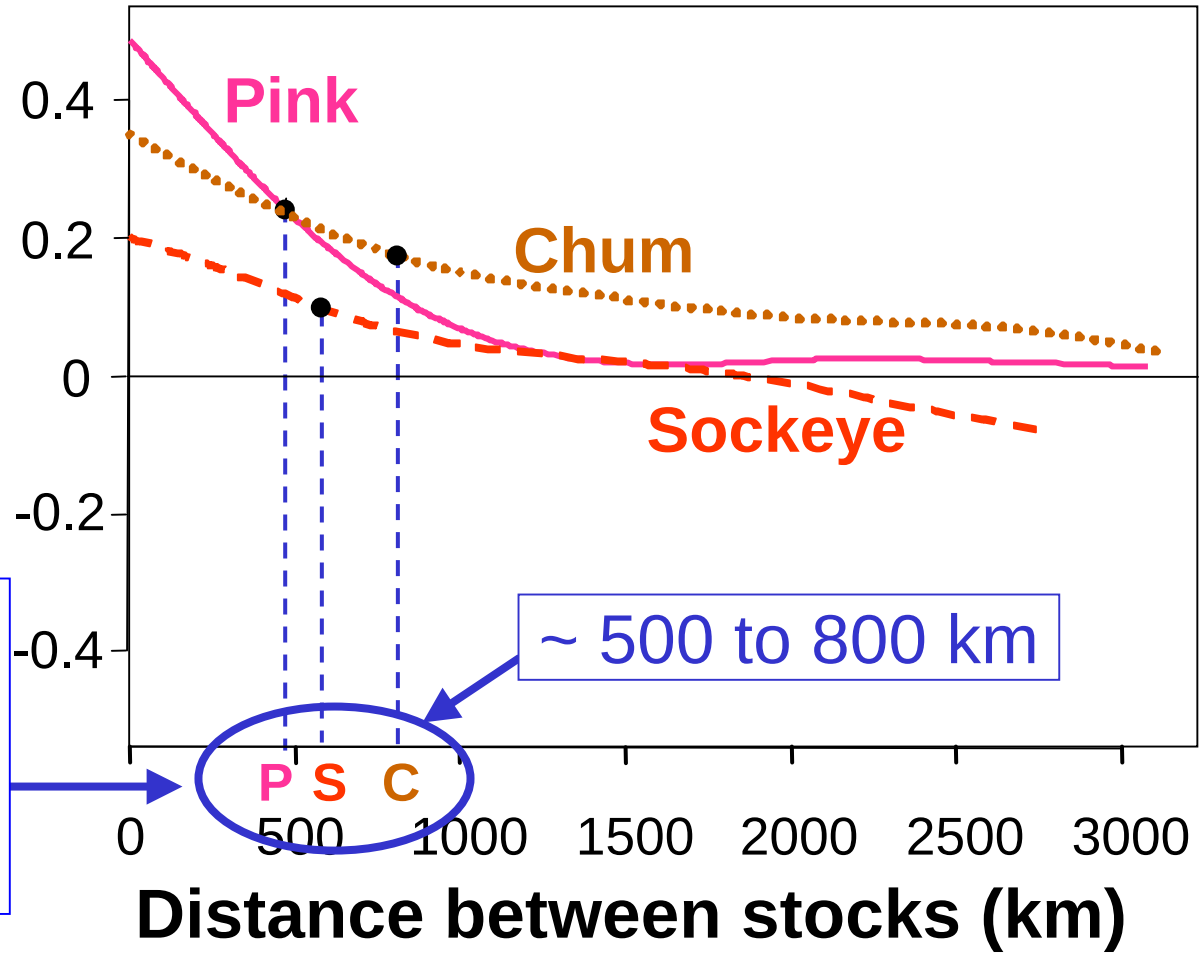


Mueter et al. (2002) *Fish. Oceanog.*



Also, correlation scale between **pink-chum** is ~ 500 km

~ 500 to 800 km

Pyper et al. (2005) *TAFS*

Mueter et al. (2002) *Fish. Oceanog.*

Conclusion on spatial scale

- Regional-scale (~ 500 to 800 km)
  - Positive correlation in productivity among stocks -- pinks, chum, sockeye

Mechanisms, part 1

At which life stage does most covariation arise?

Late freshwater or early ocean life stages

- Sockeye salmon (Peterman et al. 1998)
- Pink salmon (Pyper et al. 2001)
- Chum salmon (Pyper et al. 2002)

Mechanisms, part 2

What is driving spatial covariation in productivities?

- Which environmental variable(s) have a similar (i.e. regional) spatial scale to that of salmon productivities (~ 500 to 800 km)?

  - Upwelling?
  - Coastal sea-surface temperature (SST)?
  - Coastal sea-surface salinity?

- Result:

Summer sea-surface temperature spatial scale ~ 500 km, same as salmon productivity

- Added summer SST as explanatory variable to models of salmon productivity

  - Regional SST was specific to each stock's location of ocean entry

- 16 models that *included* summer SST fit much better than 8 models *without* SST

Mueter et al. (2002a,b)
Fish. Oceanog. and CJFAS, and Su et al. 2004 CJFAS

- Repeated analyses with PDO (large-scale index)
  - PDO was less important than regional SST

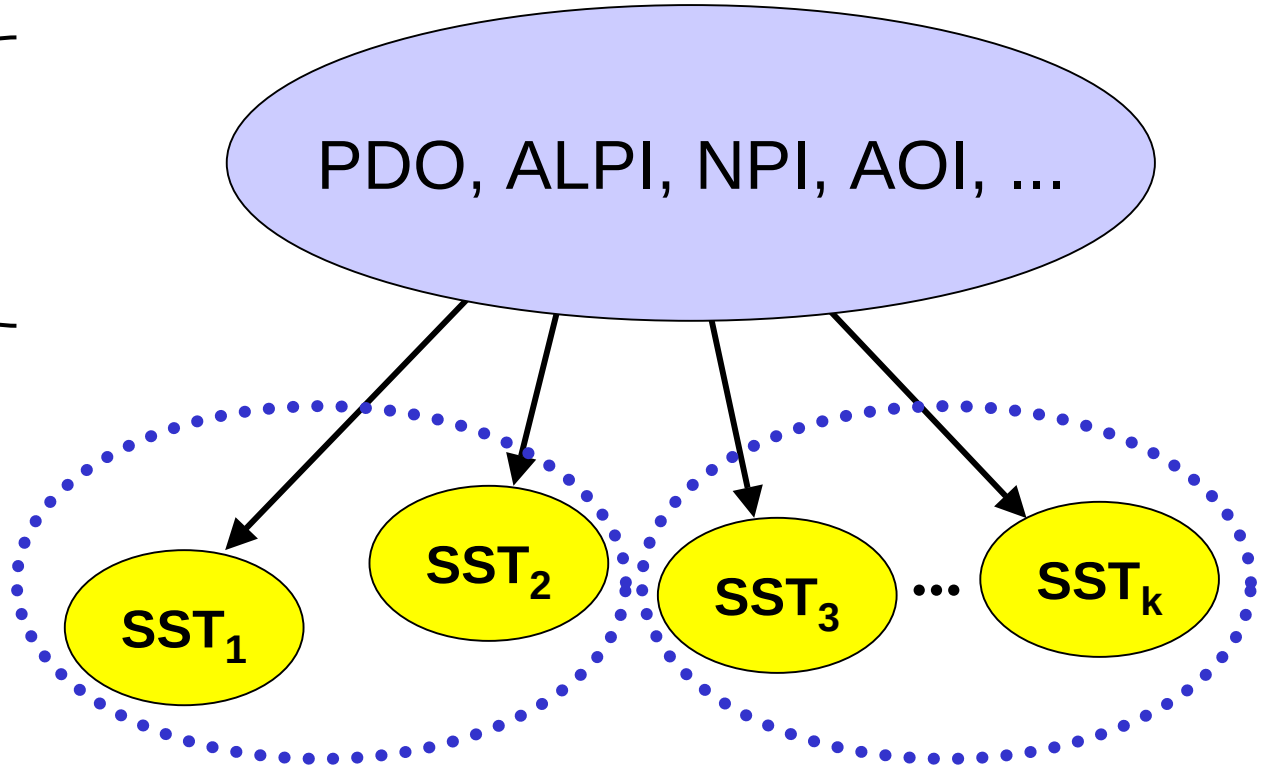
- Therefore, environmental processes at the regional scale are the most important

