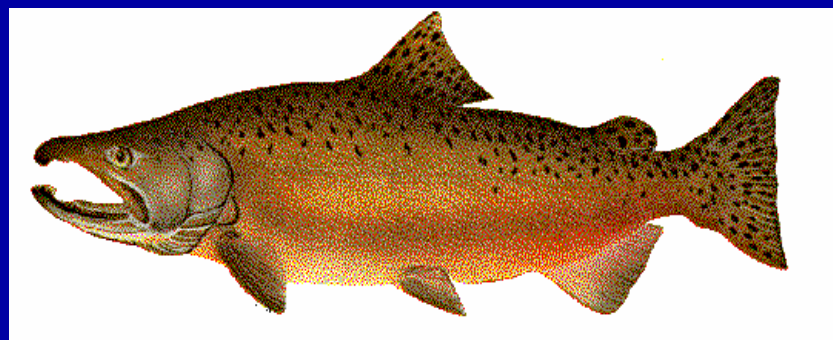


Using catch at Age models For Pacific Northwest Chinook salmon



Rishi Sharma,
Columbia River InterTribal
Fisheries Commission



Structure of Talk

- Background
- Life History and relationship to model
- PSC Chinook Model
- Statistical Catch at Age Analysis (SCAA).
- Using the SCAA on a Columbia stock.
- Testing the approach through Simulations.
- Tying recruitment variability to environmental conditions.
- Comparisons across approaches.
- Adapting to a multi-stock framework.
- Precision in Exploitation rates.
- Wrap Up.

Background

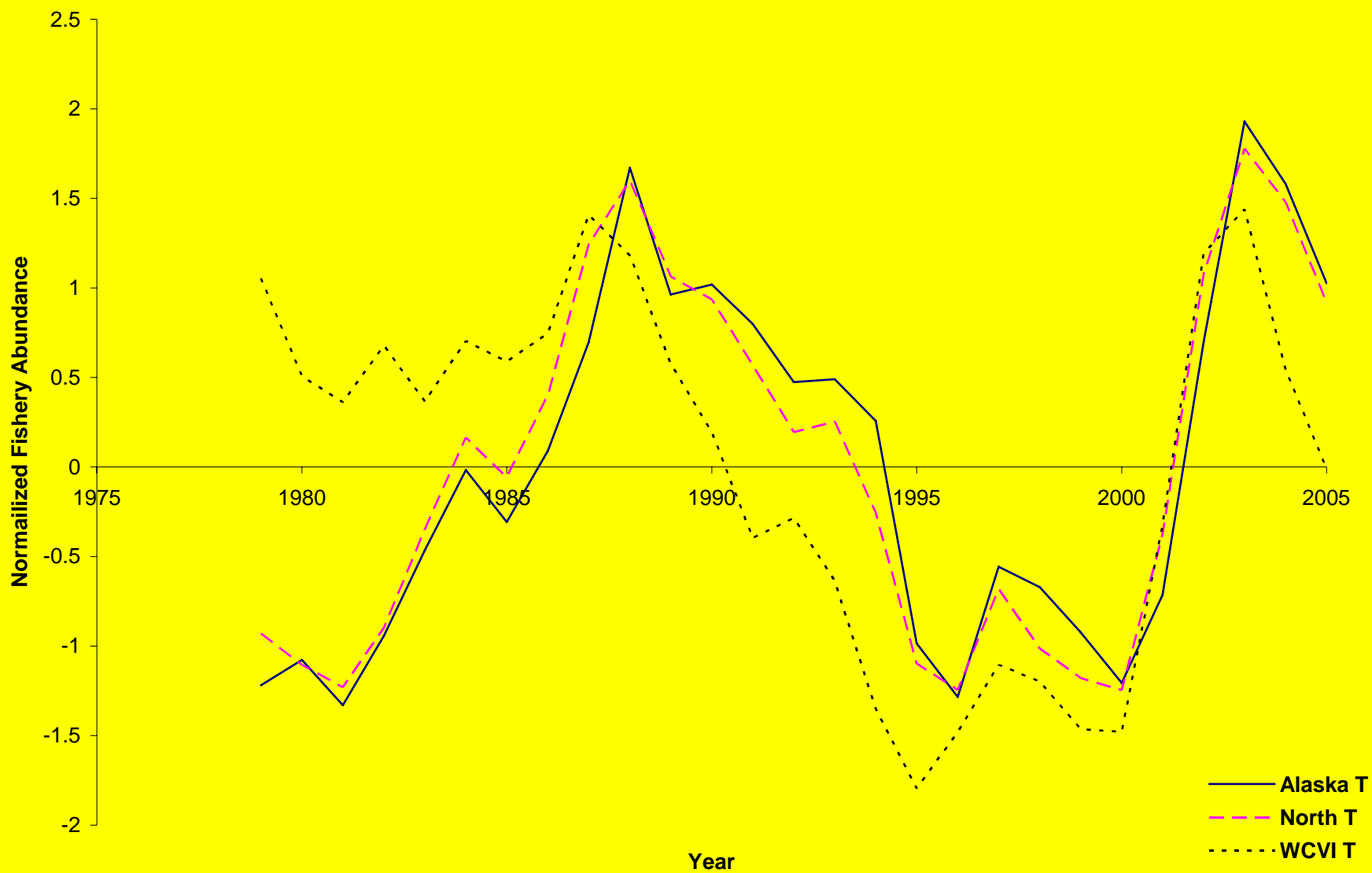
- Jurisdiction.
- Fisheries.
- Value (\$20-50 M/yr X-vessel price).
- Cost tagging and assessment (\$15 M/yr).

Why ?

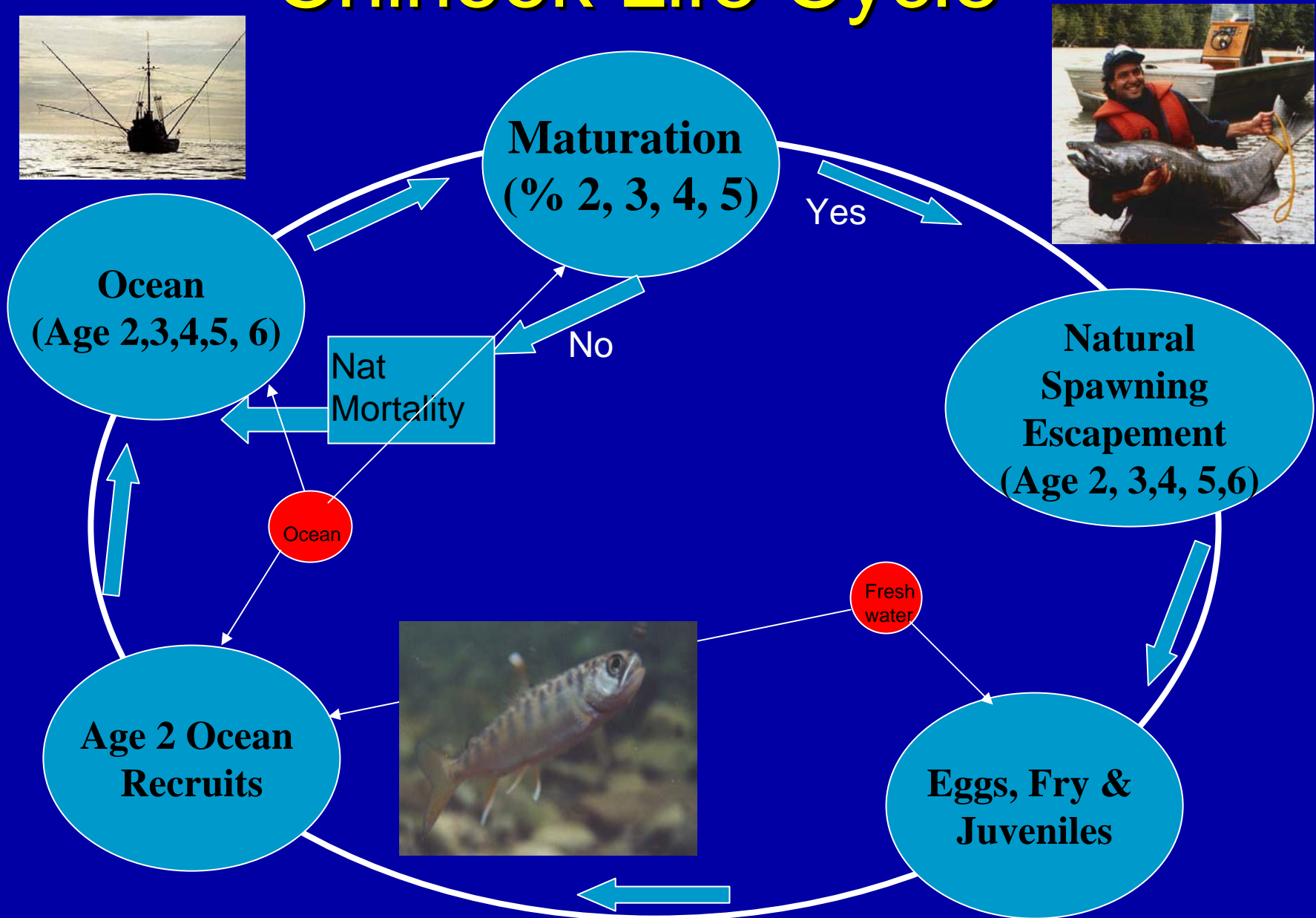
- Inter-annual variability.
- Understand mechanisms.
- Possibly improve management precision.
- Use a holistic approach to management.



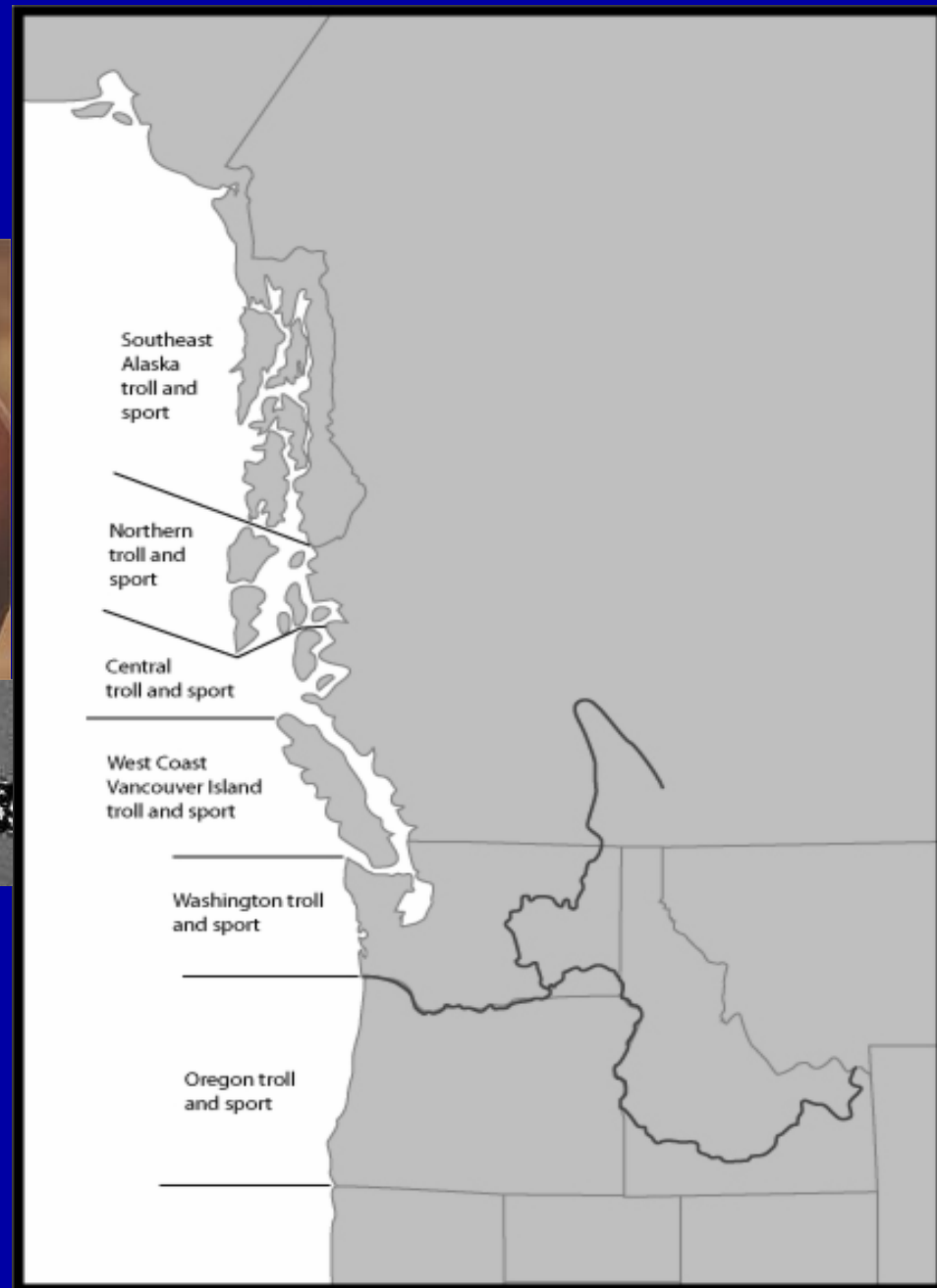
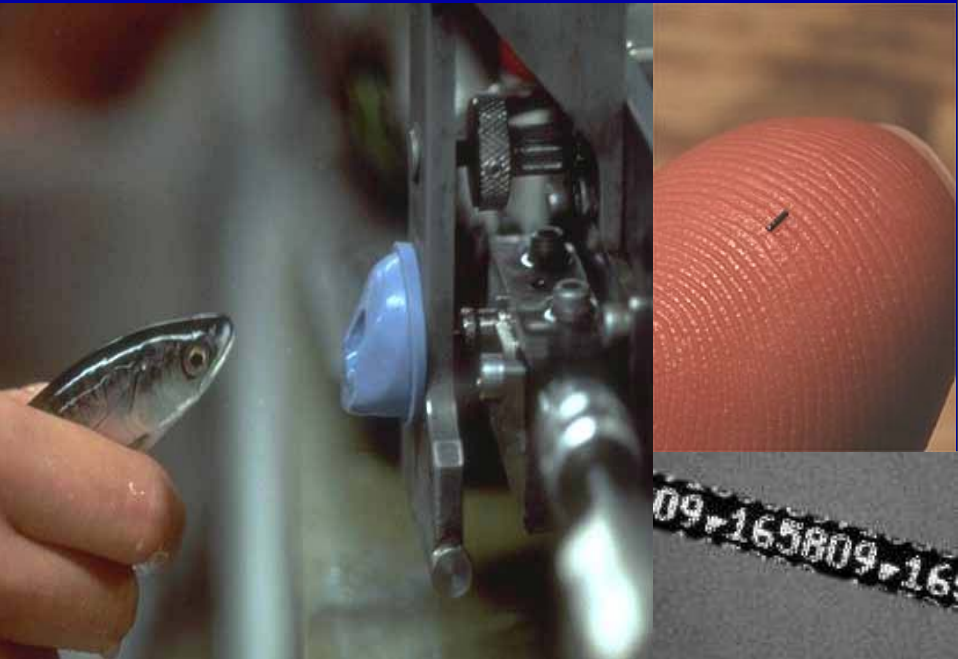
Ocean Abundance Trends over Time (Normalized)



Chinook Life Cycle

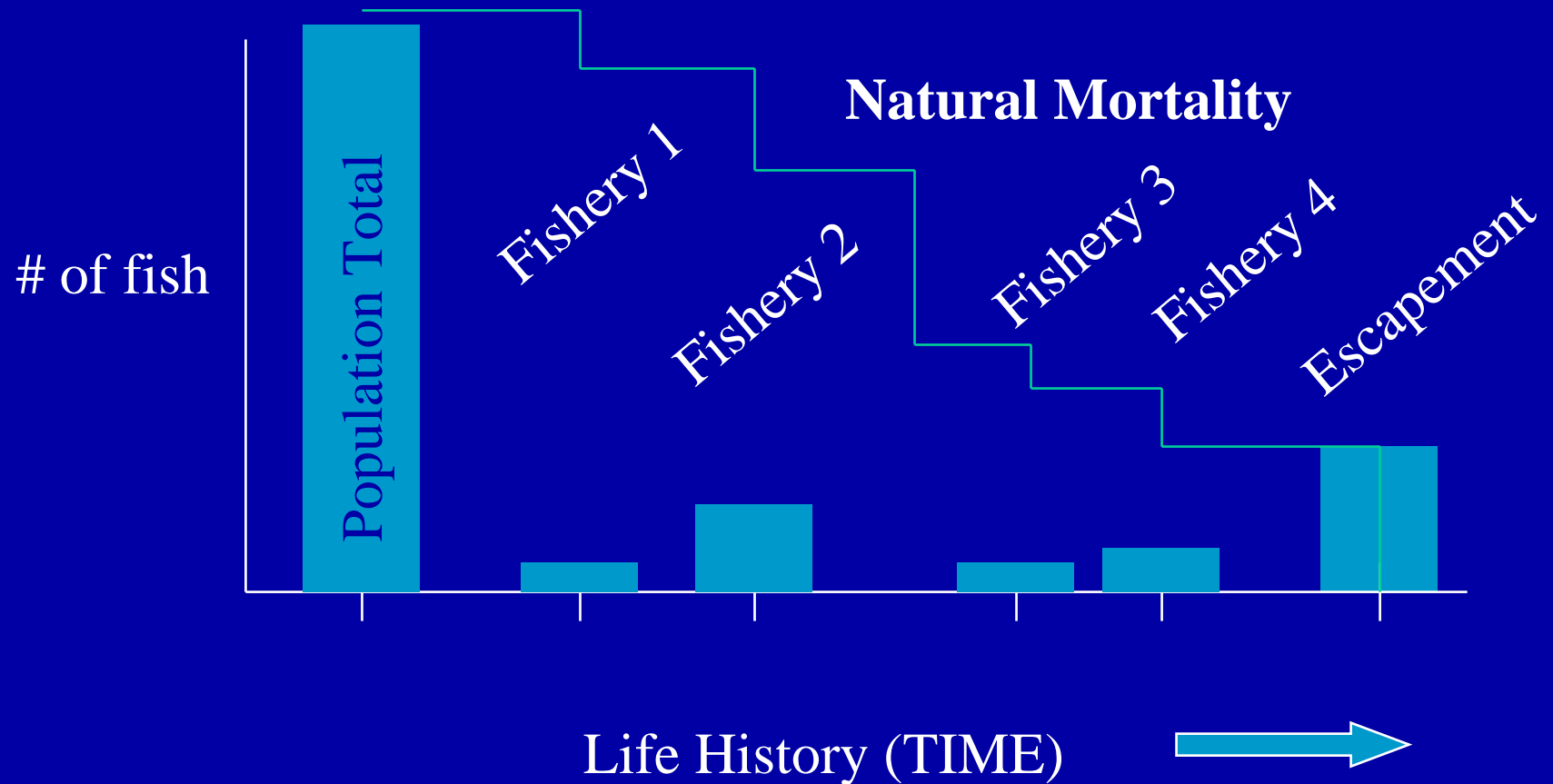


Tag Data used in assessment



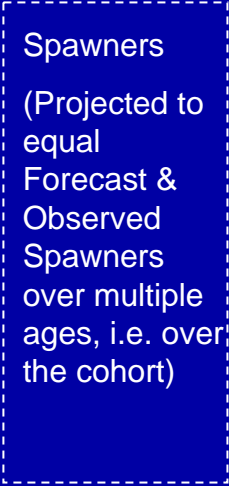
$$ER = \frac{\text{Catch}}{\text{Population}}$$

Cohort Analysis



Source: Annette Hoffman (WDFW 2001)

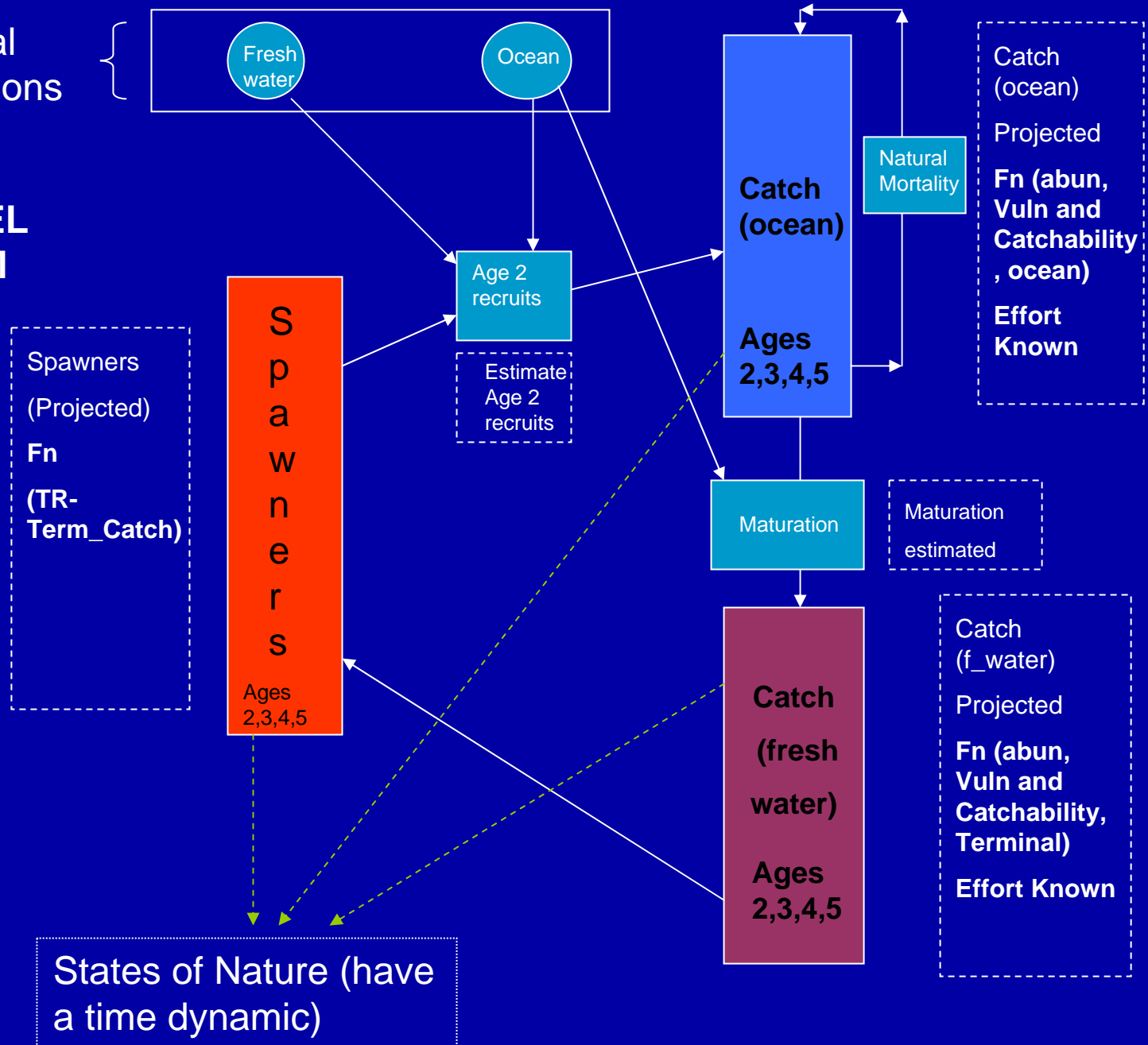
ERROR



States of Nature (have a time dynamic)

Environmental
Forcing functions

SCAA MODEL MECHANISM



Trade-Offs

- Lesser assumptions.
- Estimation framework.
- Numerically intensive & Challenging.

Essential Approach

$$\text{Number}_{\text{age}+1, \text{time}+1} = \text{Number}_{\text{age}, \text{time}} - \text{Deaths}_{\text{age}, \text{time}} - \text{Maturation}_{a, t}$$

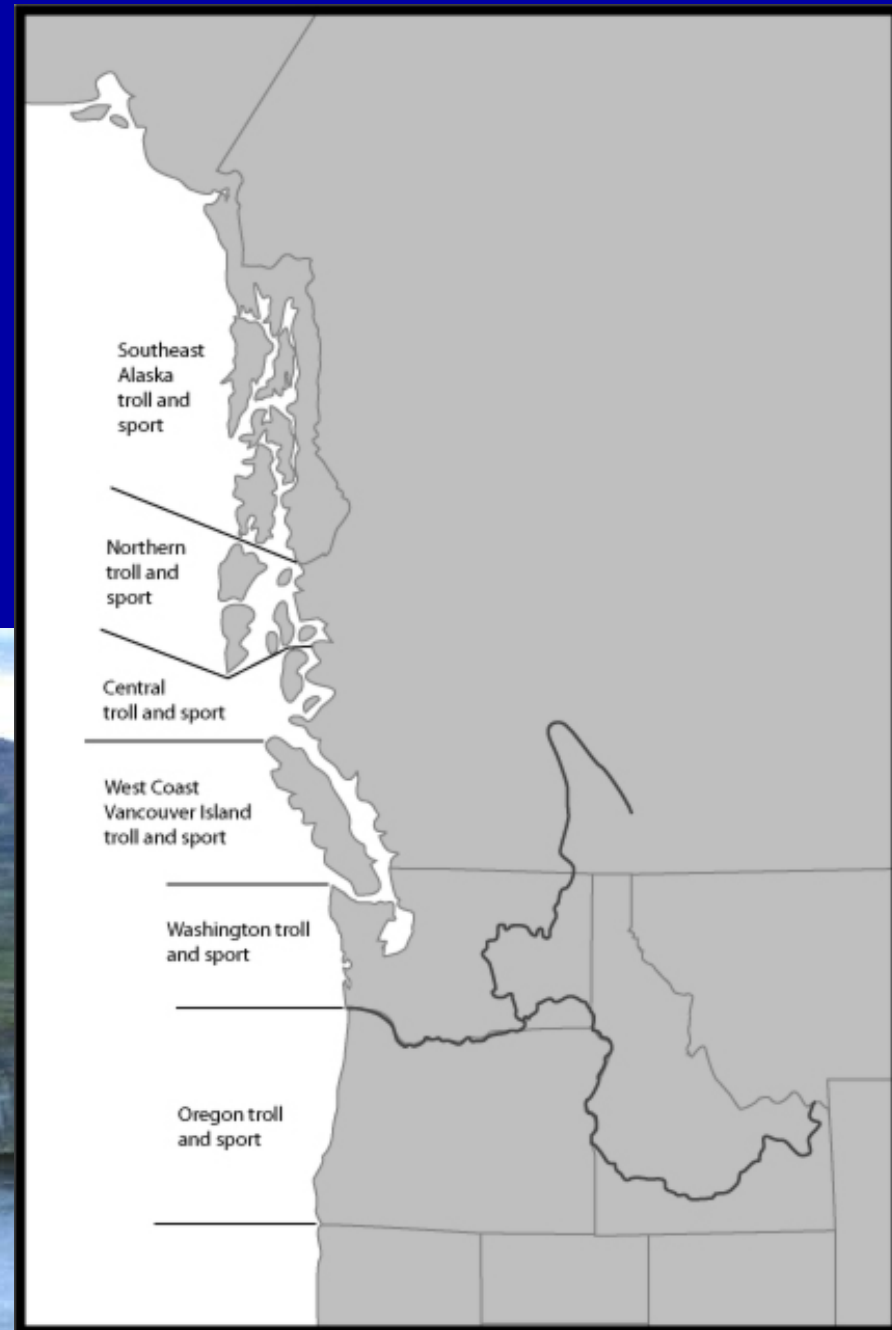
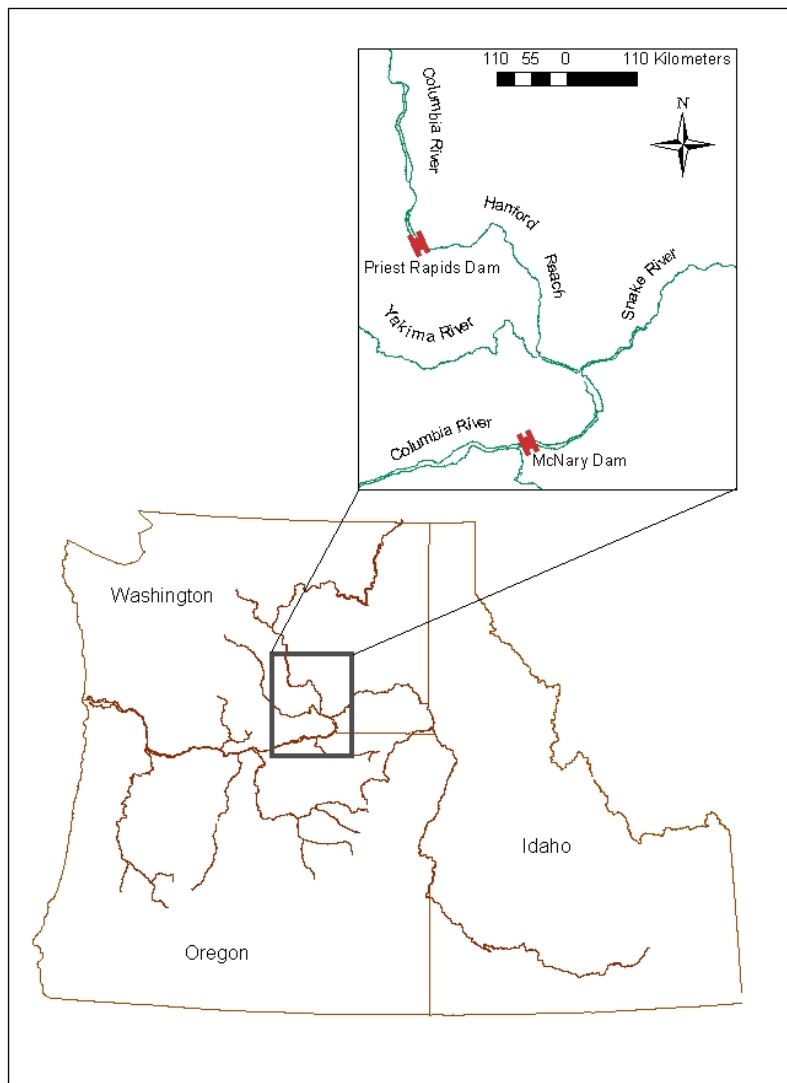
$$\text{Deaths}_{\text{age}, \text{time}} = \text{Fishing}_{\text{age}, \text{time}} + \text{Nat.Mortality}_{\text{age}, \text{time}}$$

$$\text{Fishing_Mortality}_{\text{age}, \text{time}} = (\text{catchability}_{\text{time}}) * (\text{vulnerability}_{\text{age}, \text{time}}) * (\text{Effort}_t)$$

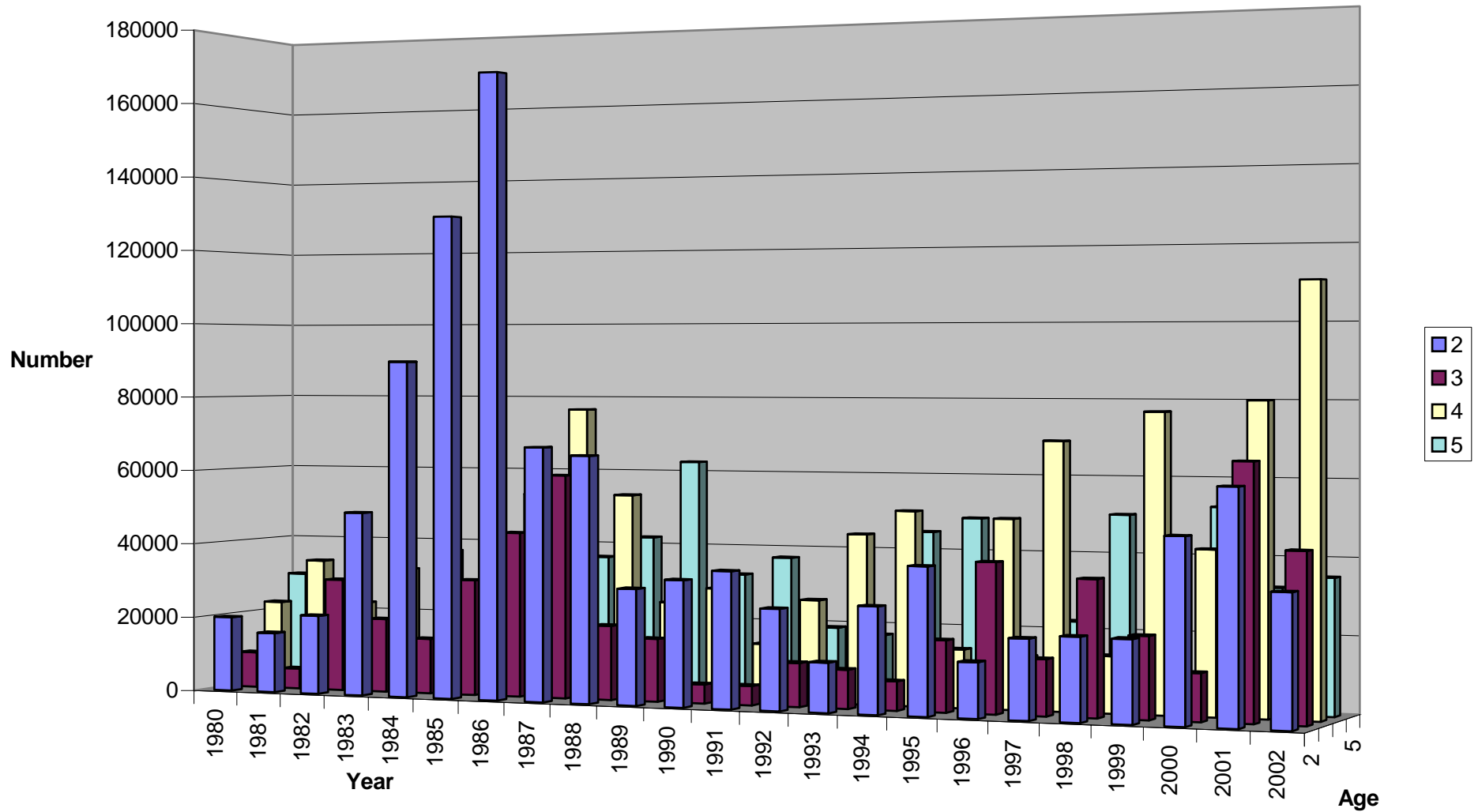
Maximum Likelihood
Estimation

$$L(\theta | C_{a,t,f}) = \prod_{f=1}^n \frac{1}{\sqrt{2\pi\sigma_f^2}} \exp \left[-\frac{(C_{a,t,f}) - (\hat{C}_{a,t,f})^2}{2\sigma_f^2} \right]$$

$$-\ln L(\theta | C_{a,t,f}) = \sum_{f=1}^n \ln(\sigma_f) + \frac{\ln((C_{a,t,f}) - \ln(\hat{C}_{a,t,f}))^2}{2\sigma_f^2}$$