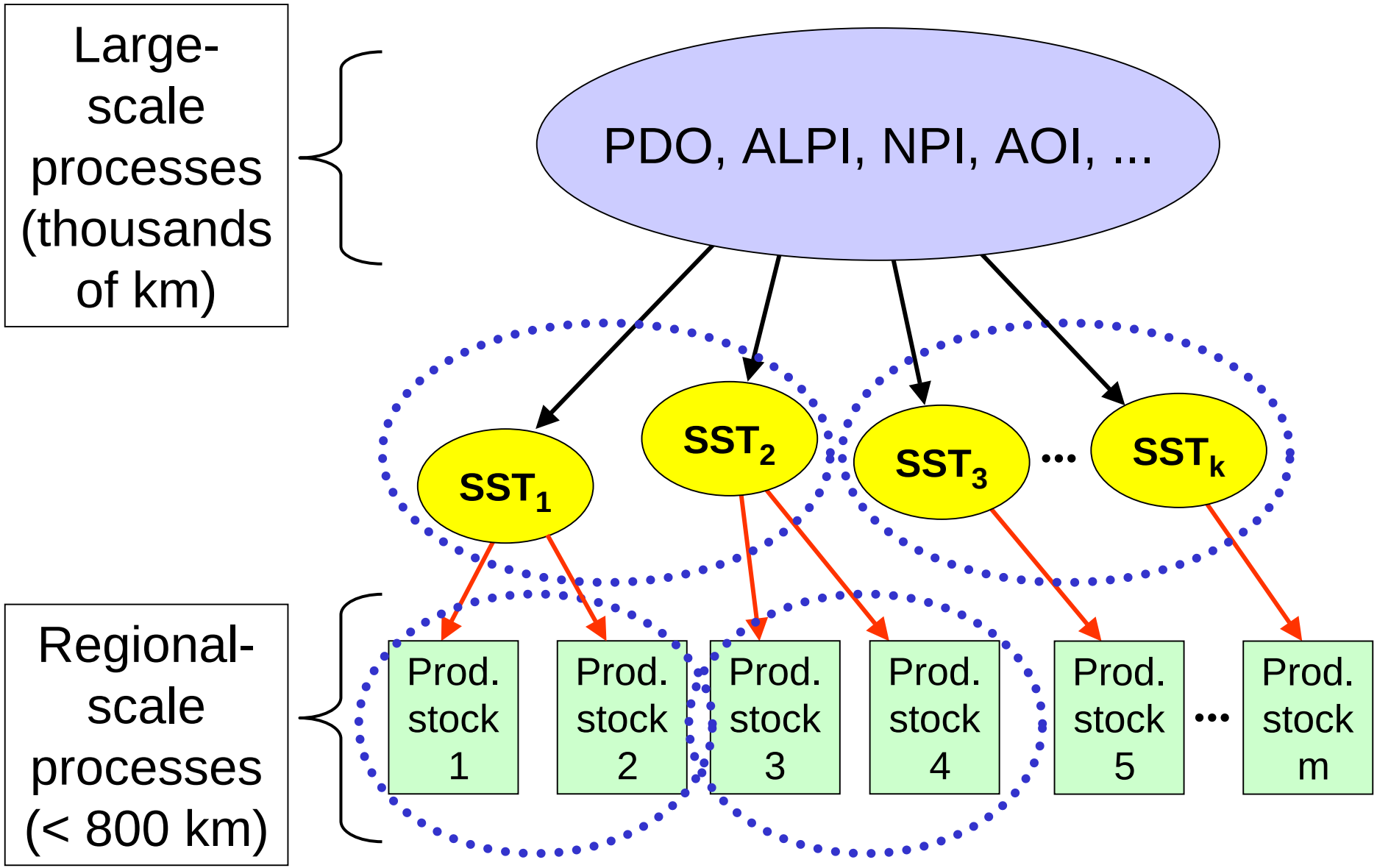
  - Larger, ocean-basin scale processes reflected by PDO, AOI, etc. may drive large-scale forcing, but there are different responses in different regions.

Mueter et al. (2002) *CJFAS*


Large-scale processes (thousands of km)
PDO, ALPI, NPI, AOI, ...

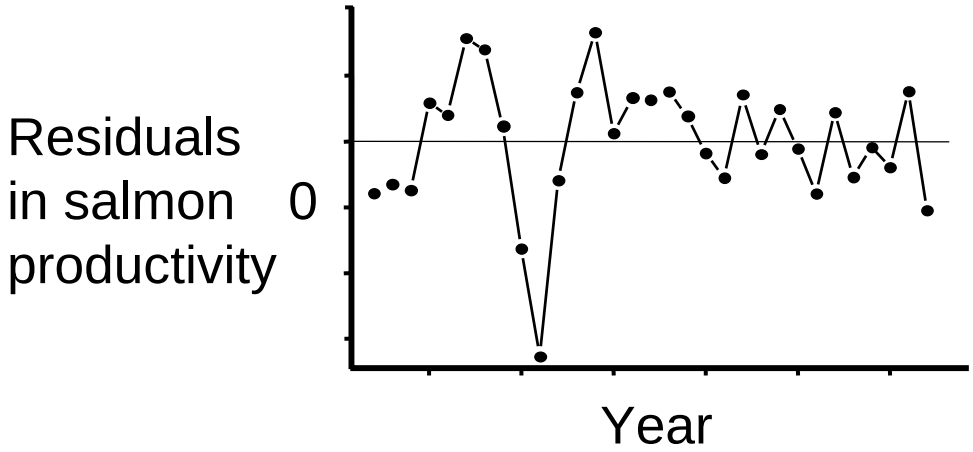
Large-scale processes (thousands of km)




Large-scale processes (thousands of km)
PDO, ALPI, NPI, AOI, ...
SST1
SST2
SST3
...
SSTk
Regional-scale processes (< 800 km)
Prod. stock 1
Prod. stock 2
Prod. stock 3
Prod. stock 4
Prod. stock 5
...
Prod. stock m

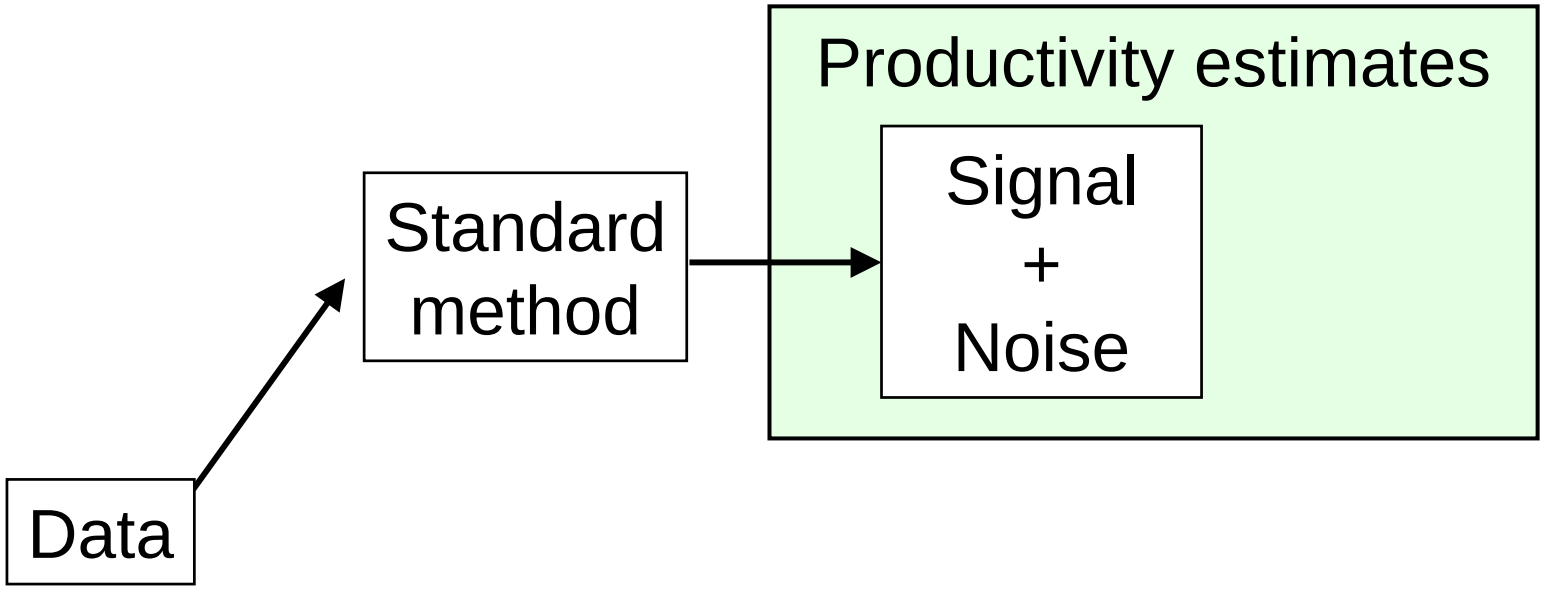
3. New results that account for observation errors