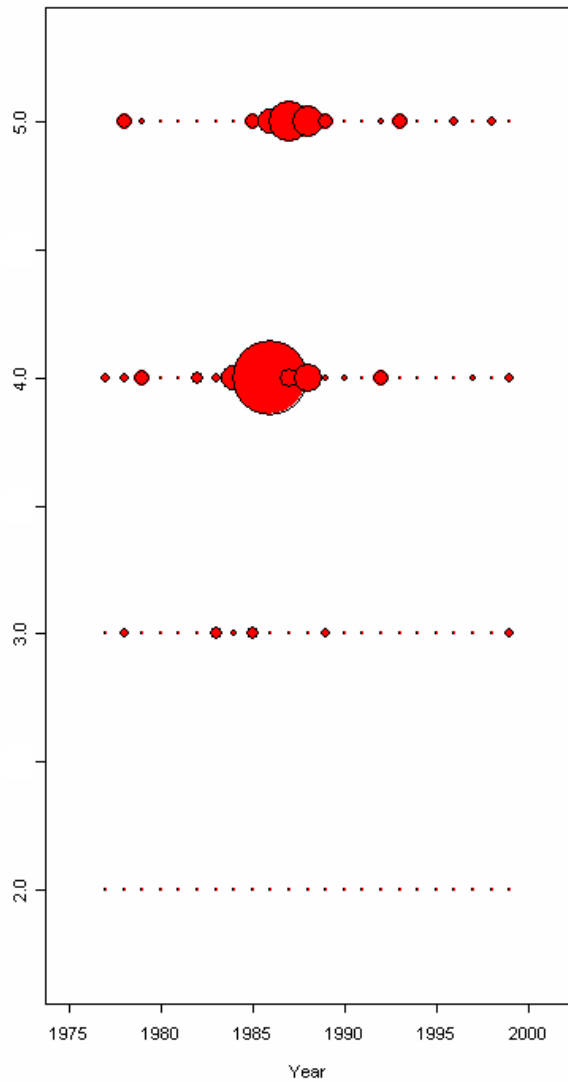


Escapement by age



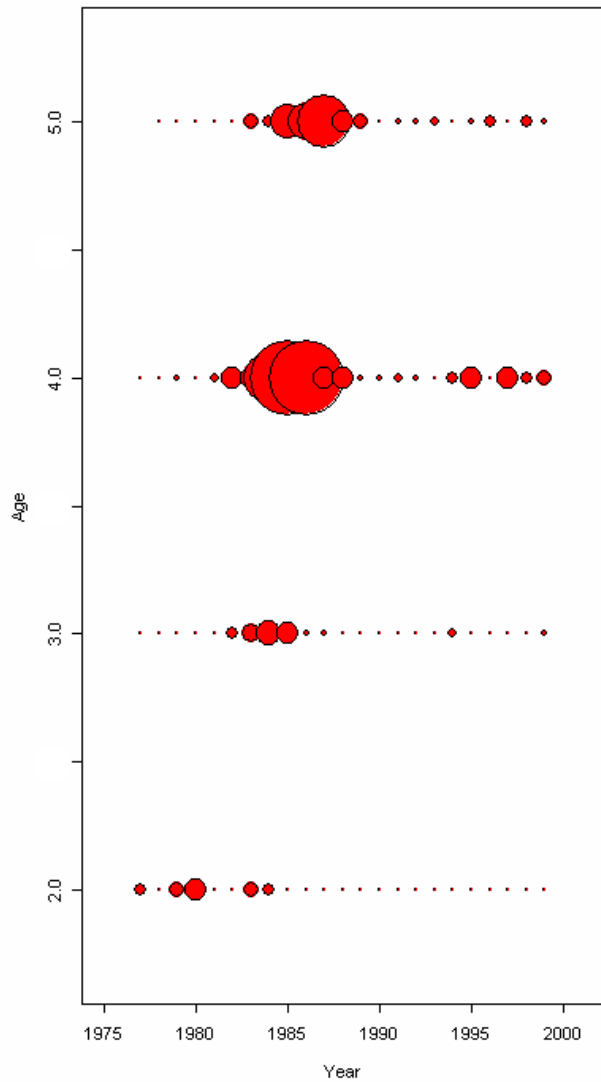
Age

Ocean Catch



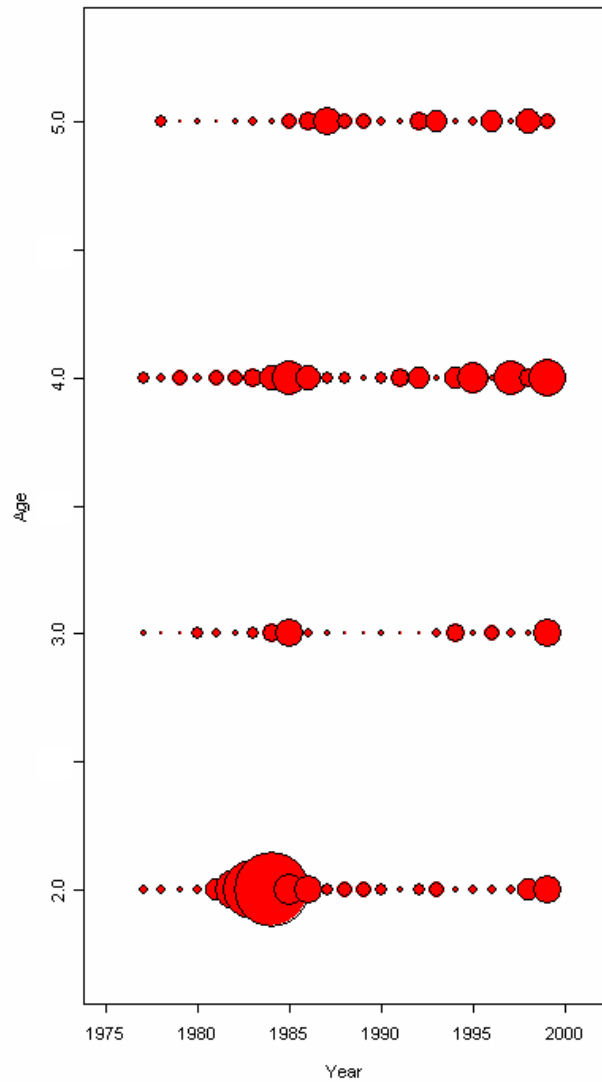
Age

Terminal Catch



Age

Escapement



Alternative Model Structures

Comparisons: Simple 2 fishery model

Parameters	Model 1 All time variant Maturation	Model 2: Maturation decadal structure	Model 3: Different catchability by decade	Model 4: Different vulnerability*catchability by decade (ENV DRIVEN)	Model 5: Constant recruitment varying catchability by time period	Model 6: Model 5+age 2's	Model 7: Model 4 but time periods q& v corresponding to PST, Mat corresponding to Env
initial ages	3	3	3	3	3	3	3
vuln_ocn	3	3	3	9	9	9	9
vuln_term	3	3	3	9	9	9	9
q_ocn	1	1	3	3	25	25	3
q_term	1	1	3	3	25	25	3
maturity rates	75	9	9	9	9	9	9
initialAge 2's	25	25	25	25	1	25	25
Total paramters	111	45	49	61	81	105	61
-LN(likelihood)	374.5	391.6	370	352	484	359	336
AIC	971	873	838	827	1129	927	794

6

4

3

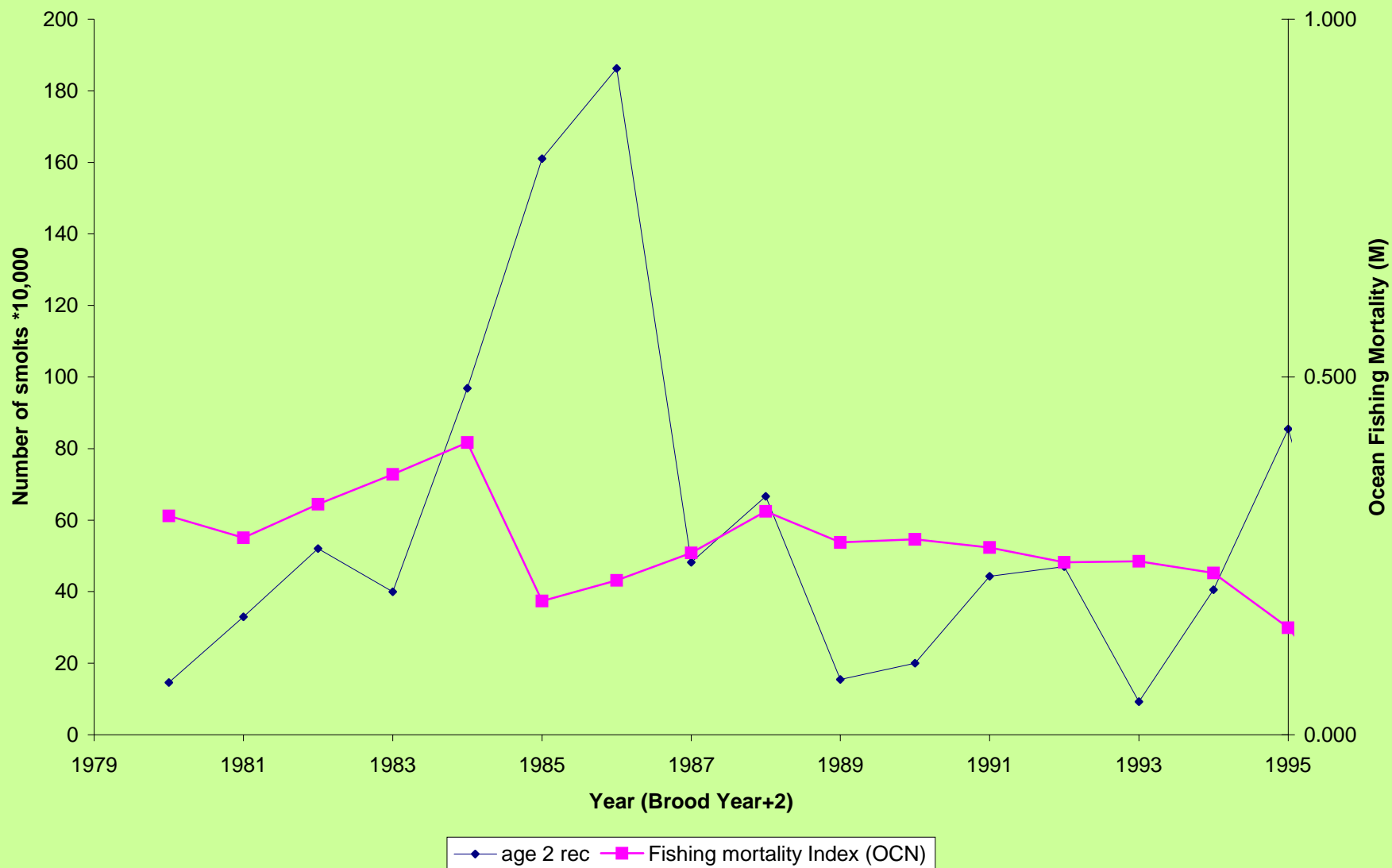
2

7

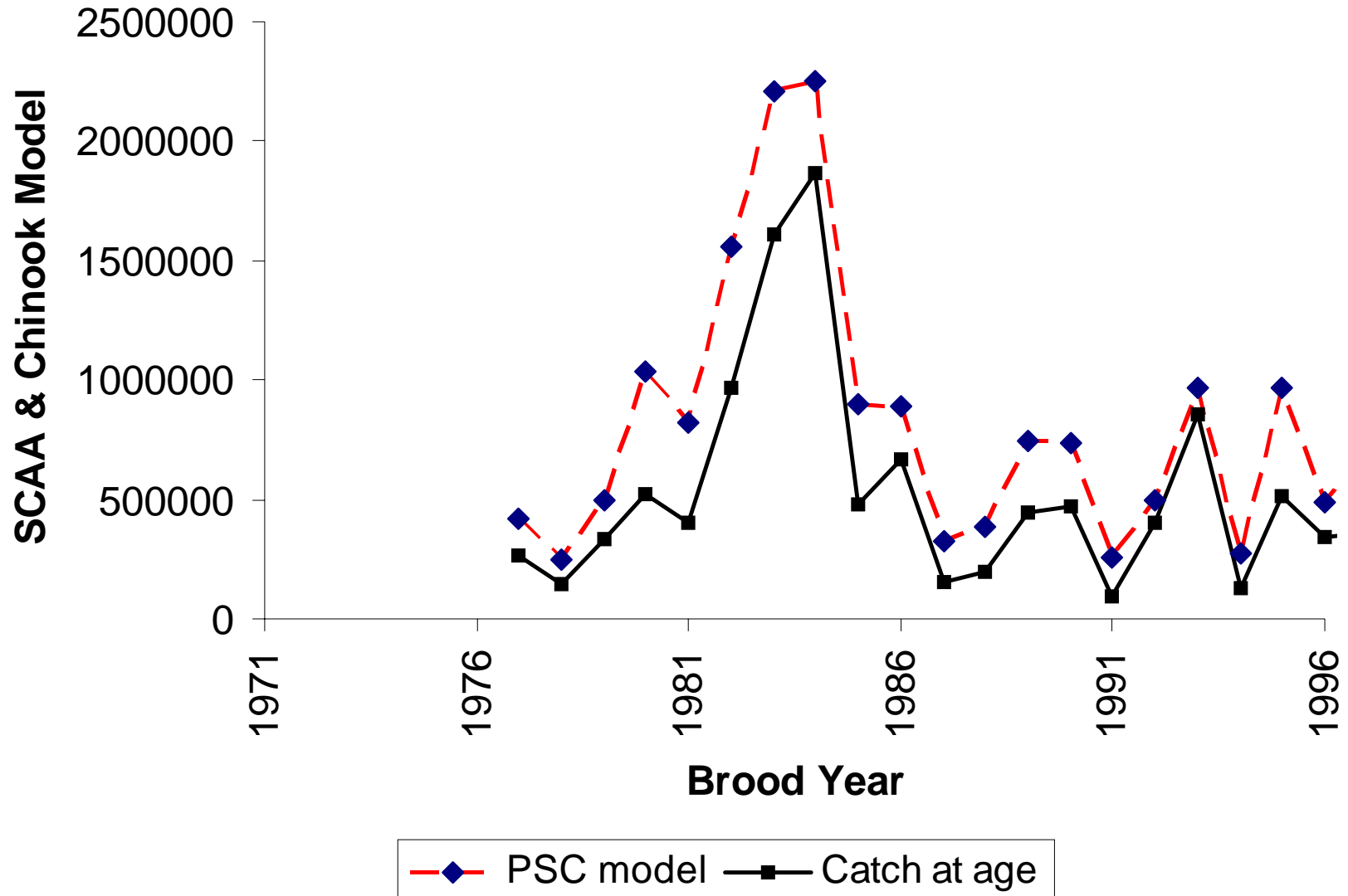
5

1

URB age 2 recruitment



Comparison with current management model



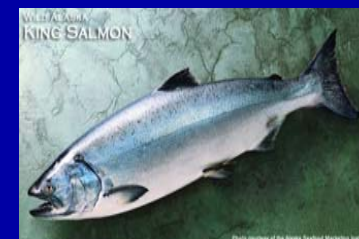


MEAN SQUARE ERROR COMPARISONS

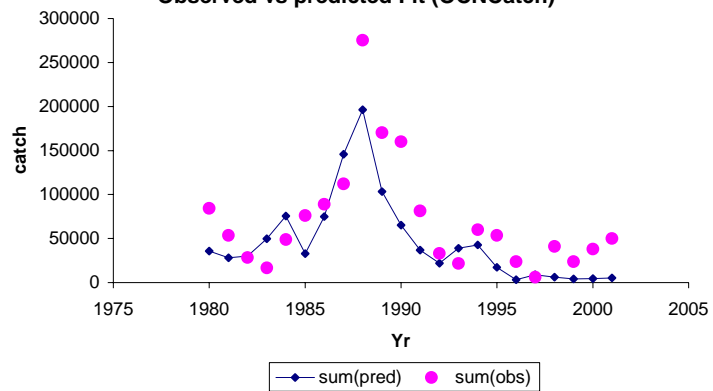
root(MSE)	Decadal Mat SCAA	Ocean Catch	
		PSC	% PSC
Age 2	1350	5163	26%
Age 3	10399	20880	50%
Age 4	22214	33061	67%
Age 5	21343	25589	83%

root(MSE)	SCAA	Terminal catch	
		PSC	% PSC
Age 2	10979	12098	91%
Age 3	8196	11115	74%
Age 4	7421	11741	63%
Age 5	8458	26986	31%

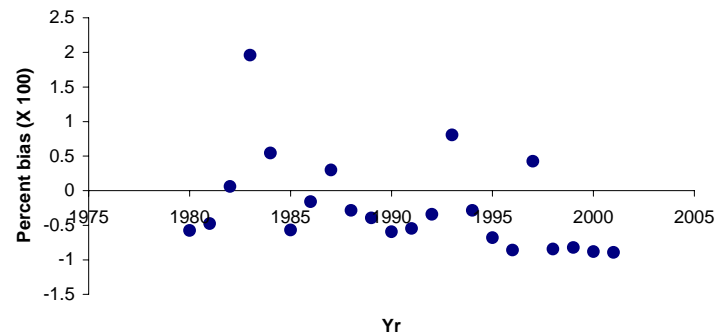
root(MSE)	SCAA	Escapement	
		PSC	% PSC
Age 2	18257	42650	43%
Age 3	9064	9096	100%
Age 4	14988	22446	67%
Age 5	18558	19927	93%



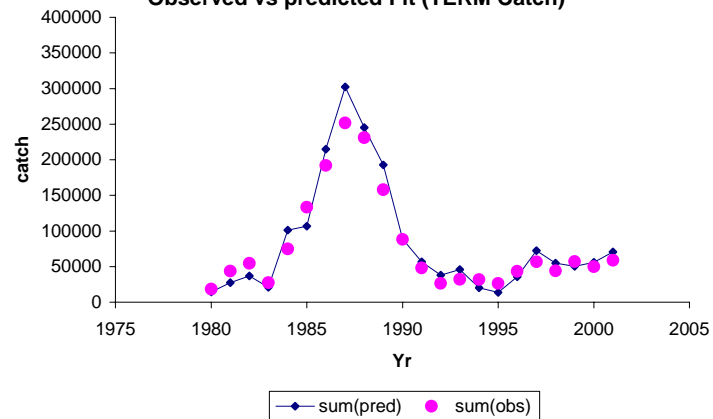
Observed vs predicted Fit (OCNCatch)



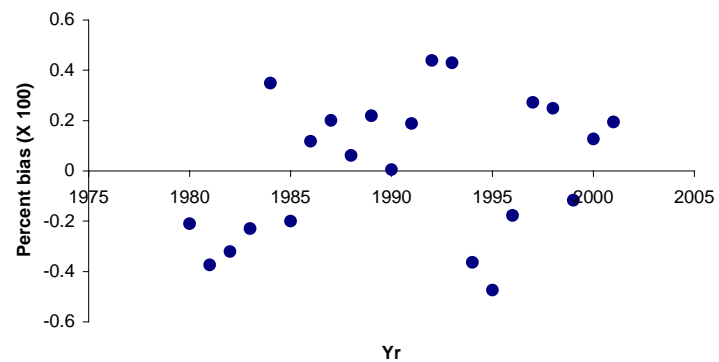
magnbias (OCN)



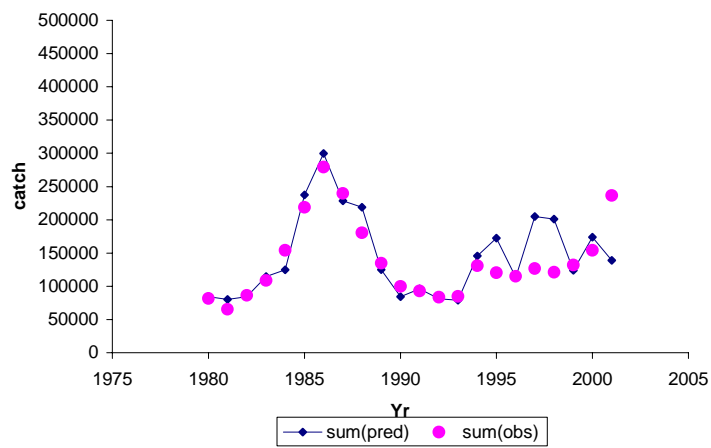
Observed vs predicted Fit (TERM Catch)



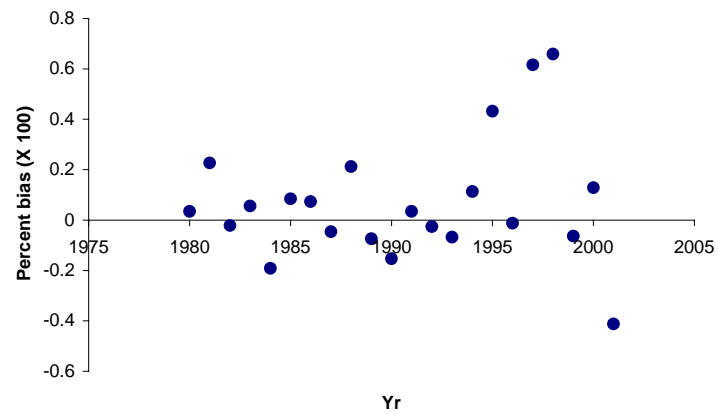
magnbias (TERM)



Observed vs predicted Fit (ESC)



magnbias (ESC)

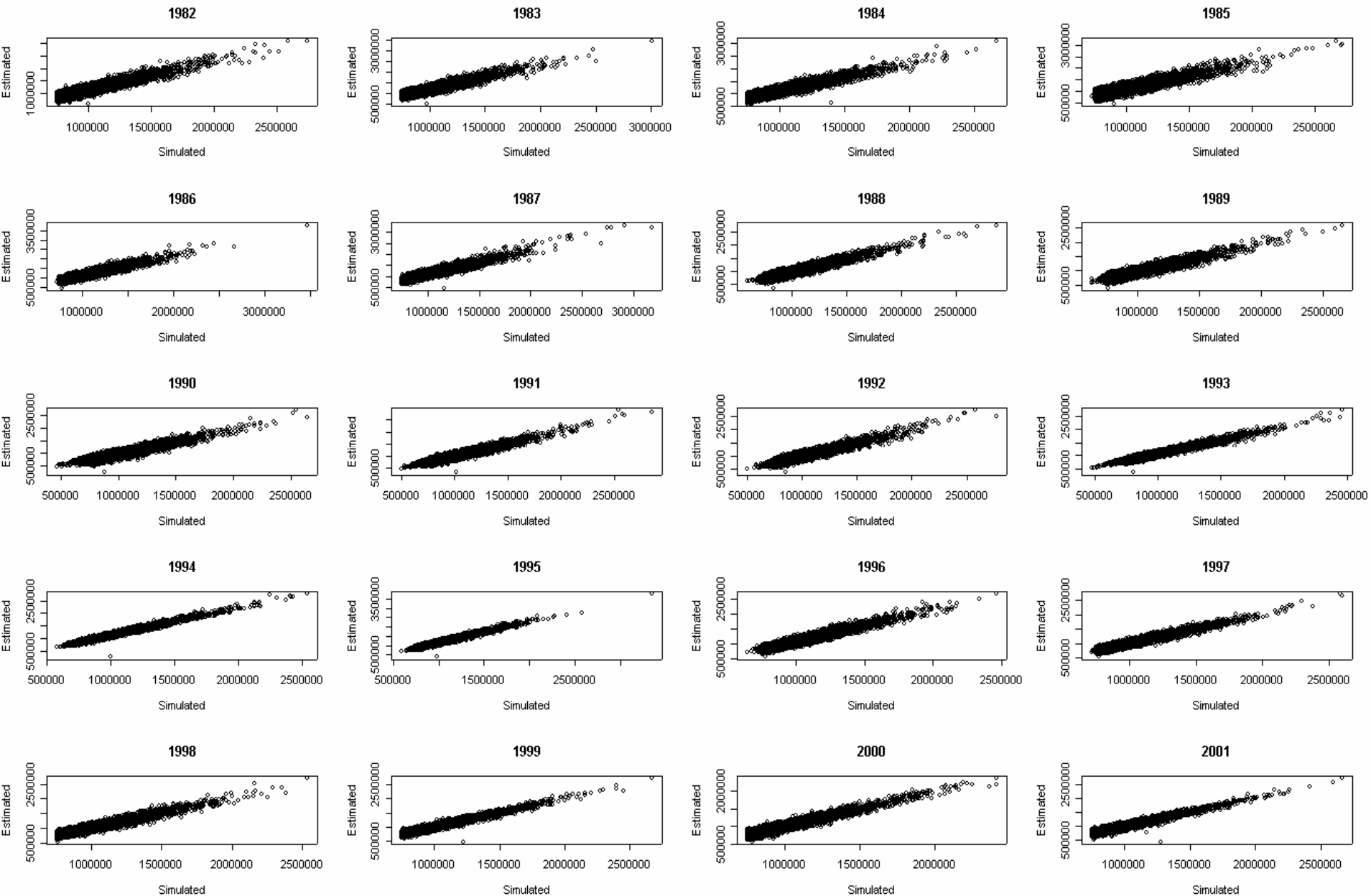


Testing the Approach

Simulation Testing

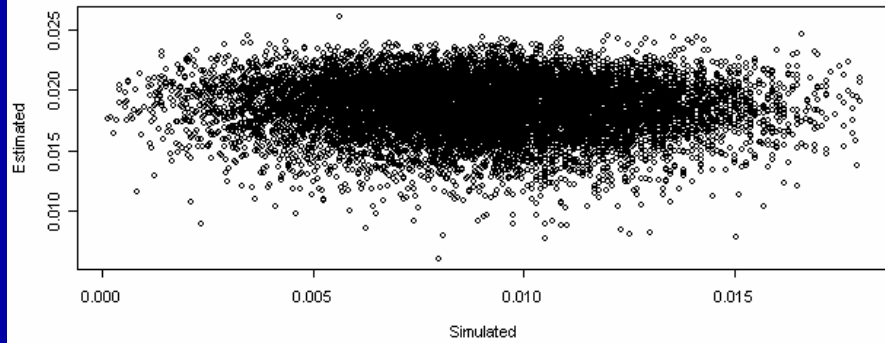
- Used a Ricker stock recruit with process error. Simulated different catchability, vulnerability and maturation schedules by different fisheries and time periods.
- Estimated the recruitment deviates, and thereby age 2 recruitment.
- Estimated vulnerability, catchability and maturation by time periods specified.
- Ran 10,000 times (each run takes approximately 10 seconds-27 hours).

Age 2 Recruitment

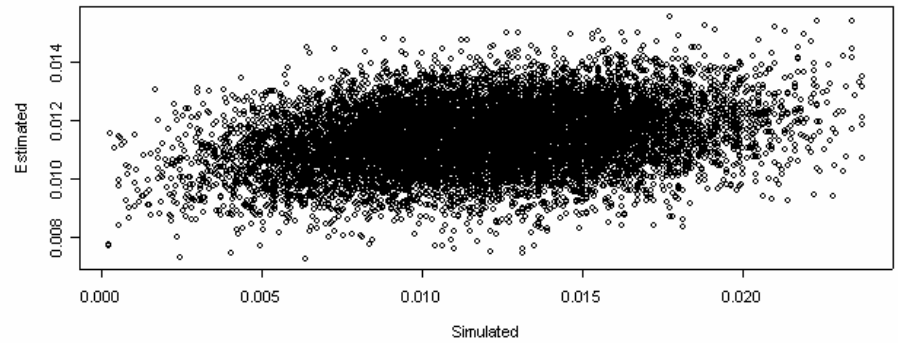


Catchability

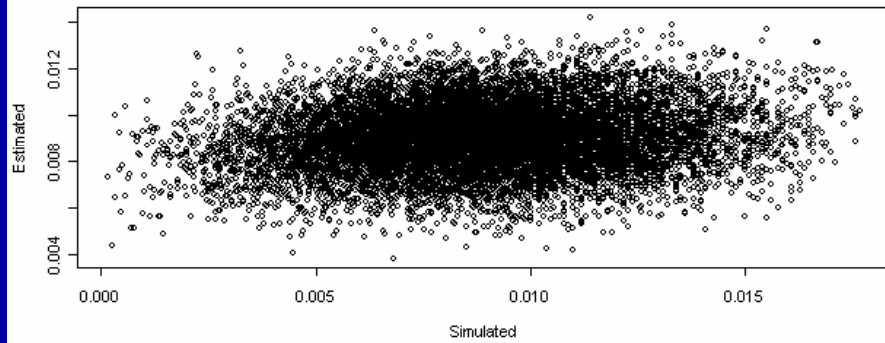
Terminal catchability Period 1



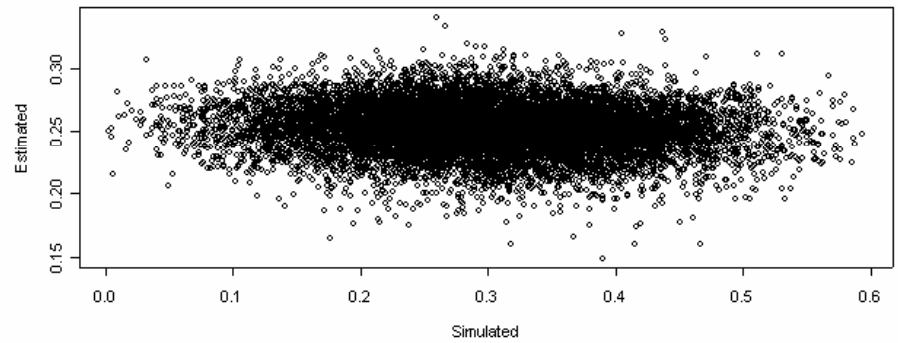
Terminal catchability Period 2



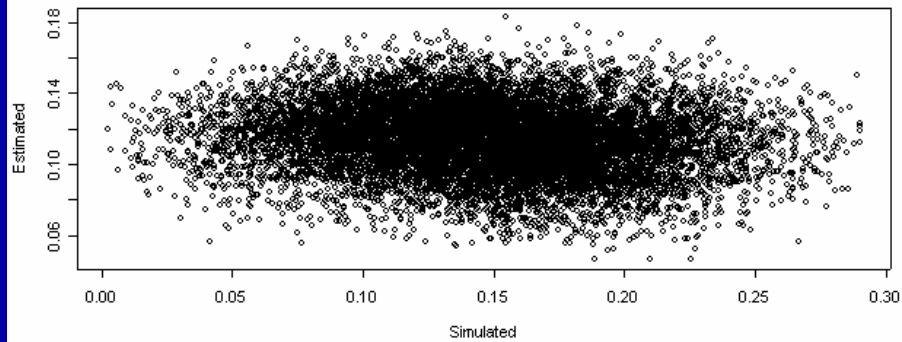
Terminal catchability Period 3



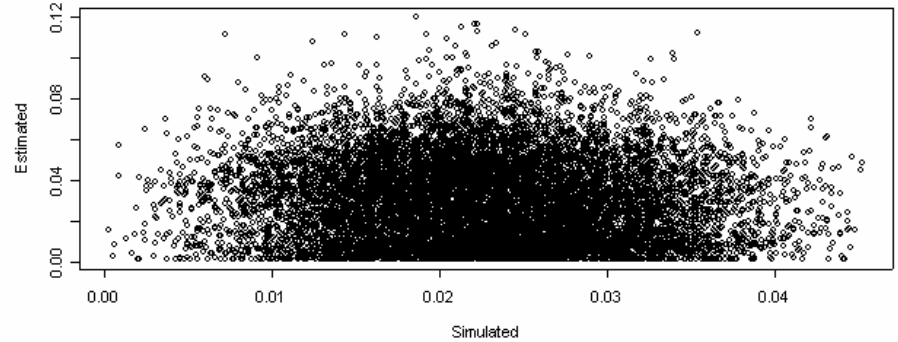
Ocean catchability Period 1



Ocean catchability Period 2

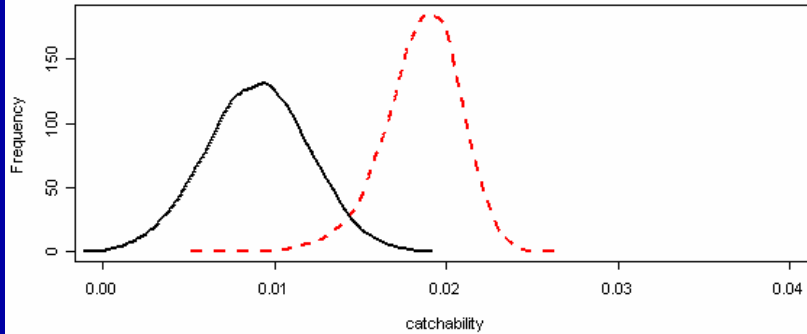


Ocean catchability Period 3

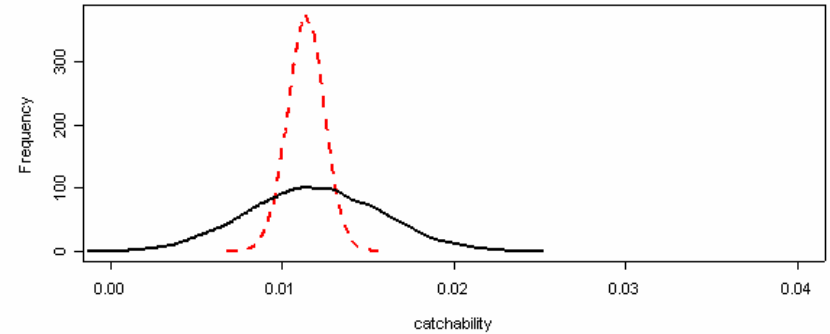


Catchability

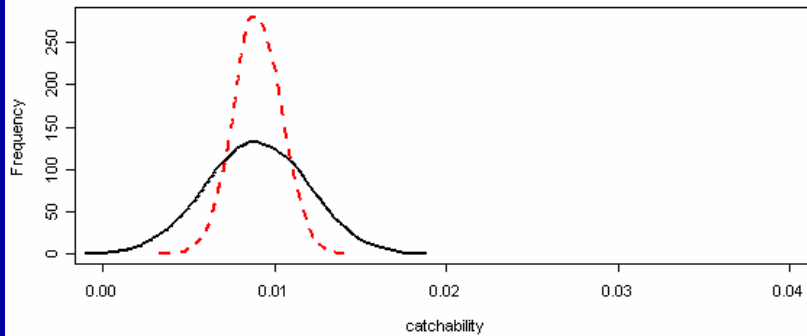
Terminal catchability Period 1



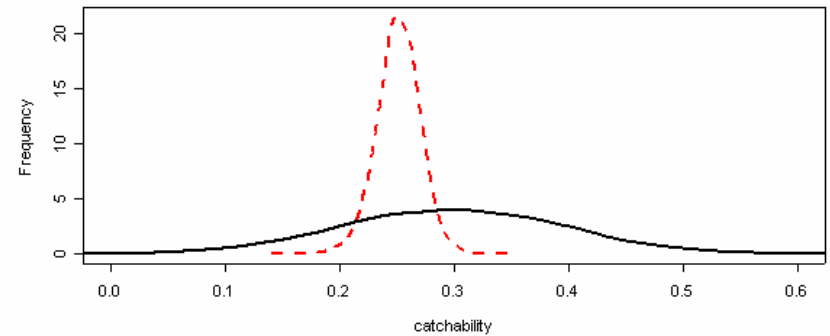
Terminal catchability Period 2



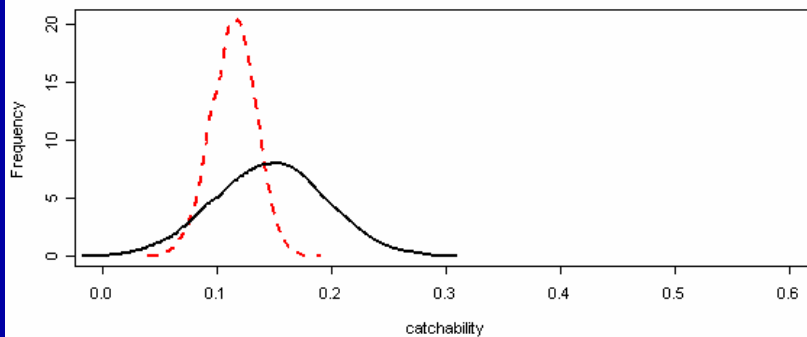
Terminal catchability Period 3



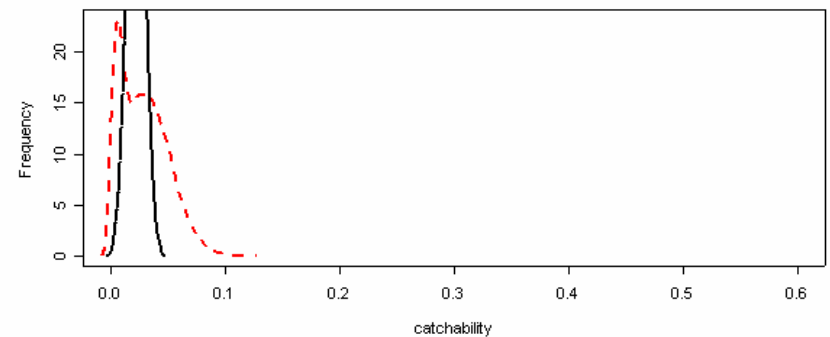
Ocean catchability Period 1



Ocean catchability Period 2



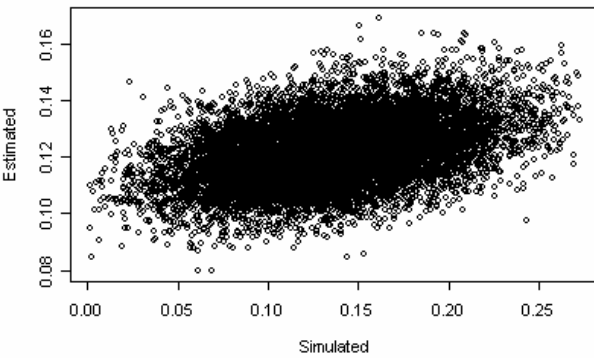
Ocean catchability Period 3



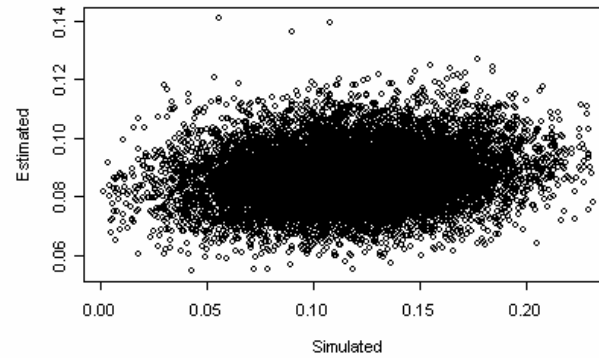
Catchability --- Estimated — Simulated (real)