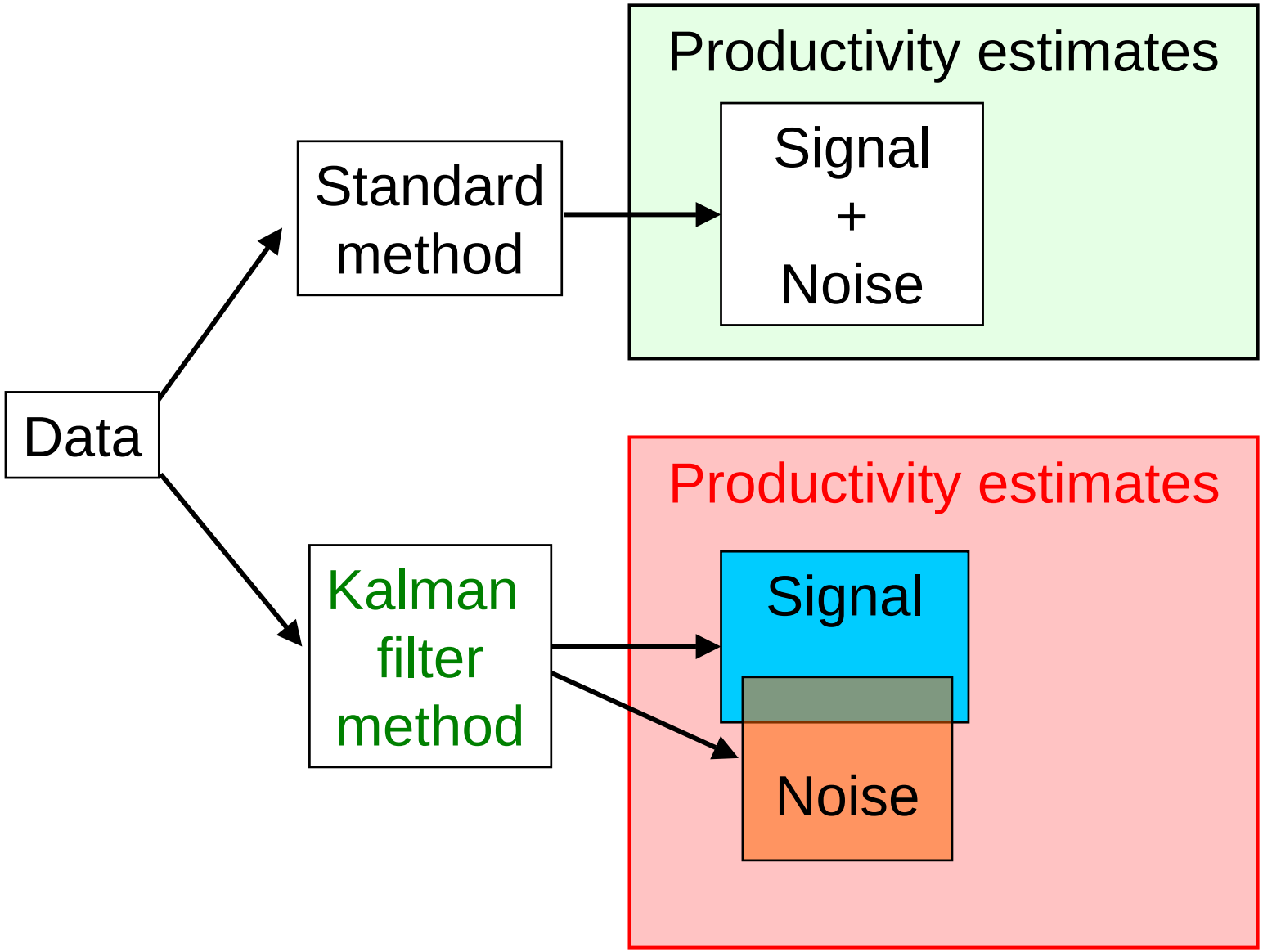
- Errors in estimation of abundance of spawners and recruits (observation error = "noise")



- Interested in process variation (="signal"), not in "noise"

- Used Kalman filter method
  - From engineering
  - Helps detect "signal" amid "noise"


Productivity estimates
Signal
+
Noise
Standard
method
Data



Peterman et al.
2000 *CJFAS*

- Brian Pyper's (*in prep.*) comparisons of Kalman filter versions of Ricker stock-recruitment model

- Found time-varying Ricker *'a'* model was best for most salmon populations

Do we draw same conclusions as before when we use Kalman filter estimates of productivity ?

Standard method (least squares)

$$\ln(R_t / S_t) = a - bS_t + u_t$$

R = adult recruits
S = spawners

- Constant *a* and *b* parameters

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- Constant *a* and *b* parameters

Kalman filter method

"Observation" equation

$$\ln(R_t / S_t) = a_t - bS_t + v_t$$

Note: time-varying Ricker *a* parameter

"System" equation

$$a_t = a_{t-1} + w_t$$

"random walk"

- Estimates a_t each year

Peterman et al. (2000) *CJFAS*

Independent testing of methods is rarely done

We tested via simulations:

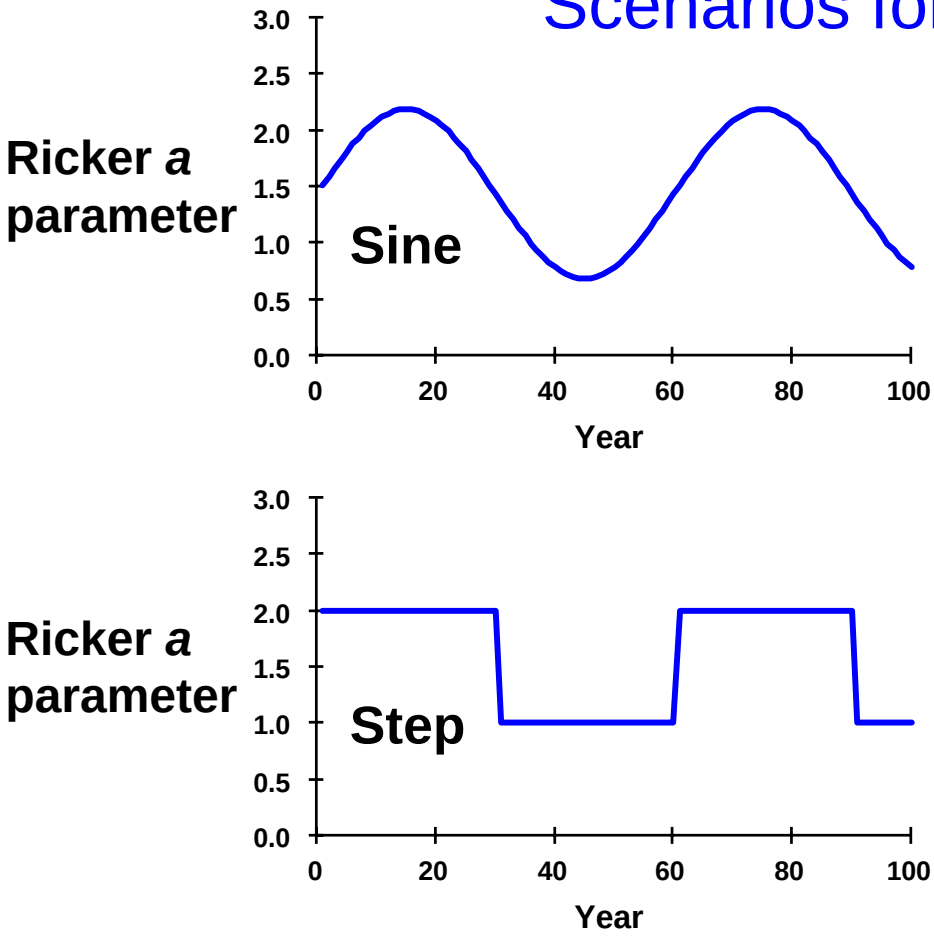
- Standard method
- Kalman filter method
- ...

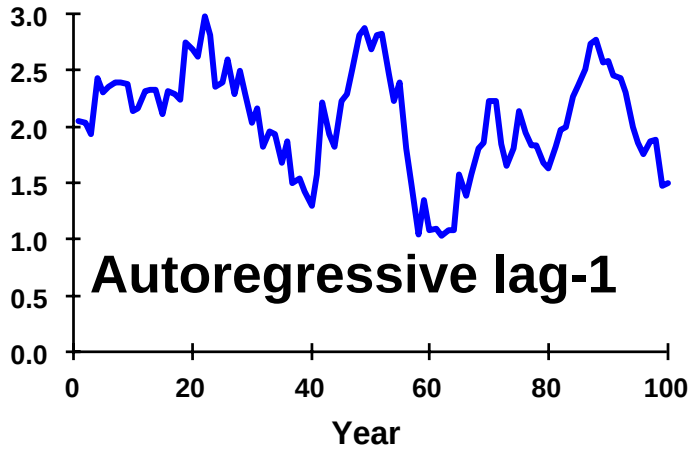
1. Specified hypothetical "true" change in Ricker a_t parameter, then:
   - Generated population dynamics stochastically

2. Estimated underlying parameters from simulated data

3. Compared estimates with "true" values

Scenarios for "true" Ricker *a* ("signal")

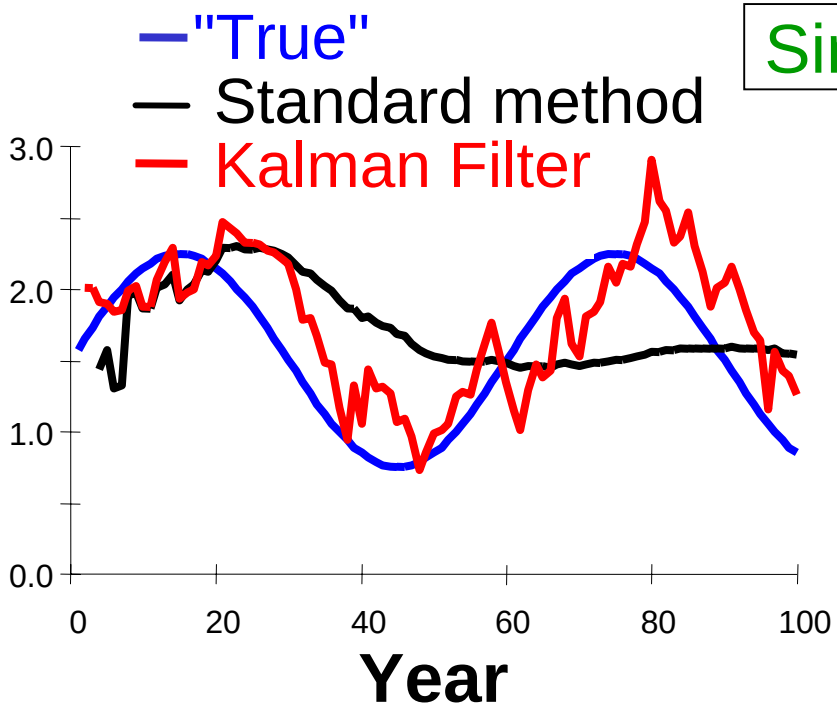




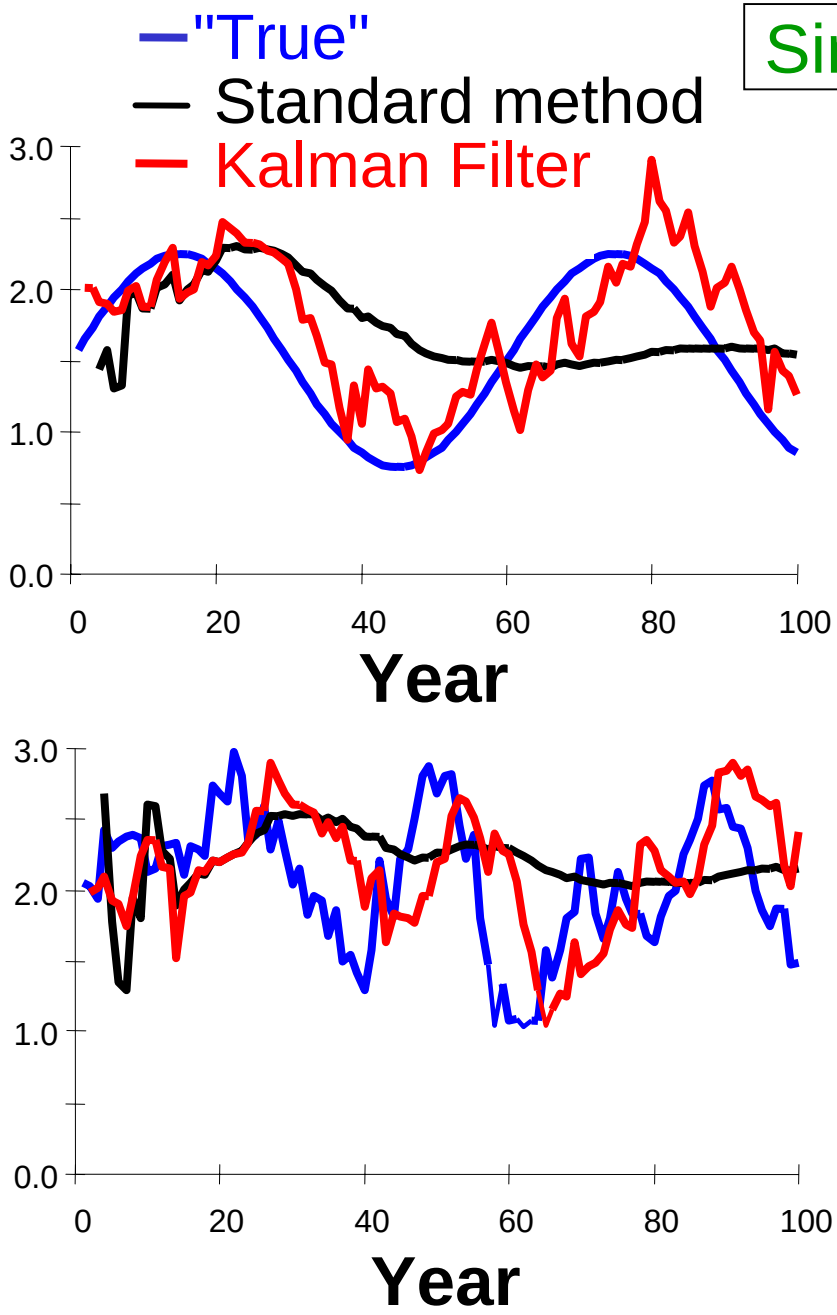
Peterman et al. (2000) *CJFAS*

Simulation test

Index of Productivity (Ricker 'a' parameter)

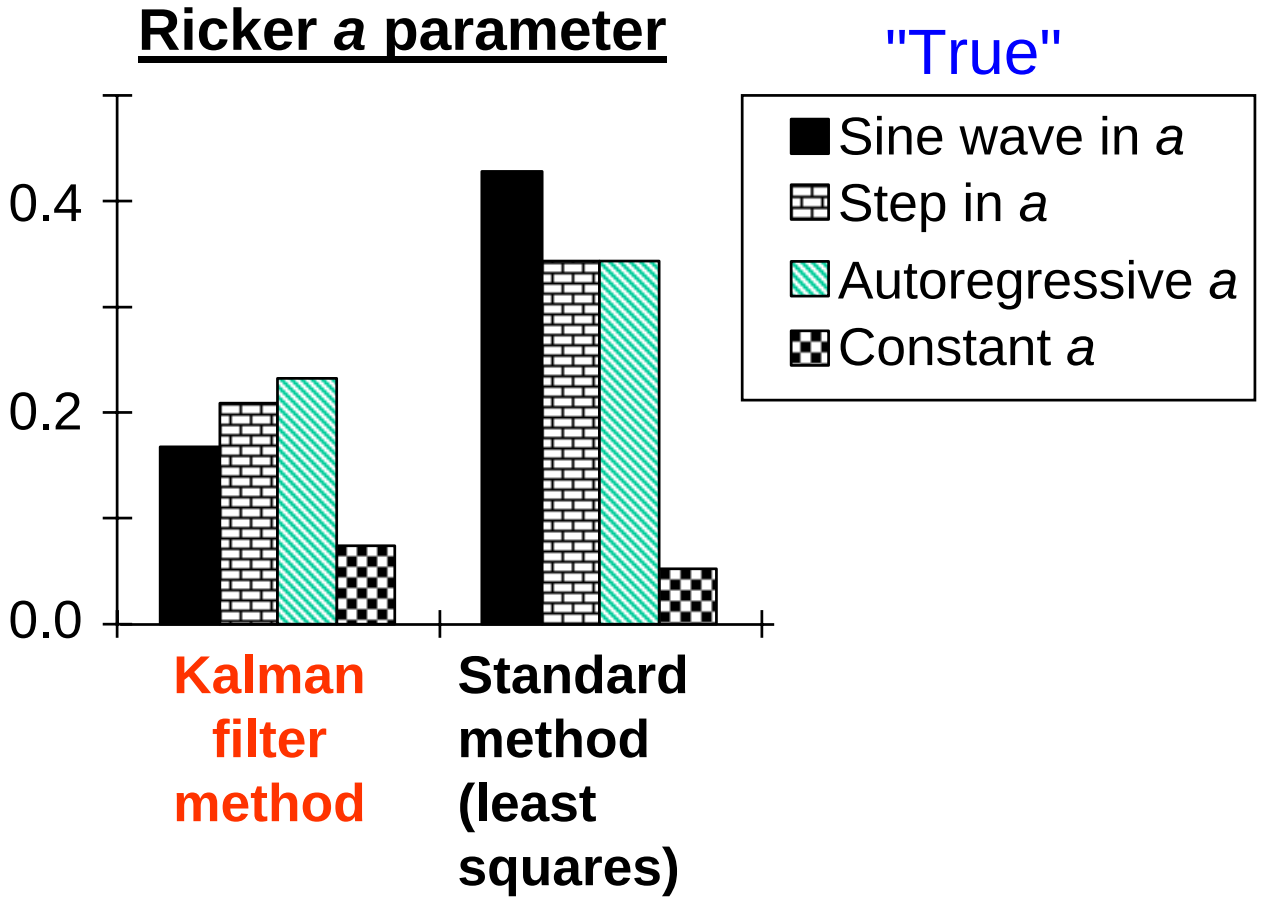


Simulation test



Peterman et al. (2000) *CJFAS*

Mean squared error in Ricker *a* parameter estimates compared to the "true"



Therefore, used a Kalman filter to reconstruct historical time series of productivity

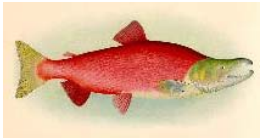
Peterman et al. (2000) *CJFAS*

Standardized time series

i.e., Transformed each reconstructed data series:

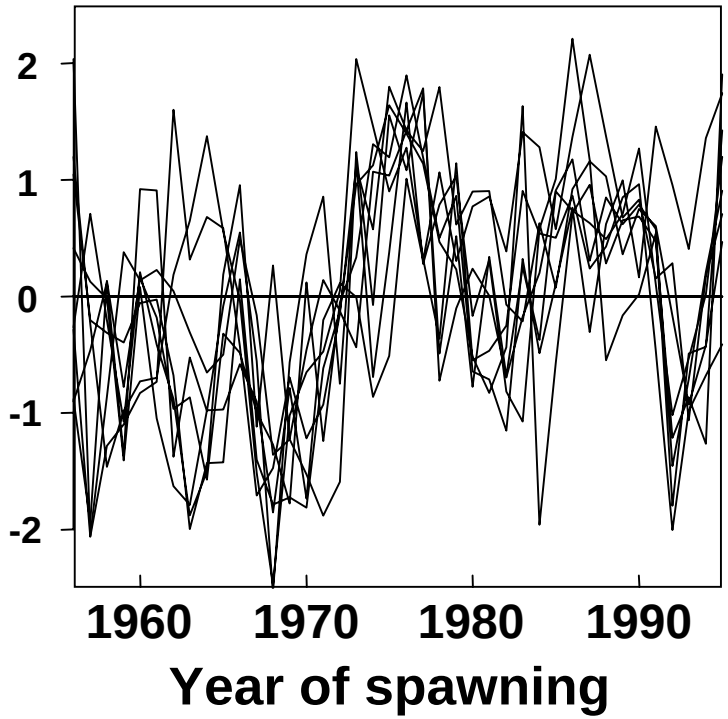
mean = 0 and SD = 1.0

- Made different time series data sets comparable



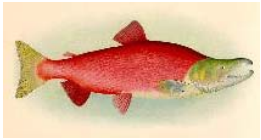
Productivity of 8 Bristol Bay, Alaska sockeye stocks

Standardized residuals from Ricker model



mean r = 0.43

Peterman et al. 2003
CJFAS



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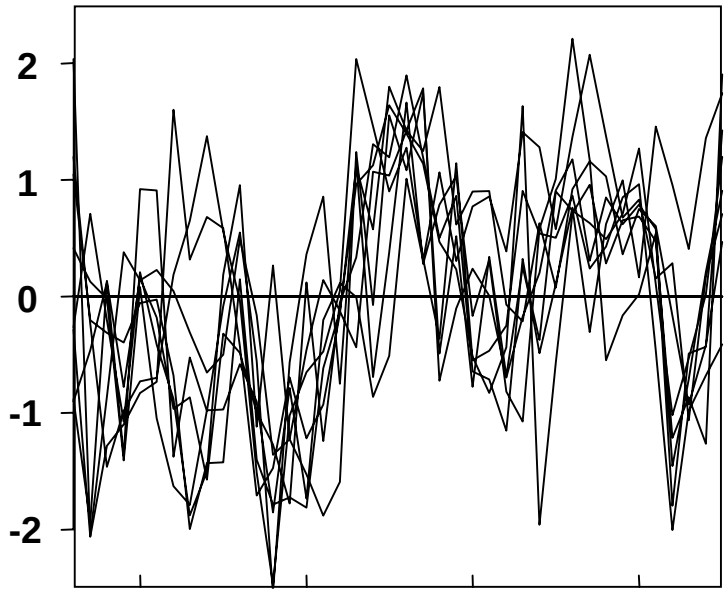
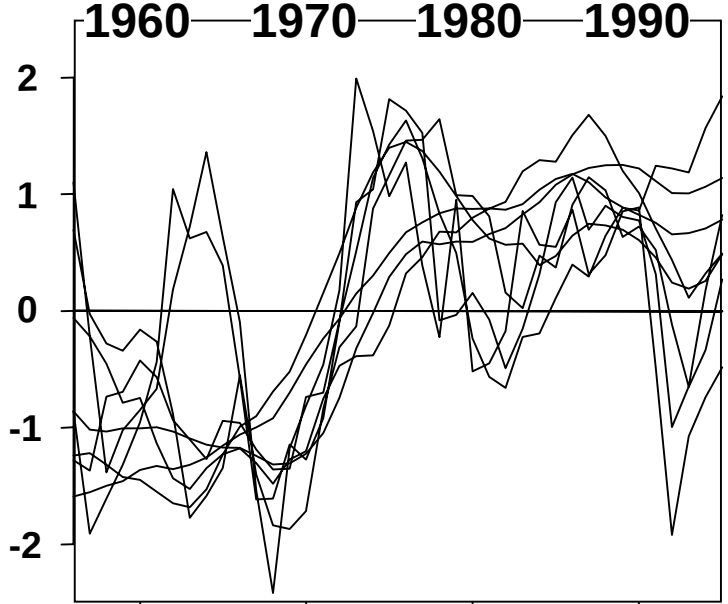


mean r = 0.43

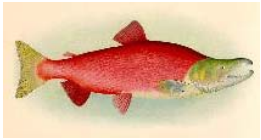
Standardized productivity (Ricker *'a'* parameter) from Kalman filter



mean r = 0.60

Year of spawning

Peterman et al. 2003 CJFAS



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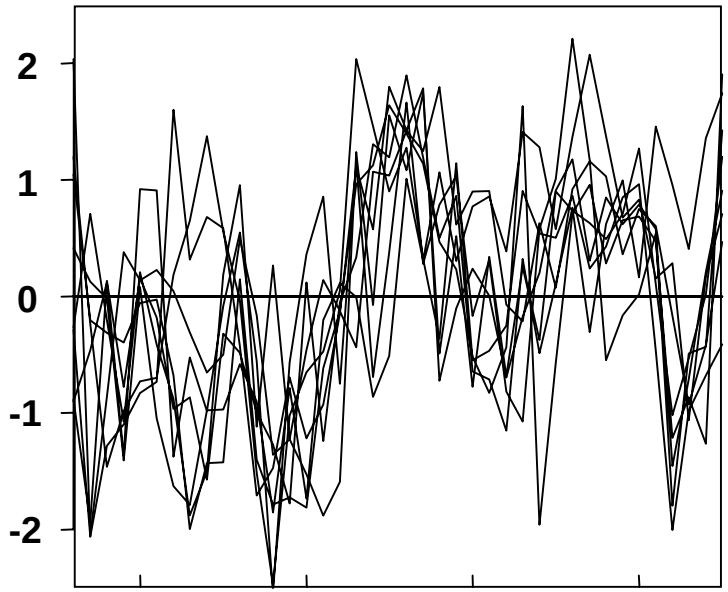

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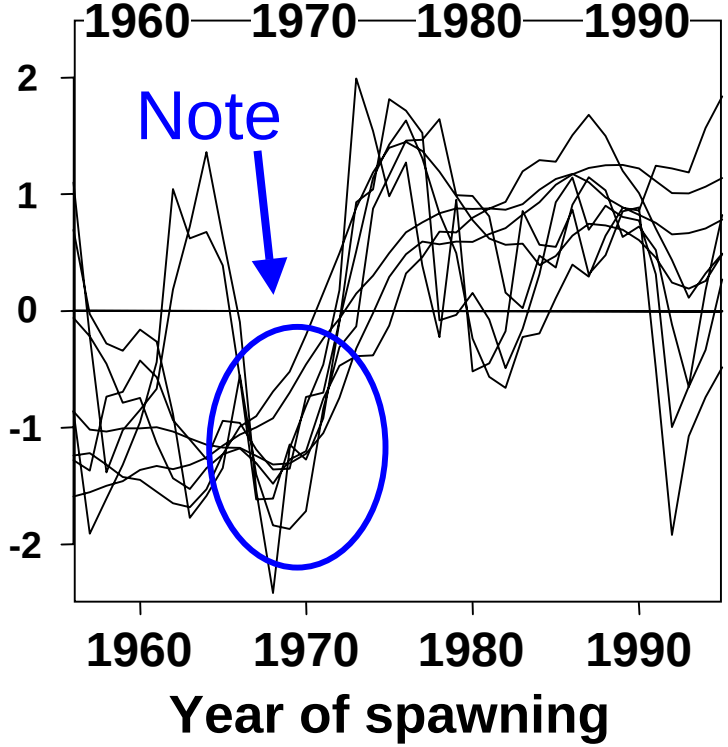
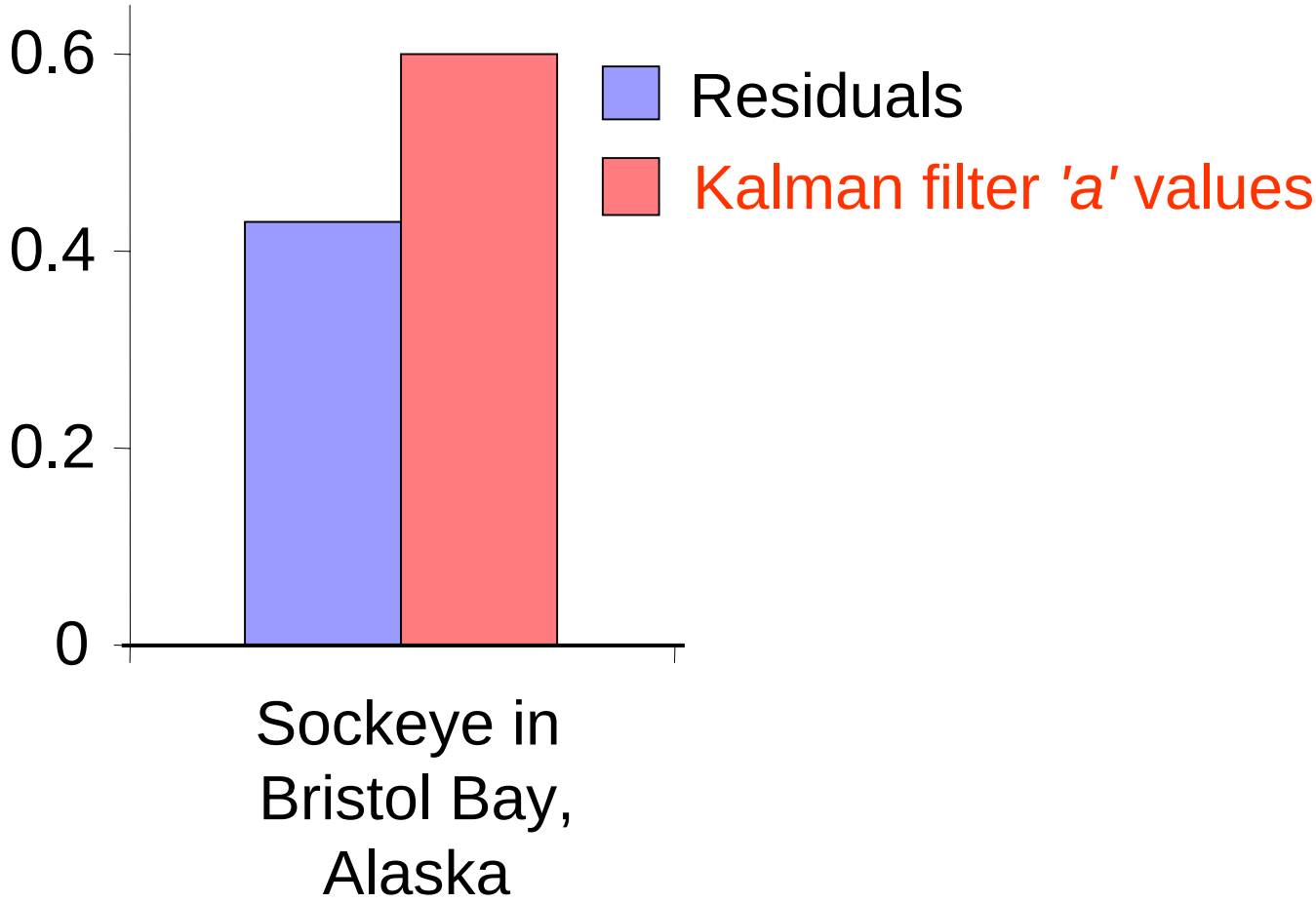