Maturation

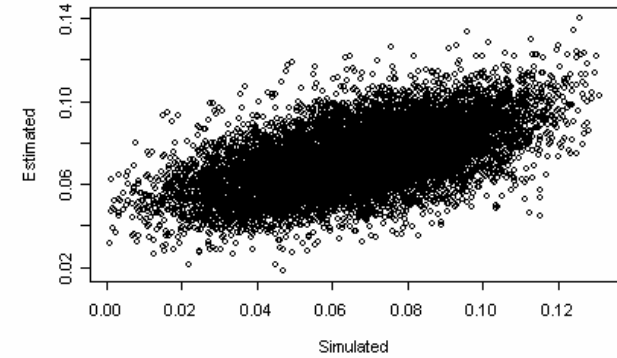
Age 2 Maturation Period 1



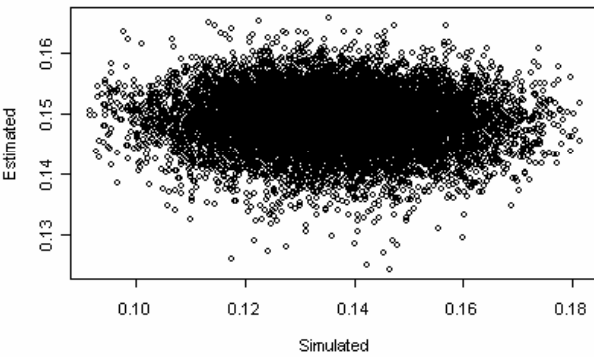
Age 2 Maturation Period 2



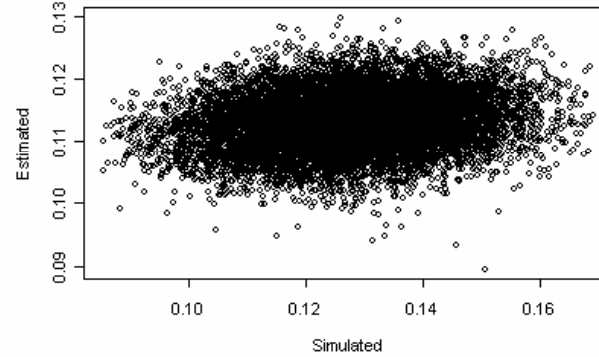
Age 2 Maturation Period 3



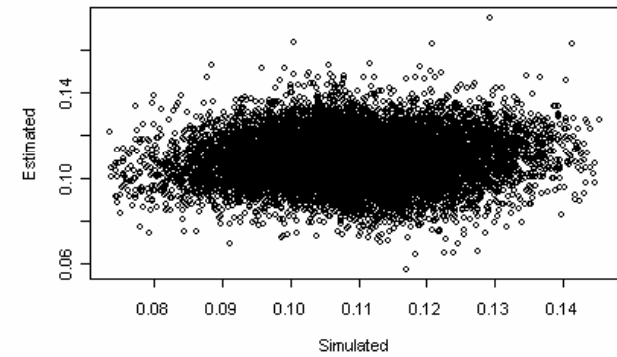
Age 3 Maturation Period 1



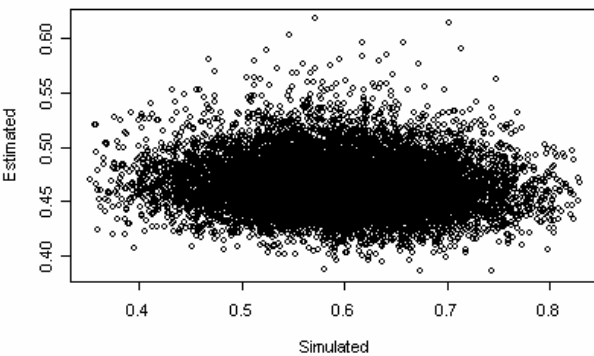
Age 3 Maturation Period 2



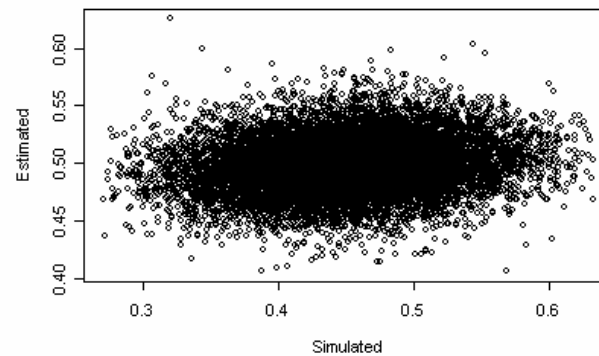
Age 3 Maturation Period 3



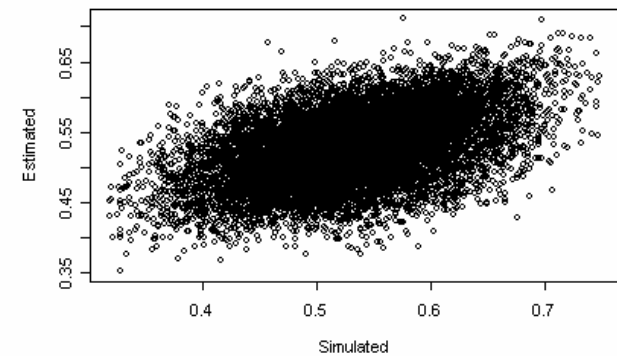
Age 4 Maturation Period 1



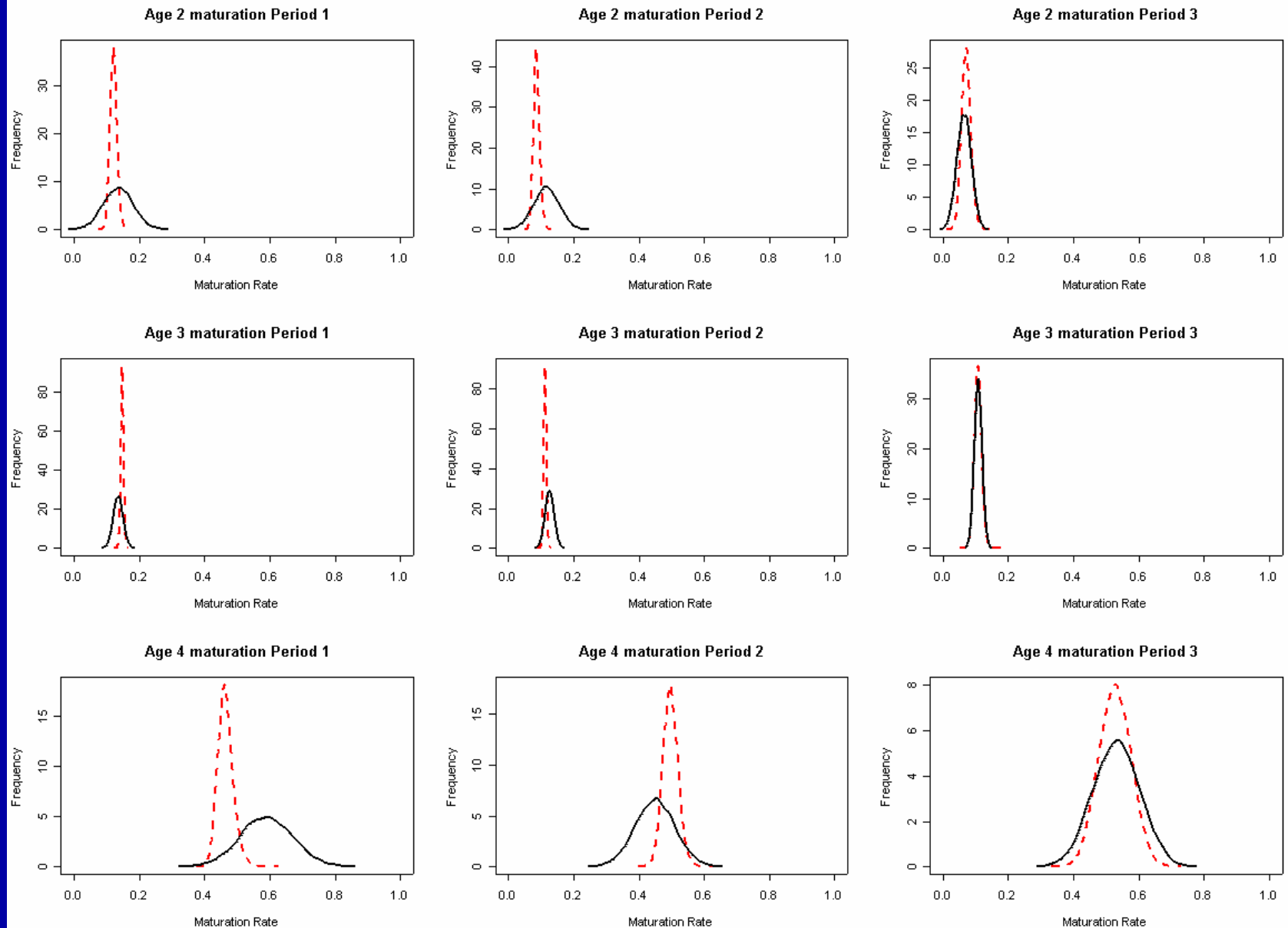
Age 4 Maturation Period 2



Age 4 Maturation Period 3



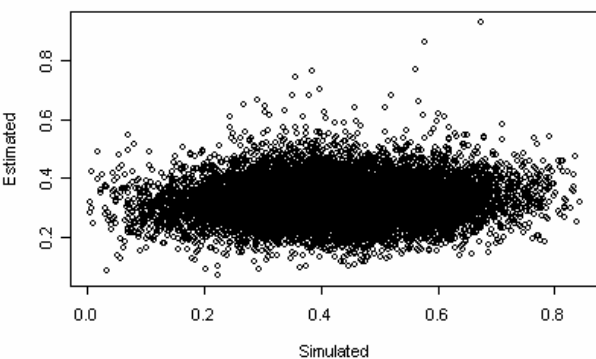
Maturation



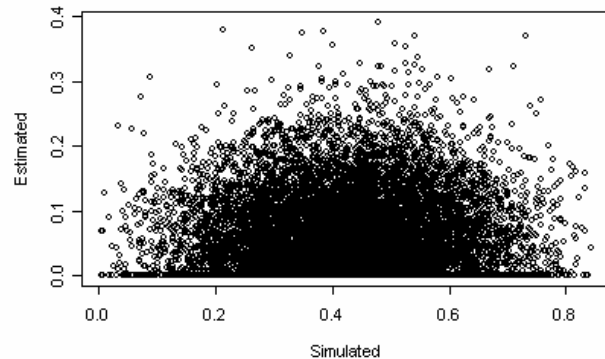
Maturation --- Estimated — Simulated (real)