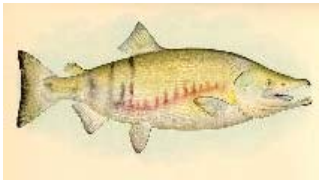
mean r = 0.60

Peterman et al. 2003 CJFAS

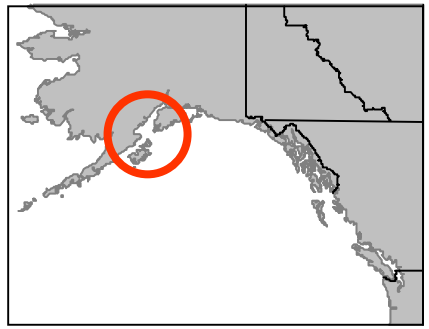
Kalman filtering reduces "noise" and increases correlation

Mean pairwise correlation in productivity among stocks

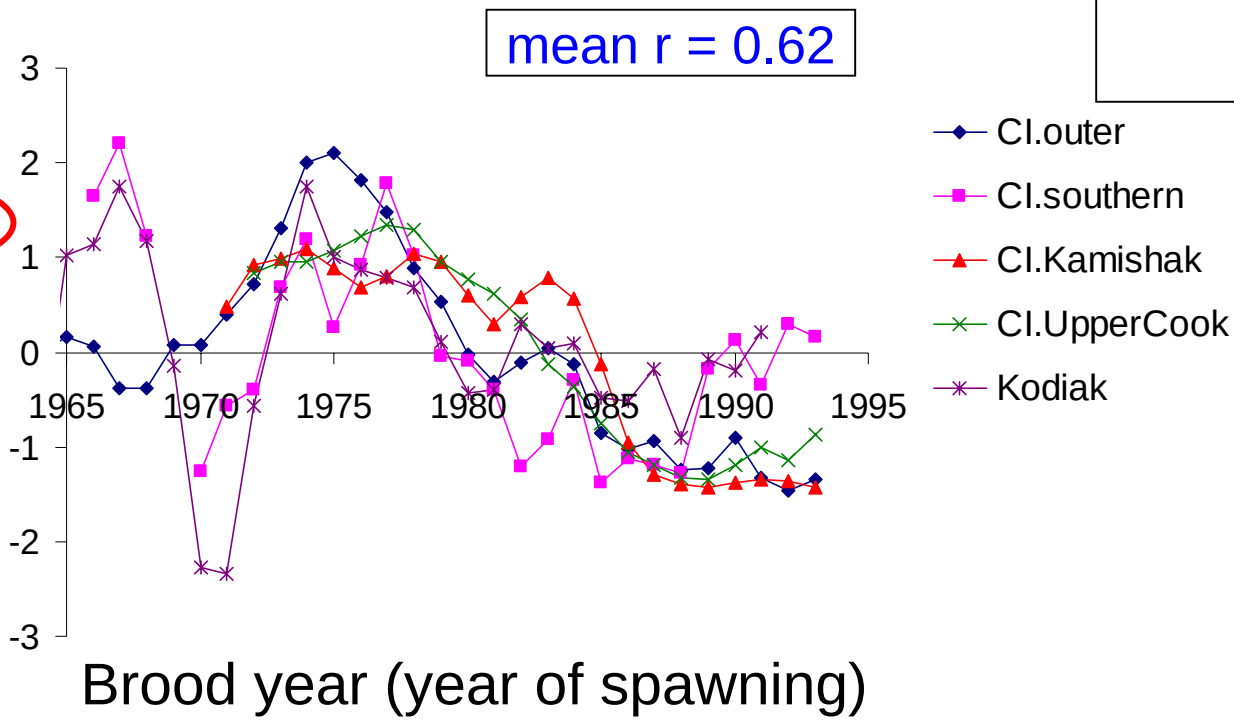




Cook Inlet & Kodiak chum salmon

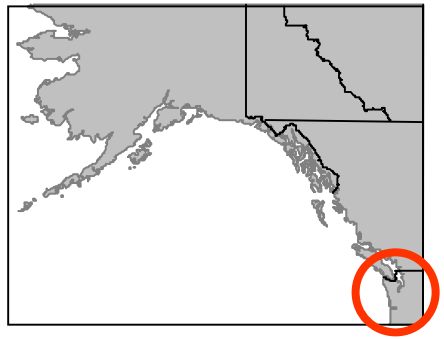


Standardized productivity (Ricker *'a'* parameter) from Kalman filter



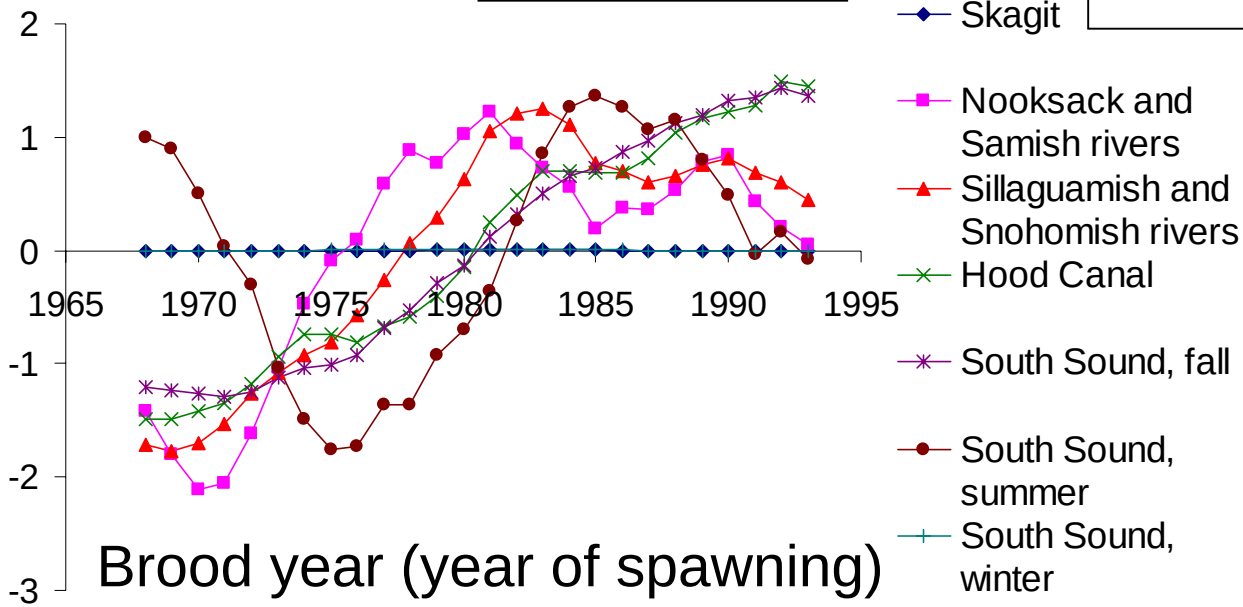
Brood year (year of spawning)

Inside Washington chum salmon



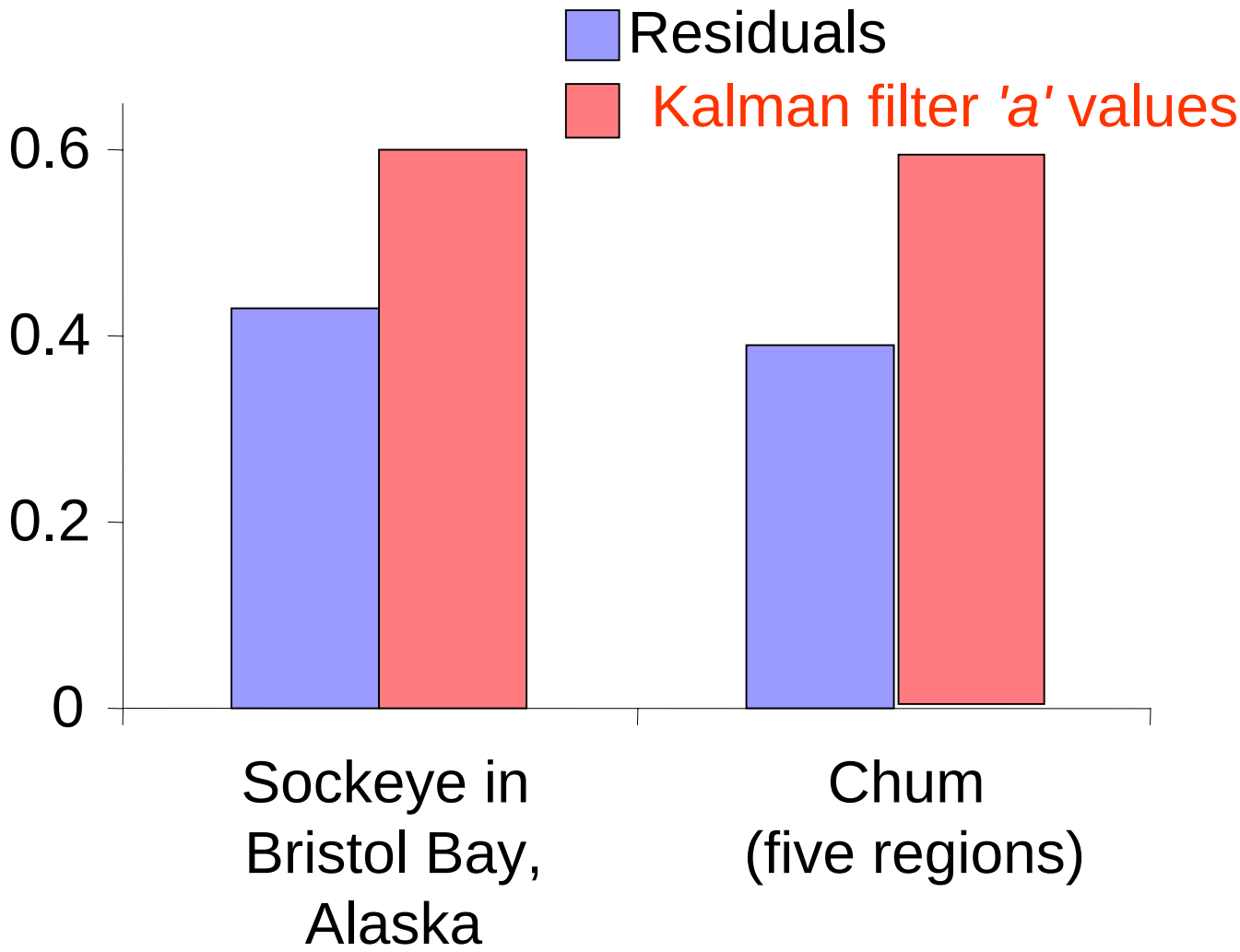
mean r = 0.61

Standardized productivity (Ricker *'a'* parameter) from Kalman filter

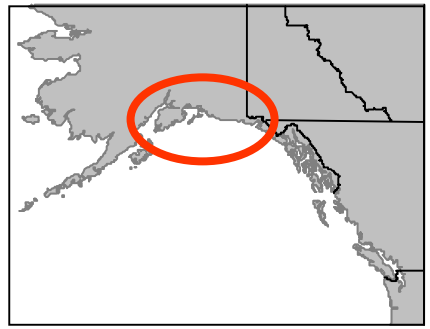


Kalman filtering reduces "noise" and increases correlation

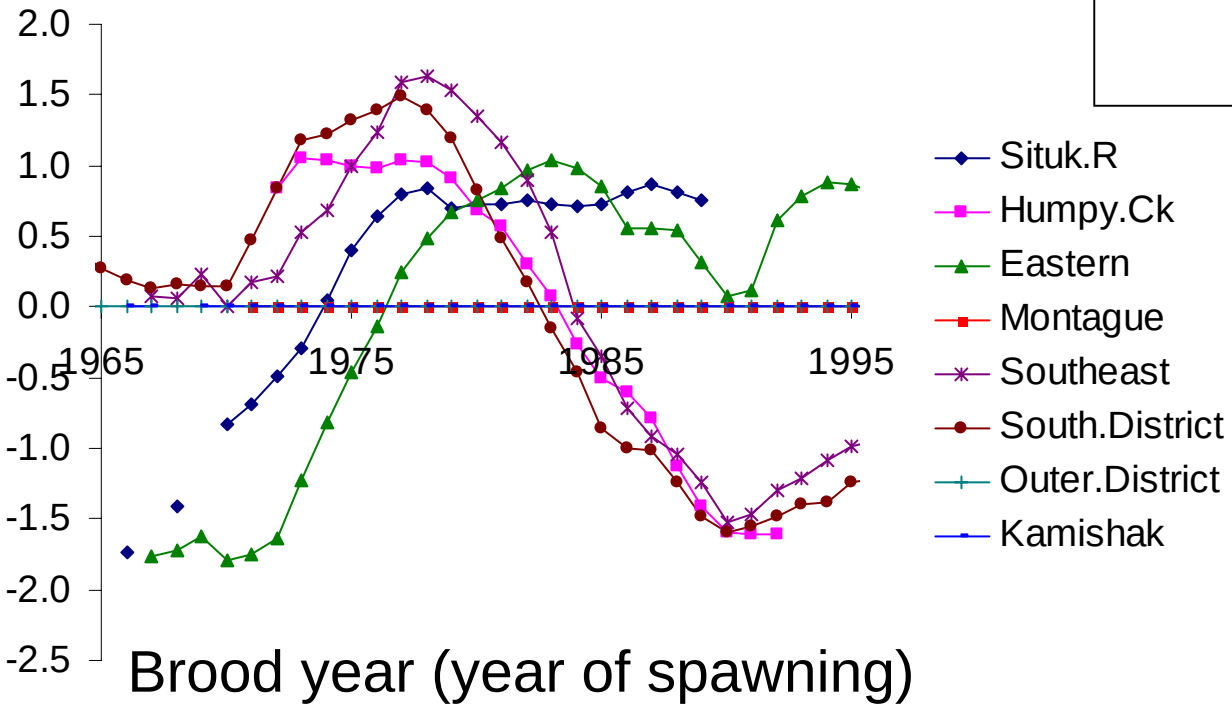
Mean correlation in productivity among stocks



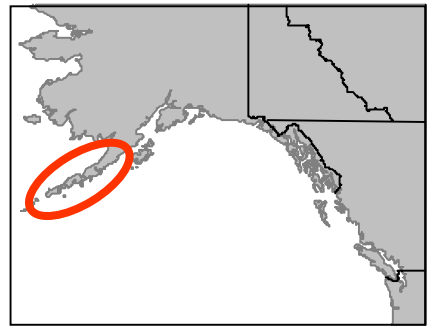
Yakutat, Prince Wm. Sound, Lower Cook pink salmon



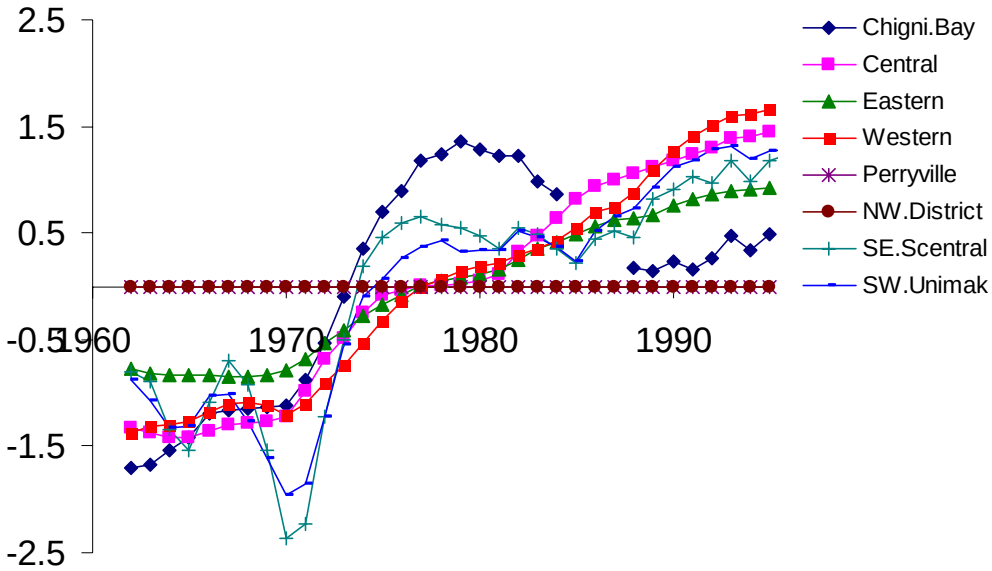
Standardized productivity (Ricker *'a'* parameter) from Kalman filter