Terminal Vulnerability

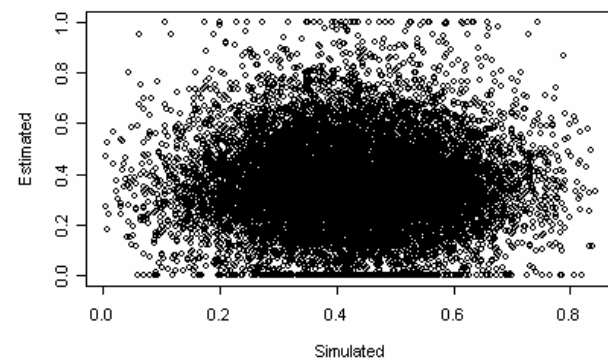
Age 2 Vulnerability Period 1



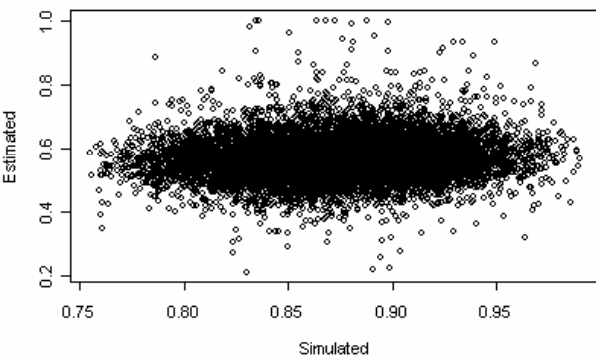
Age 2 Vulnerability Period 2



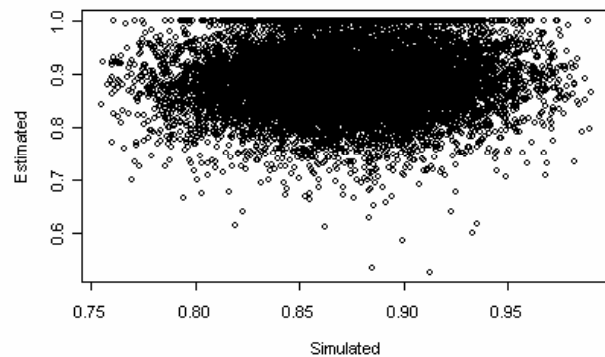
Age 2 Vulnerability Period 3



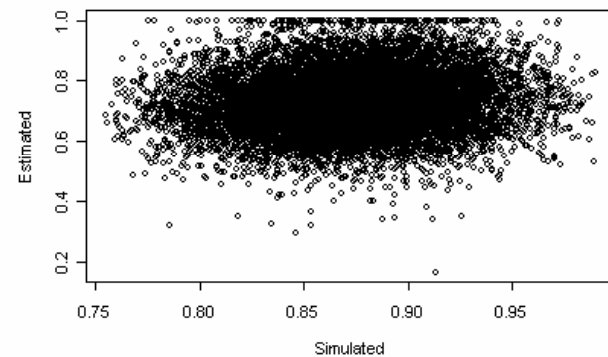
Age 3 Vulnerability Period 1



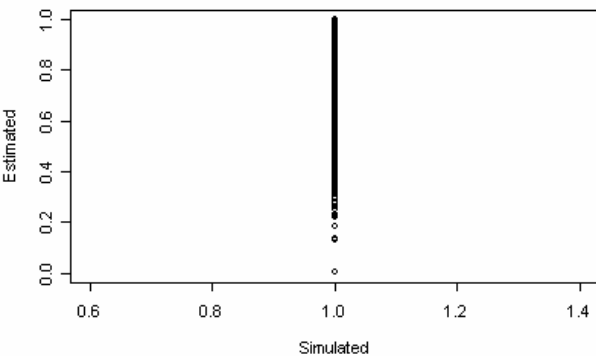
Age 3 Vulnerability Period 2



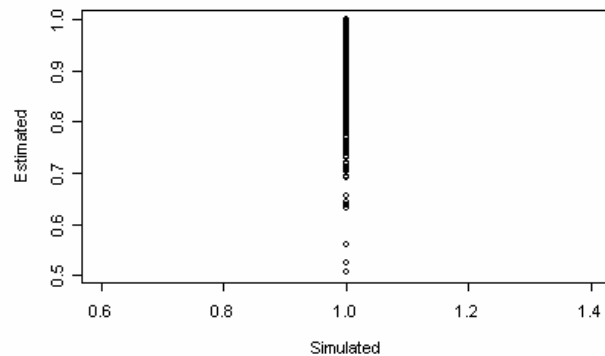
Age 3 Vulnerability Period 3



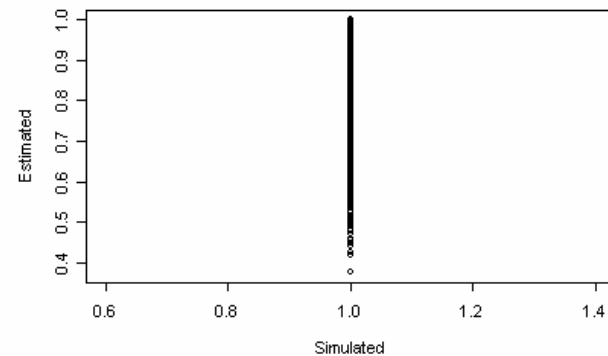
Age 4 Vulnerability Period 1



Age 4 Vulnerability Period 2

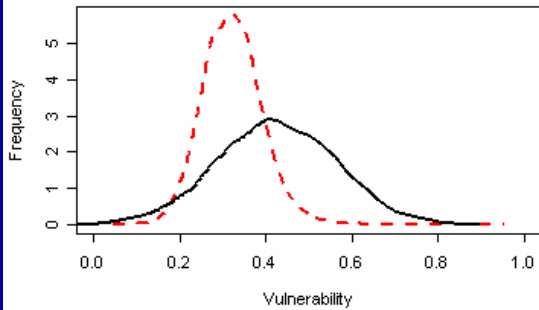


Age 4 Vulnerability Period 3

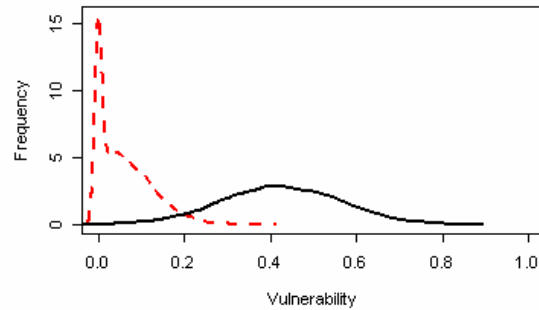


Terminal Vulnerability

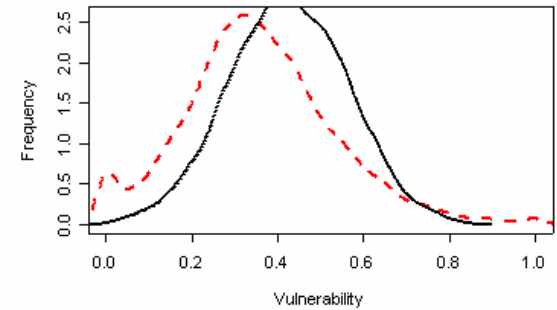
Age 2 Vulnerability Period 1



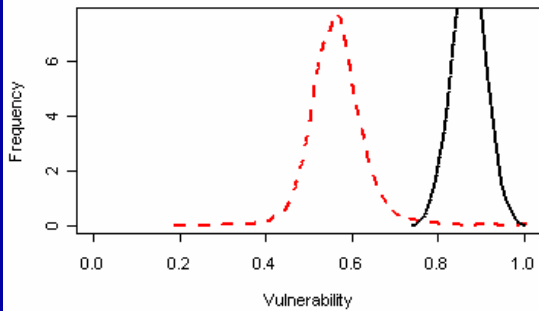
Age 2 Vulnerability Period 2



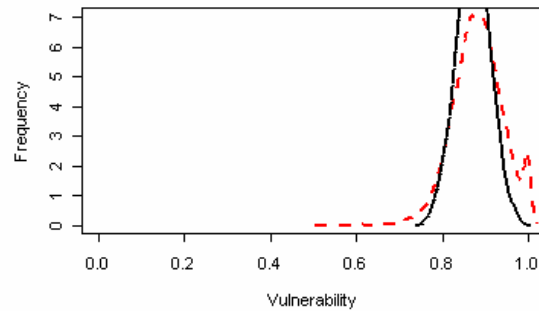
Age 2 Vulnerability Period 3



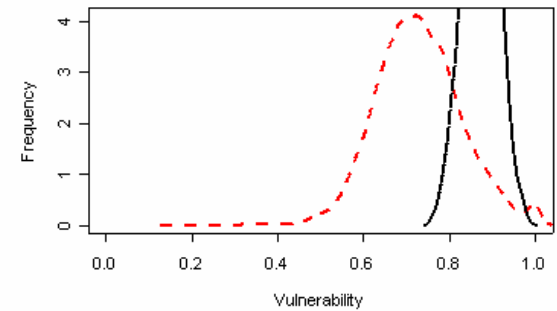
Age 3 Vulnerability Period 1



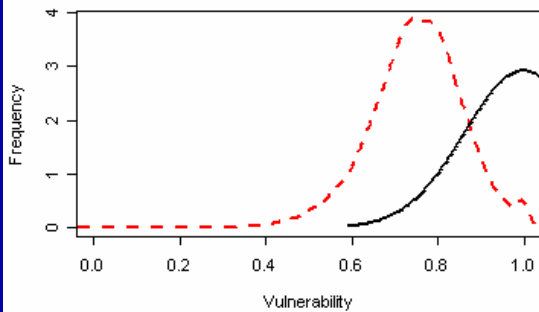
Age 3 vulnerability Period 2



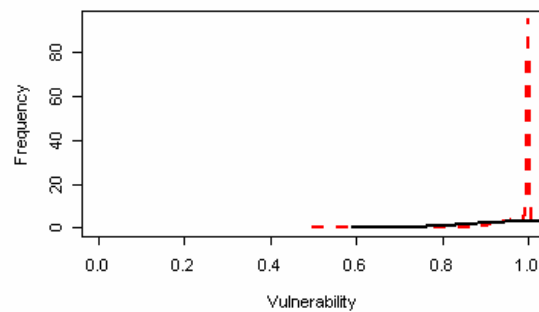
Age 3 vulnerability Period 3



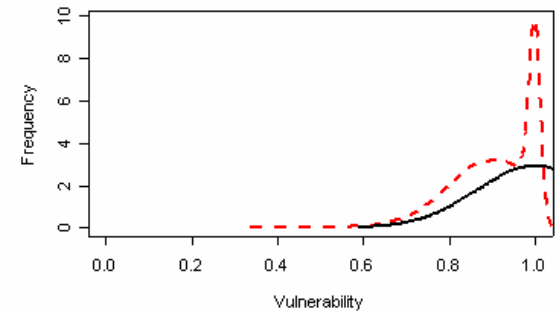
Age 4 Vulnerability Period 1



Age 4 vulnerability Period 2



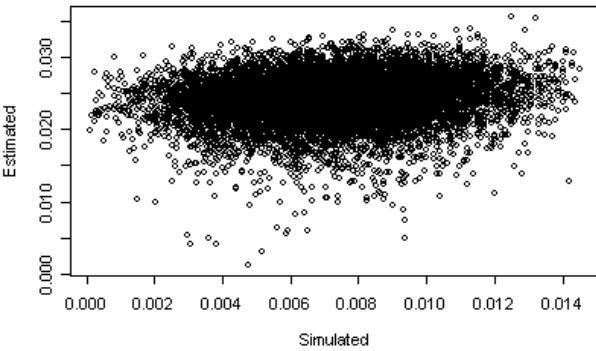
Age 4 vulnerability Period 3



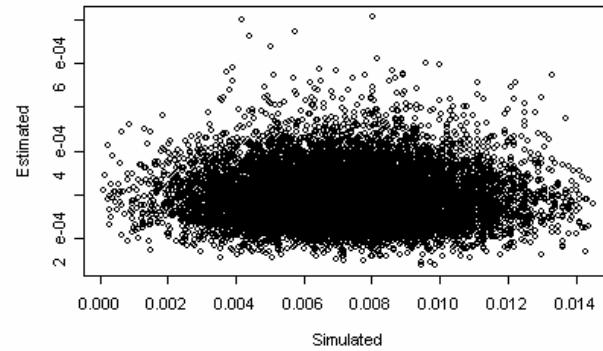
Vulnerability ---Estimated — Simulated (real)

Ocean Vulnerability

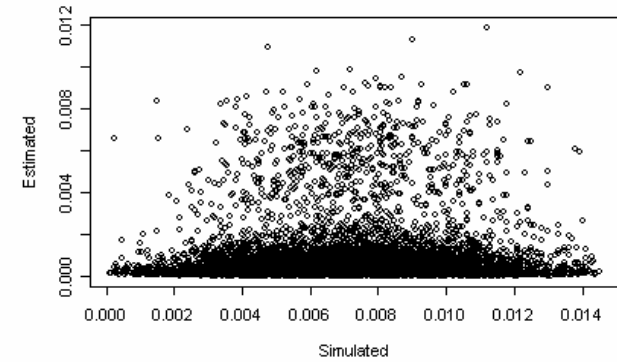
Age 2 Vulnerability Period 1



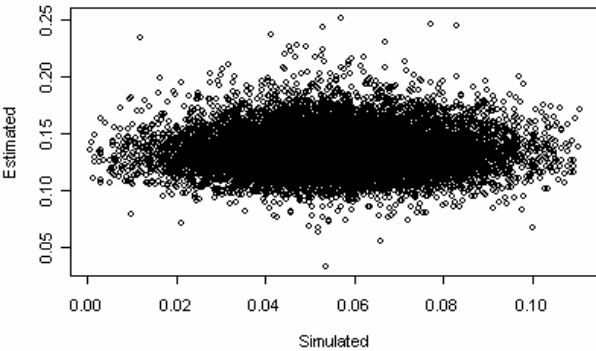
Age 2 Vulnerability Period 2



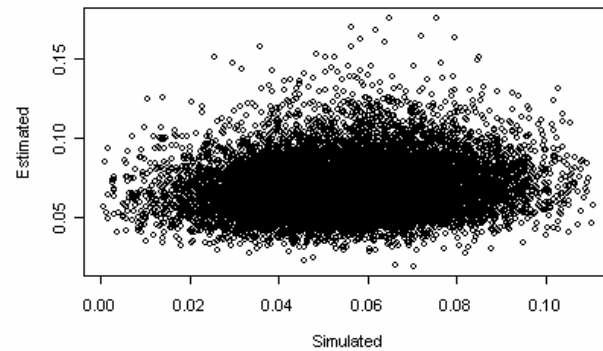
Age 2 Vulnerability Period 3



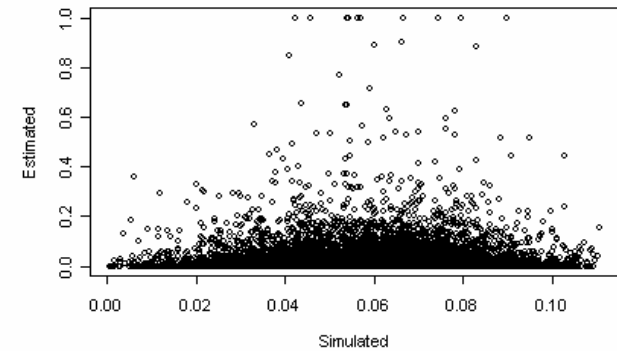
Age 3 Vulnerability Period 1



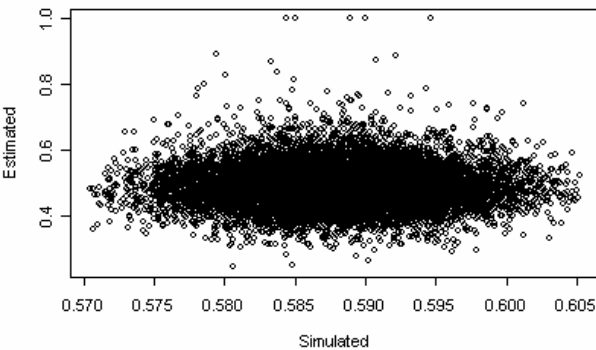
Age 3 Vulnerability Period 2



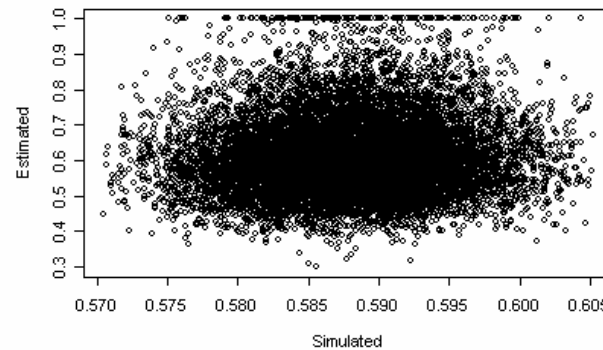
Age 3 Vulnerability Period 3



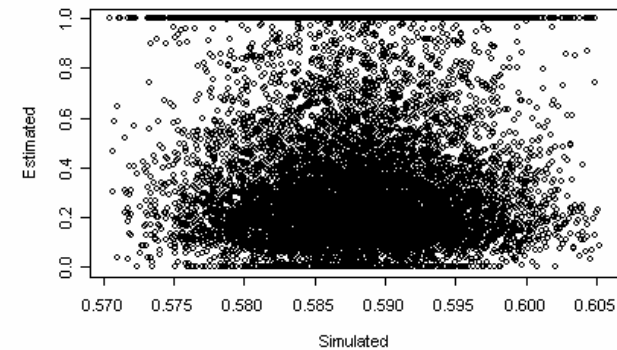
Age 4 Vulnerability Period 1



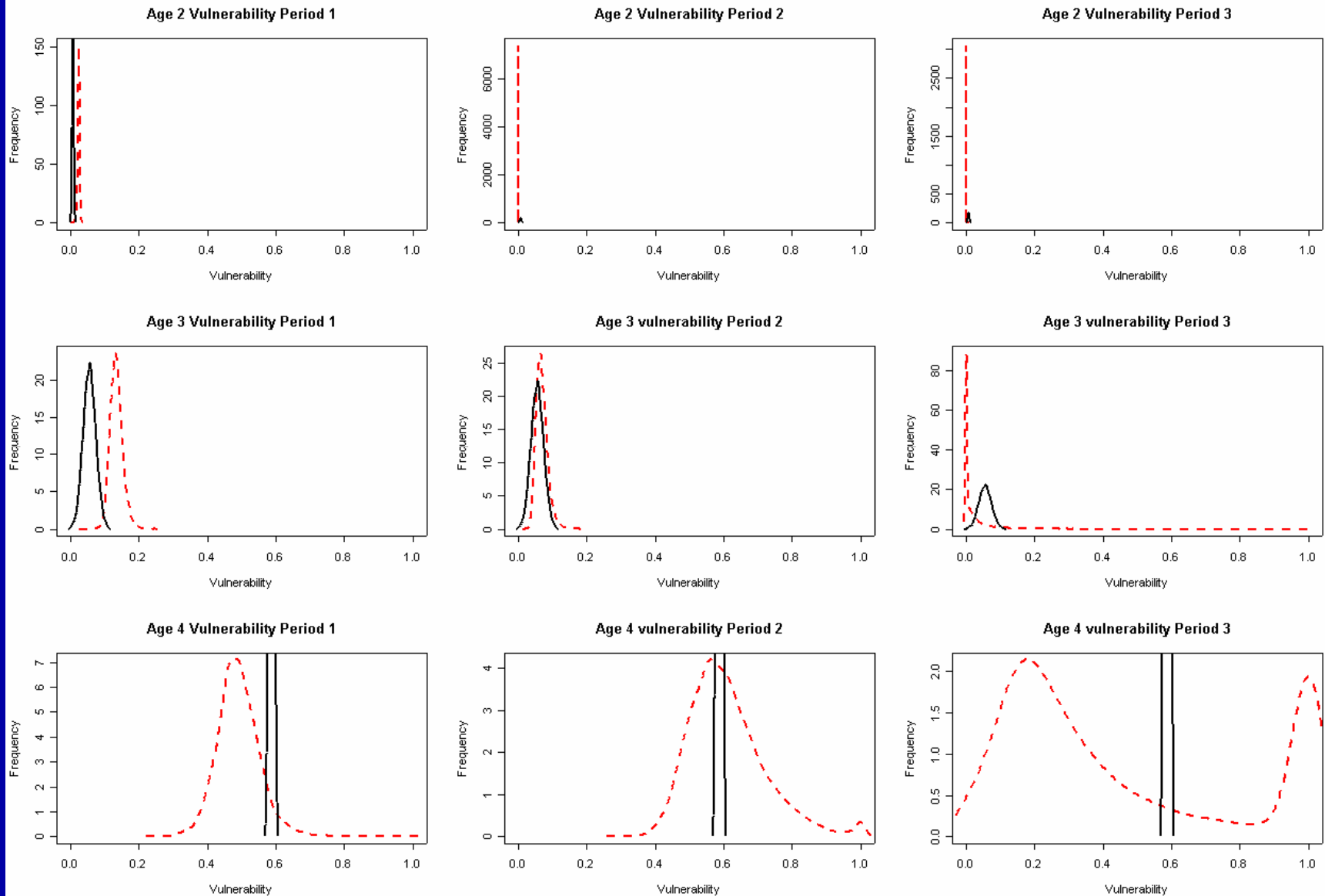
Age 4 Vulnerability Period 2



Age 4 Vulnerability Period 3



Ocean Vulnerability



Vulnerability --- Estimated — Simulated (real)

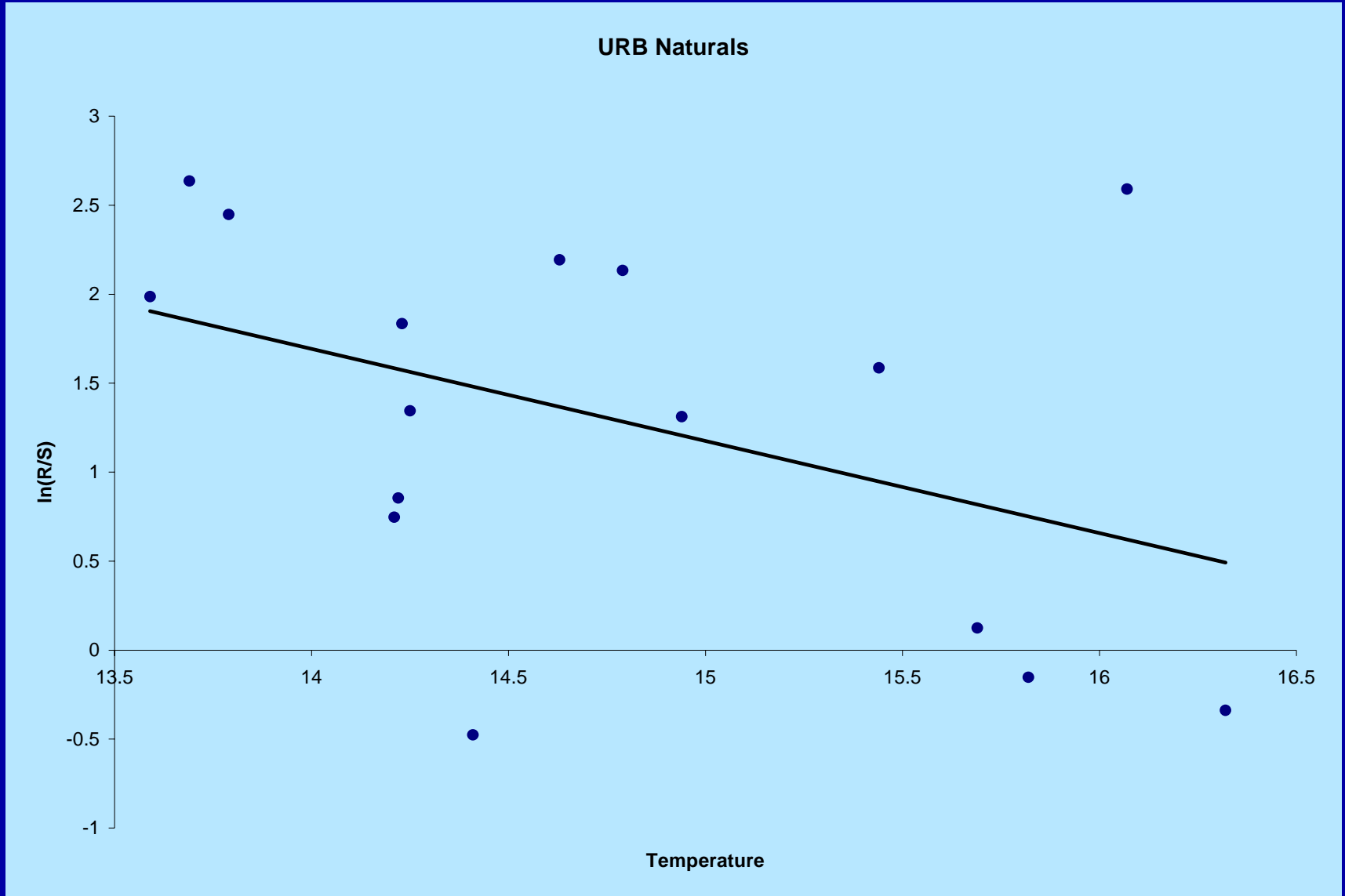
Summary of simulations

- Model has a high accuracy on estimating Recruitment & Exploitation Rates.
- Model is biased (underestimating) on true parameters on Catchability and Maturation.
- The model does not appear to capture terminal vulnerability, though ocean vulnerability is marginally better.
- Adding measurement error to the data, creates problems in estimation (lower error, $CV < 0.1$, implies greater identifiability versus larger error, $CV > 0.1$)

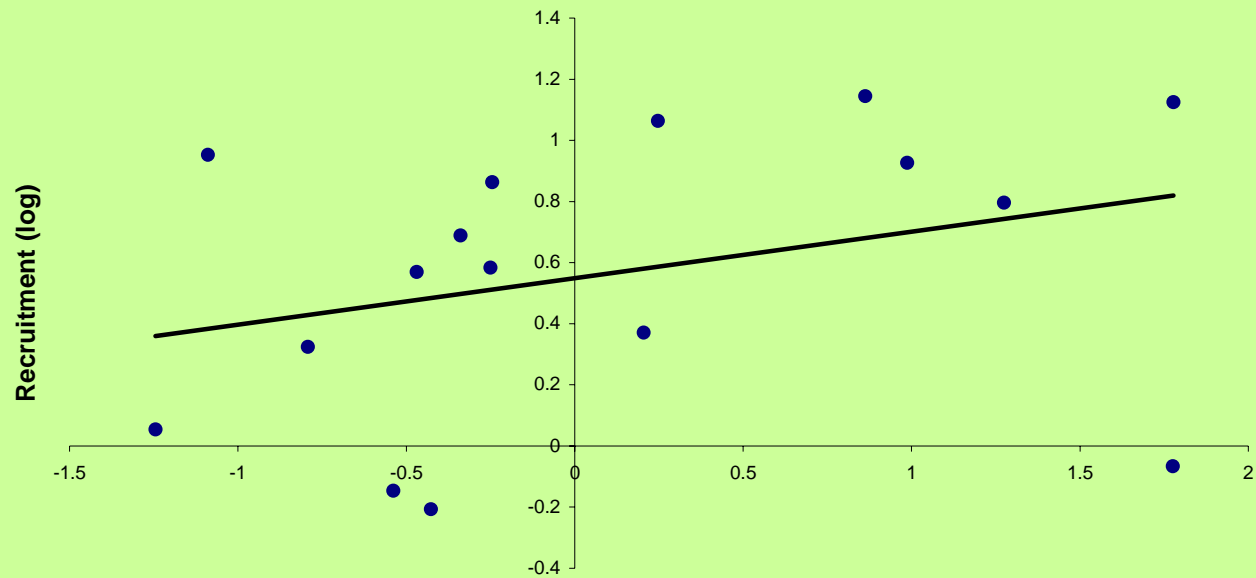
Can we tie recruitment variation to
Environmental variables?

Explaining Recruitment Variability

Adding additional Covariates

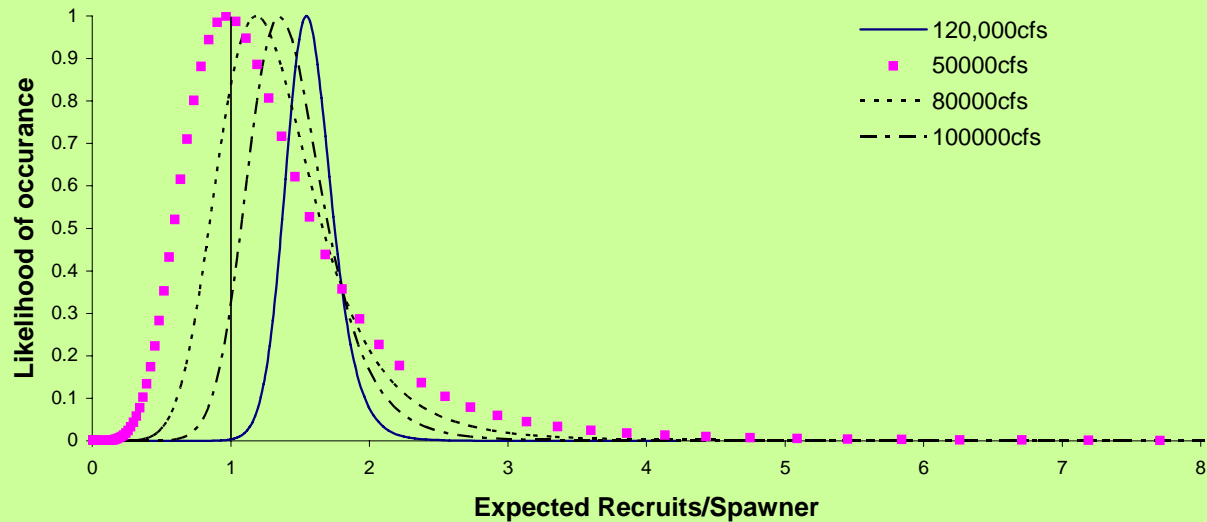


Flow versus recruitment

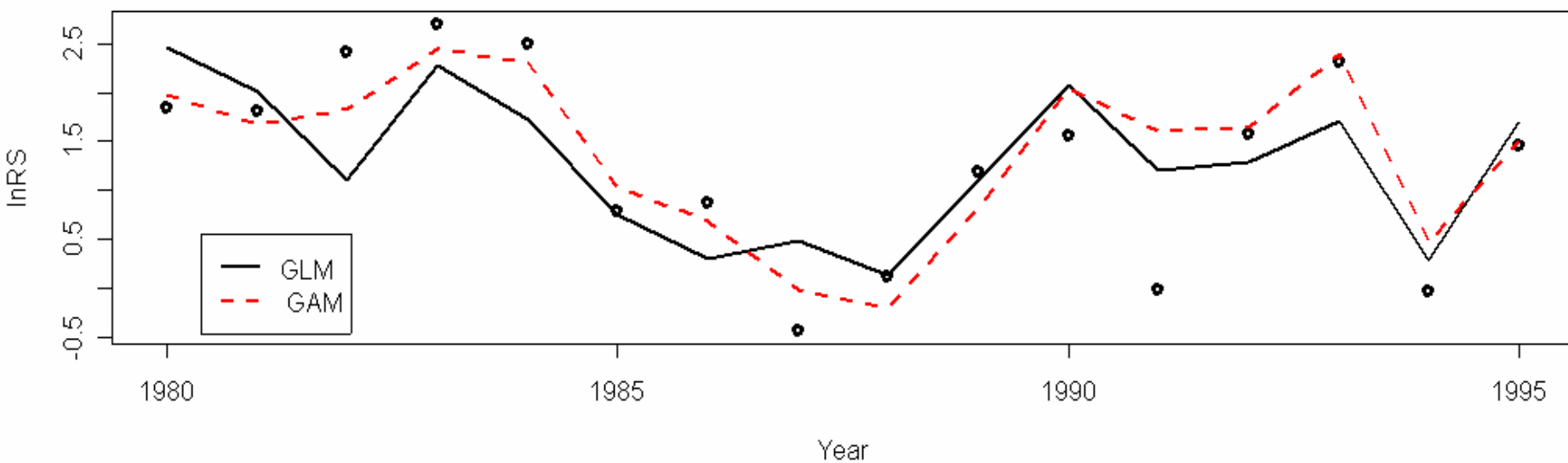


Flow (stdized from April through June at Preiest Rapids)

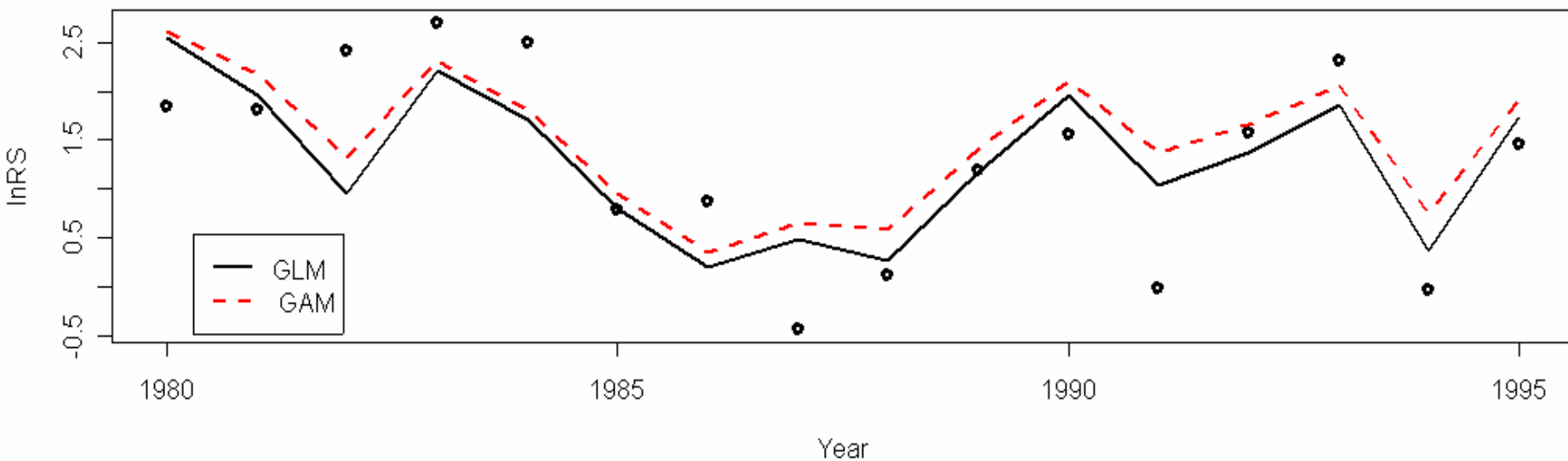
Expected Age 2 Ocean Recruits per Spawner



Recruitment Variability using Spawners, SST & Flow



Recruitment Variability using Spawners and SST



Advantages of catch at age approaches

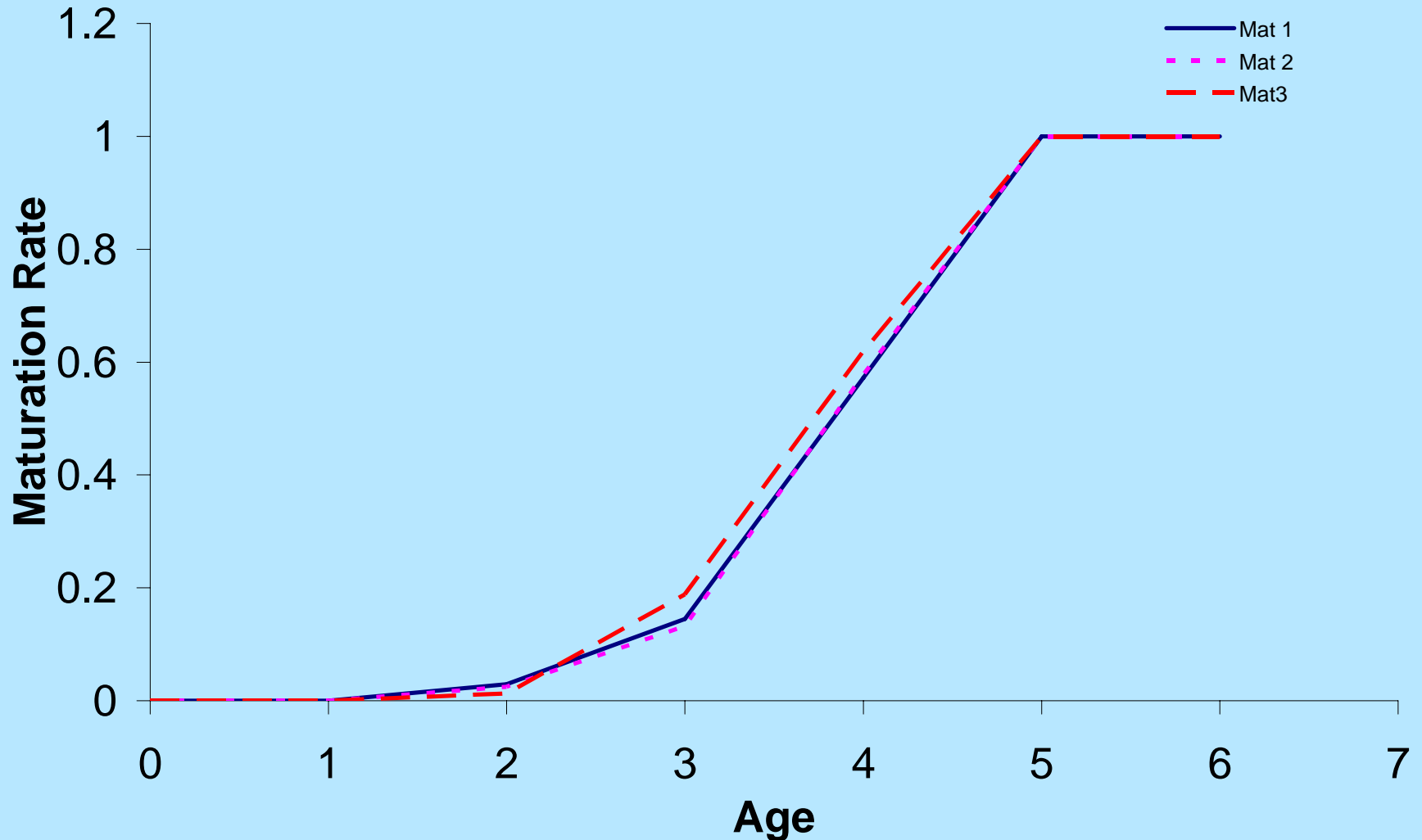
- Statistical catch at age models are more robust (empirical data and likelihood functions). Can quantify the Uncertainty in our estimates.
- Model complexity trade-off.
- Recruitment variation can partially be explained by environmental variables.
- Use GLM's or GAM's for explanatory purposes.
- Build environmental process directly into the model structure.

Testing Finer resolution Fishery structure with data

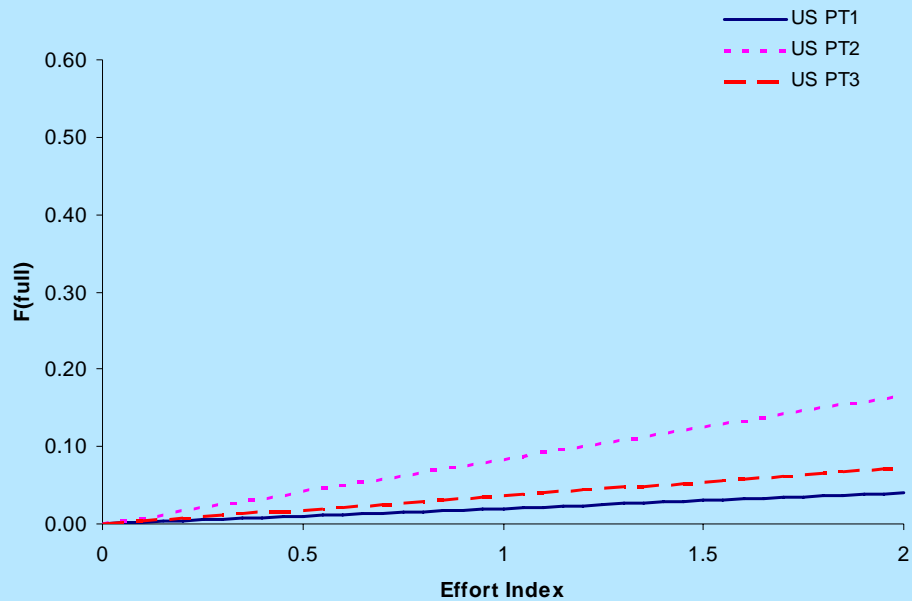
- 5 fisheries (4 ocean and 1 terminal).
- CWT data by strata and effort.
- Estimating recruitment, q , v (selectivity) by fishery and time as well as Maturation by time.