Chignik, Alaska Peninsula
pink salmon

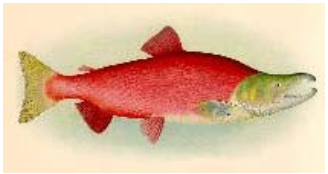


Standardized productivity (Ricker *'a'* parameter) from Kalman filter

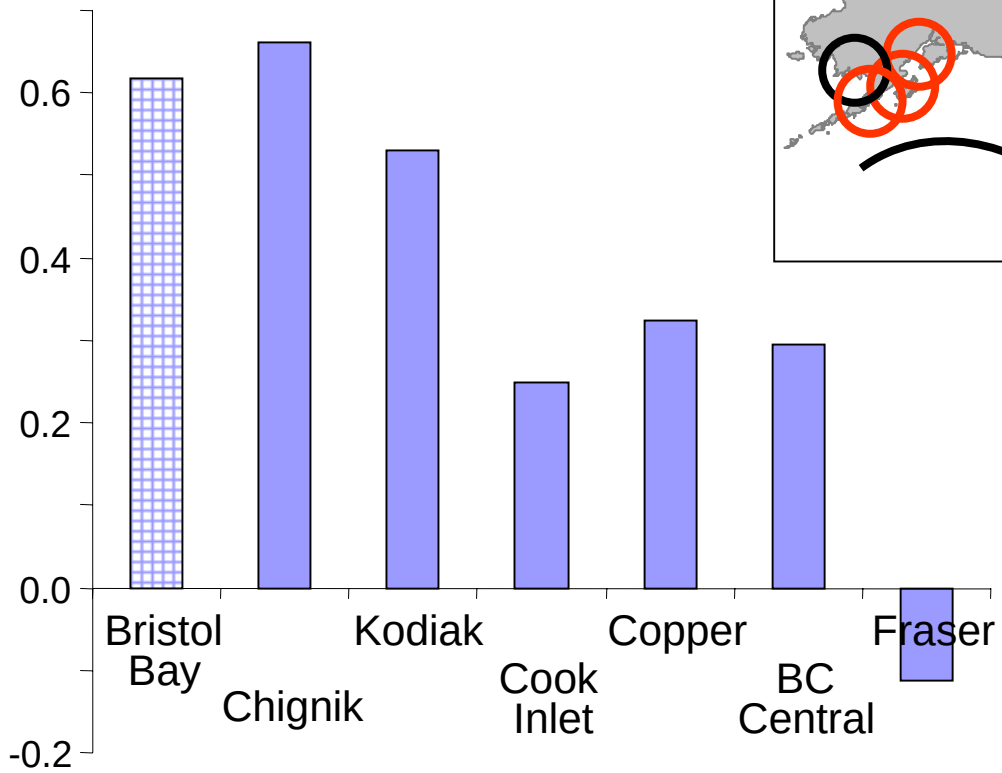


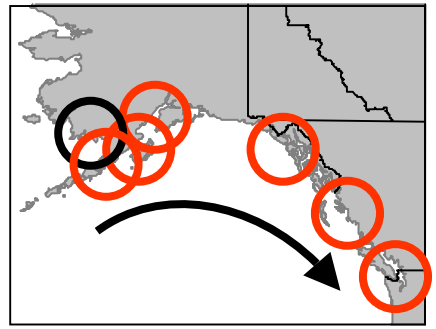
Brood year (year of spawning)

Average correlation between Bristol Bay sockeye and sockeye in other regions

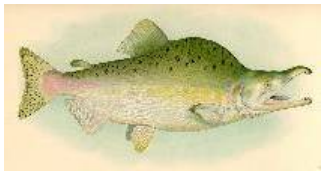


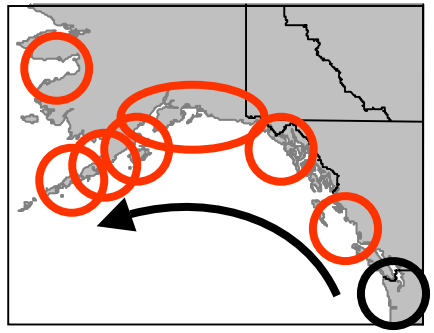
Average correlation among stocks in productivity (Ricker 'a' parameter from Kalman filter)



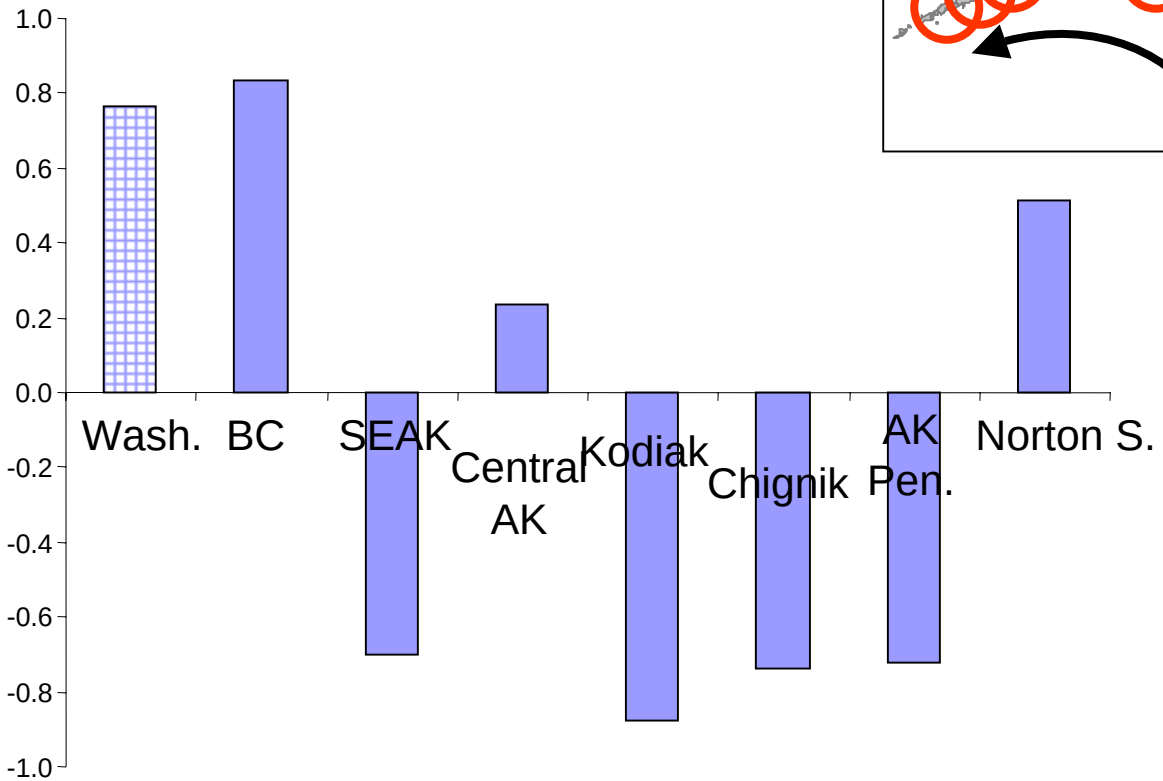


Average correlation between Washington pinks and pinks in other regions





Average correlation among stocks in productivity (Ricker 'a' parameter from Kalman filter)



Conclusions from Kalman filter results

1. Kalman filter estimates show clearer "signal" (variation in historical biological processes)

2. Clearer evidence that salmon productivity is highly positively correlated among stocks within regions

3. Still have smaller or negative correlations between regions

- Kalman filter code and worked examples in Excel and S-Plus:

  Available from Simon Fraser University:

  e-mail: peterman@sfu.ca

Relevant publications (www.rem.sfu.ca/fishgrp)

Kalman filter models: e-mail: peterman@sfu.ca

- Peterman et al. (2003) *CJFAS* 60: 809
- Peterman et al. (2000) *CJFAS* 57: 181

Salmon productivity:

- Pyper et al. (2005) *Trans. Amer. Fish. Soc.* 134: 86
- Mueter et al. (2002) *CJFAS* 59:456, plus 60: 757
- Pyper et al. (2002) *Tr. Am. Fish. Soc.* 131: 343 **chums**
- Pyper et al. (2001) *CJFAS* 58: 1501 **pinks**
- Peterman et al. (1998) *CJFAS* 55: 2503 **sockeye**

Oceanographic variables:

- Mueter et al. (2005) *Trans. Amer. Fish. Soc.* 134: 105
- Mueter et al. (2002) *Fisheries Oceanography* 11: 205