Estimated Parameters

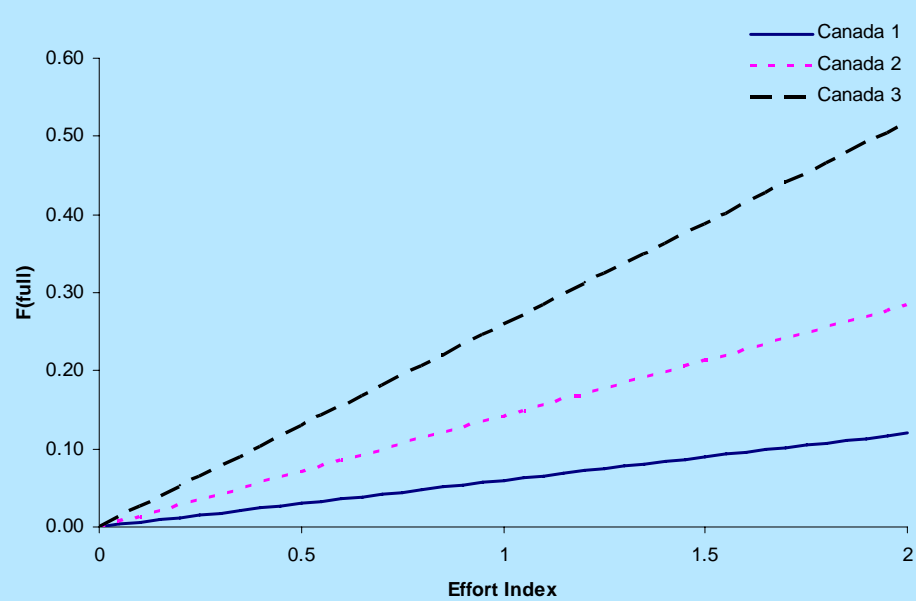
Maturation Rates



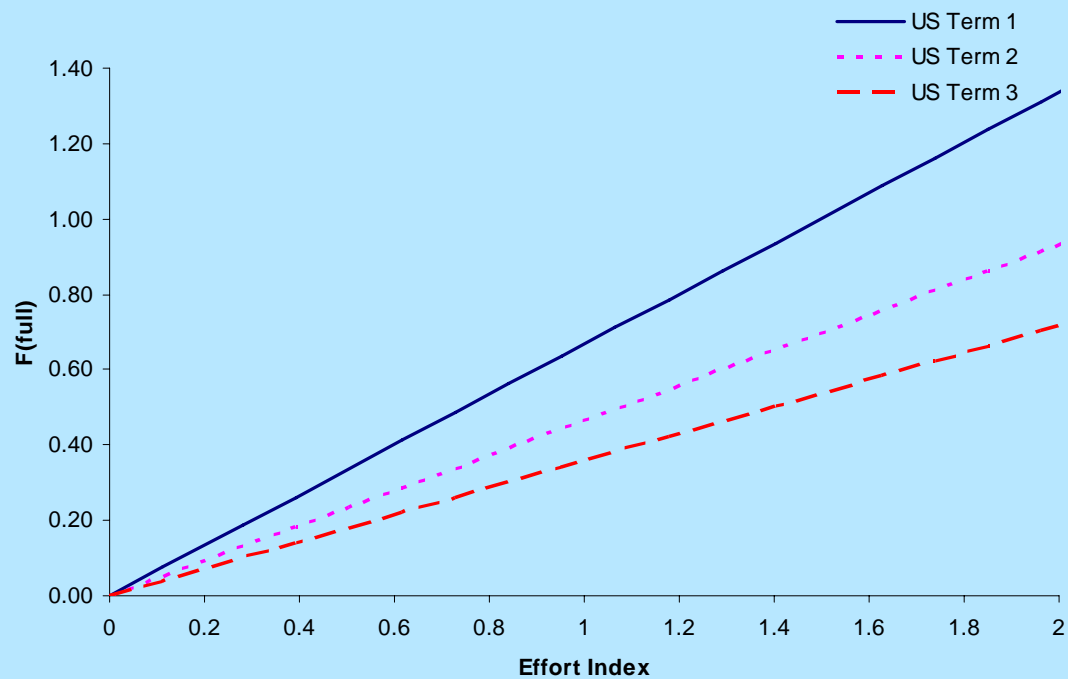
EFFORT US-PT

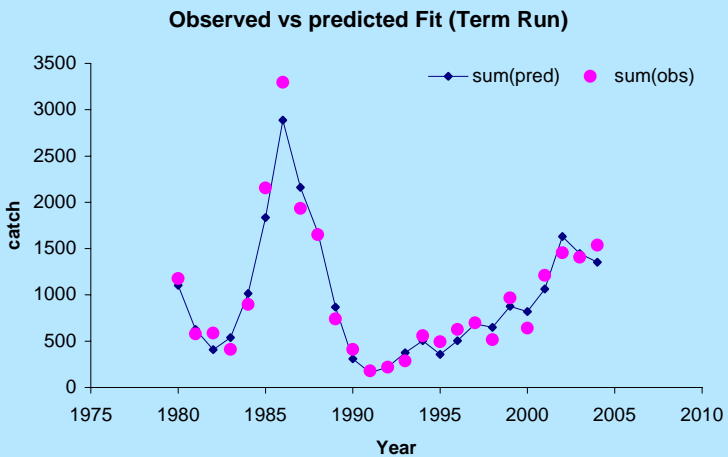
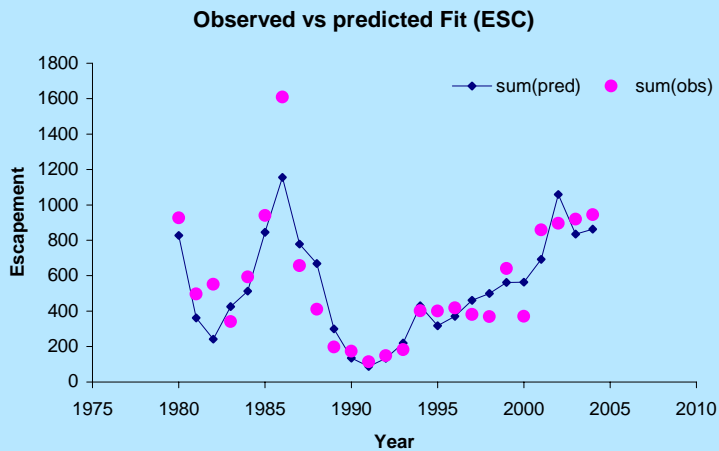
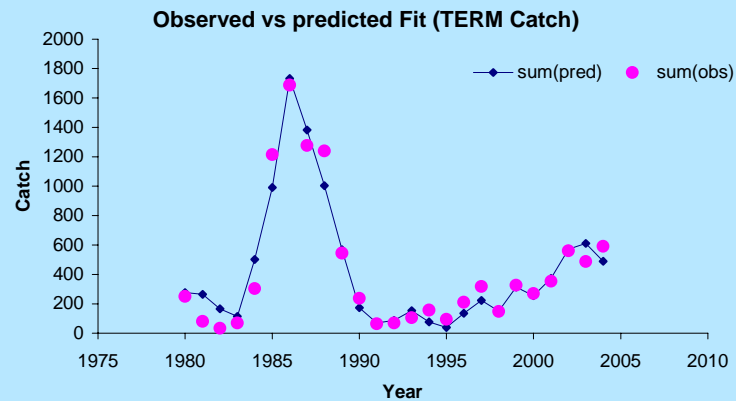
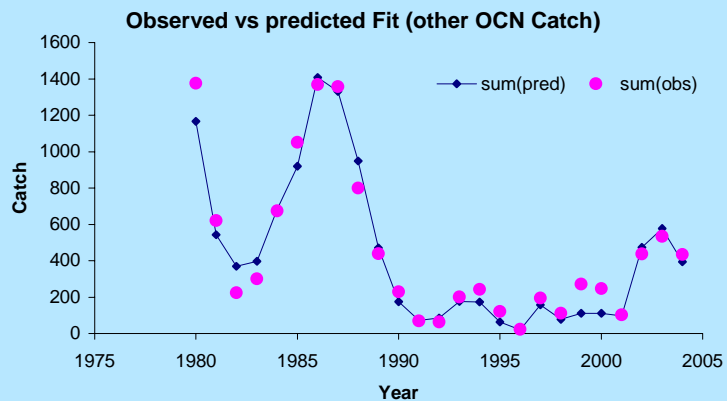
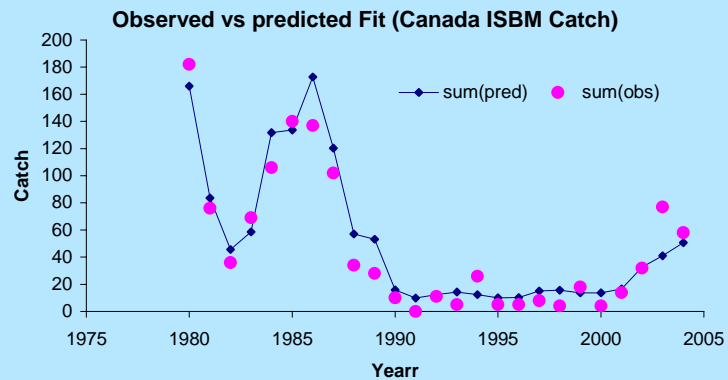
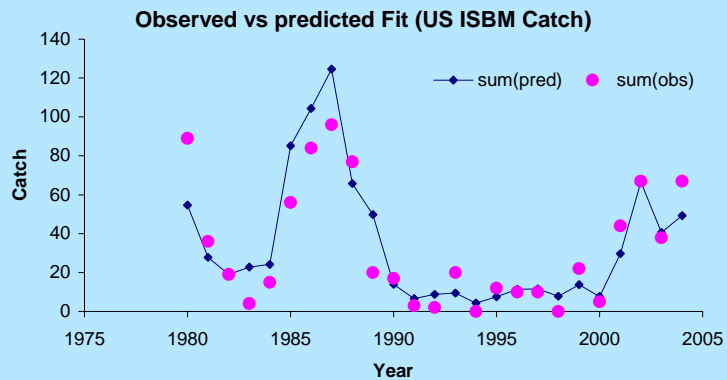


EFFORT Canada-PT



EFFORT US-TERMINAL





Backward cohort analysis with Uncertainty

$$T_{t,a} = E_{t,a} + \sum_{g \in \text{terminal}} C_{g,t} p_{g,t,a}$$

$$m_{t,a} = \frac{1}{\frac{N_{t+1,a+1}}{T_{t,a}} + 1} \quad a < a_{\max}$$

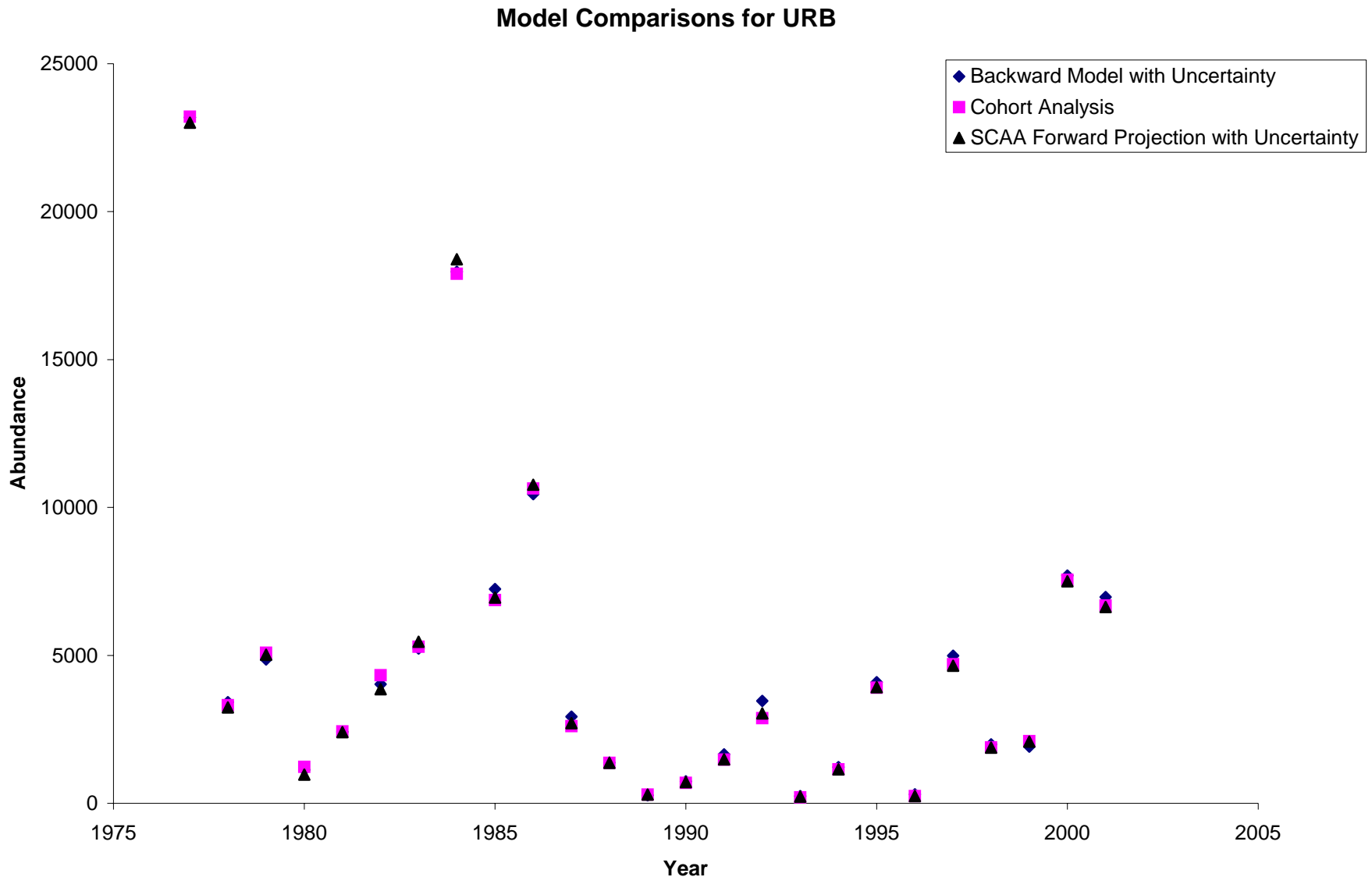
$$N_{t,a} = \frac{T_{t,a}}{\exp[-M_a] m_{t,a}} + \frac{\sum_{g \in \text{ocean}} C_{g,t} p_{g,t,a}}{\exp[-\delta M_a]}$$

$$p_{g,t,a} = \frac{C_{g,t,a}}{\sum_a C_{g,t,a}}$$

$$-\ln L(C^{obs} | \theta) = \sum_{g,t} \ln[\sigma_g] + \frac{(\ln[C_{g,t}^{obs}] - \ln[C_{g,t}])^2}{2\sigma_g^2}$$

$$-\ln L(E^{obs} | \theta) = \sum_{t,a} \ln[\sigma_E] + \frac{(\ln[\phi E_{t,a}^{obs}] - \ln[E_{t,a}])^2}{2\sigma_E^2}$$

Comparisons across methods



Multi-fishery and multi-stock Model

- Determine a set of stocks to manage for on which we have good escapement data.
- Use the above described approach with tags or GSI to get age structured catch in fisheries.
- Incorporate stock composition using a multinomial likelihood, and adding that to the objective function.

3 stock- 2fishery model

$$-Ln(L(\theta | C_{f,i})) = \sum_{i=1}^3 \sum_{f=1}^2 \ln(\sigma_{f,i}) + \frac{(C_{f,i} - \hat{C}_{f,i})^2}{2\sigma_{f,i}^2}$$

$$-Ln(L(\theta | C_{f,i}, p_{f,i})) = -\sum_{i=1}^3 \sum_{f=1}^2 C_{f,i} \ln(p_{f,i})$$

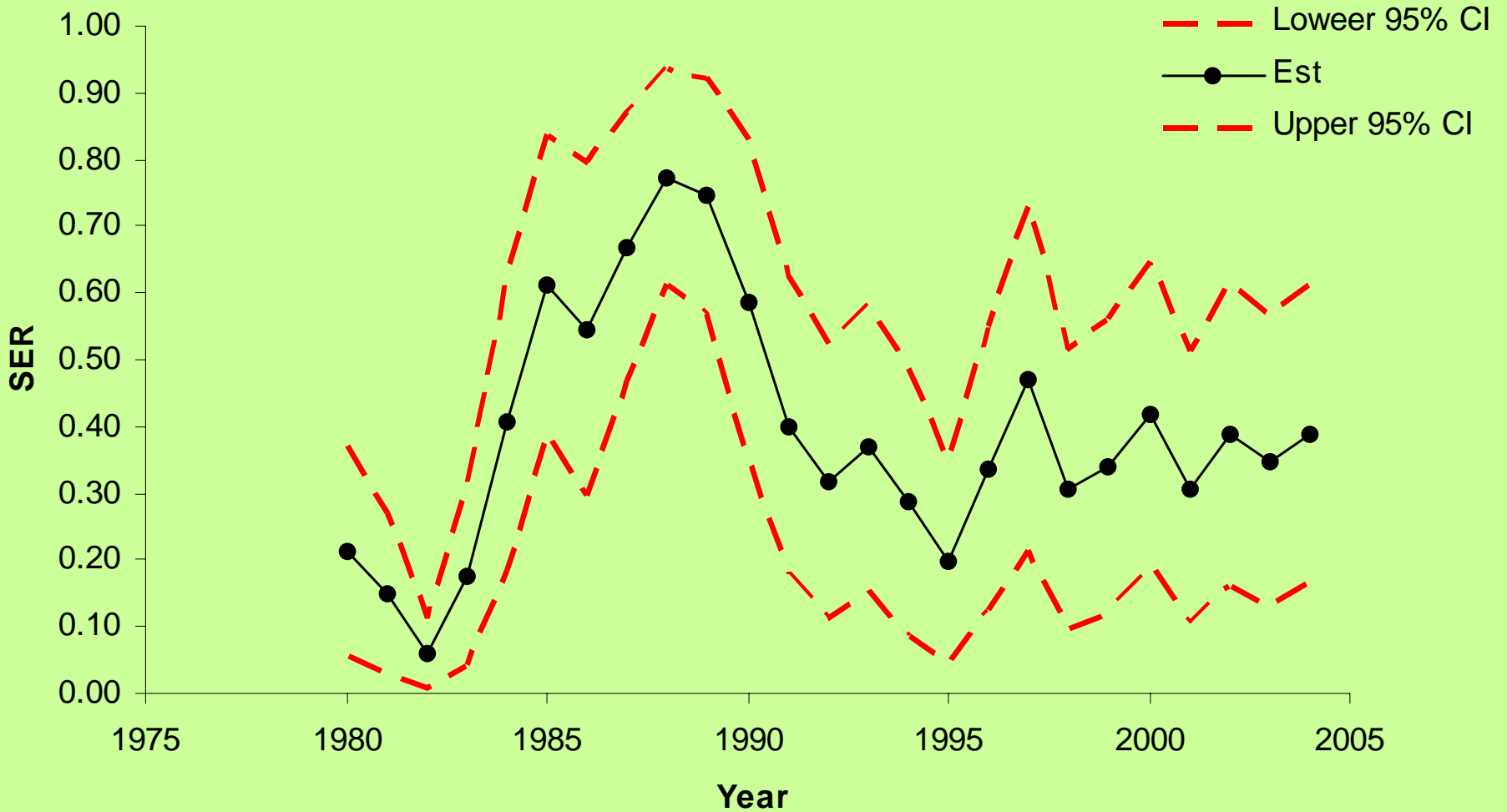
GSI and CWT

$$L(\theta | C_{a,t,f}) = \prod_{f=1}^n \frac{1}{\sqrt{2\pi\sigma_f^2}} \exp\left[-\frac{(C_{a,t,f}) - (\hat{C}_{a,t,f})^2}{2\sigma_f^2}\right]$$

$$-\ln L(\theta | C_{a,t,f}) = \sum_{f=1}^n \ln(\sigma_f) + \frac{\ln((C_{a,t,f}) - \ln(\hat{C}_{a,t,f}))^2}{2\sigma_f^2}$$

- Vary Sigma as a function of both observation (sampling) and process error.
- Quantify Uncertainty in SER for the URB CWT data.
- Once we have those estimates externally determined, a fair comparison can be made between CWT and GSI and their effect on ER's.

Simple Terminal ER (URB) :More Uncertainty



Conclusions

- Difficult problem but can be done.
- Data and computer intensive.
- If sampling error is large, the approach will not work.
- Explicitly incorporates uncertainty in the estimates.
- Possible framework to use multiple types of data.
- Provides an ER target to manage for with Uncertainty.

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Sampling error and Harvest Rates

