Exploring the influence of climate, competition and aquaculture on the dynamics of Fraser River sockeye salmon and the economics of their fisheries

Yajie Liu,

SINTEF Fisheries and Aquaculture, Norway

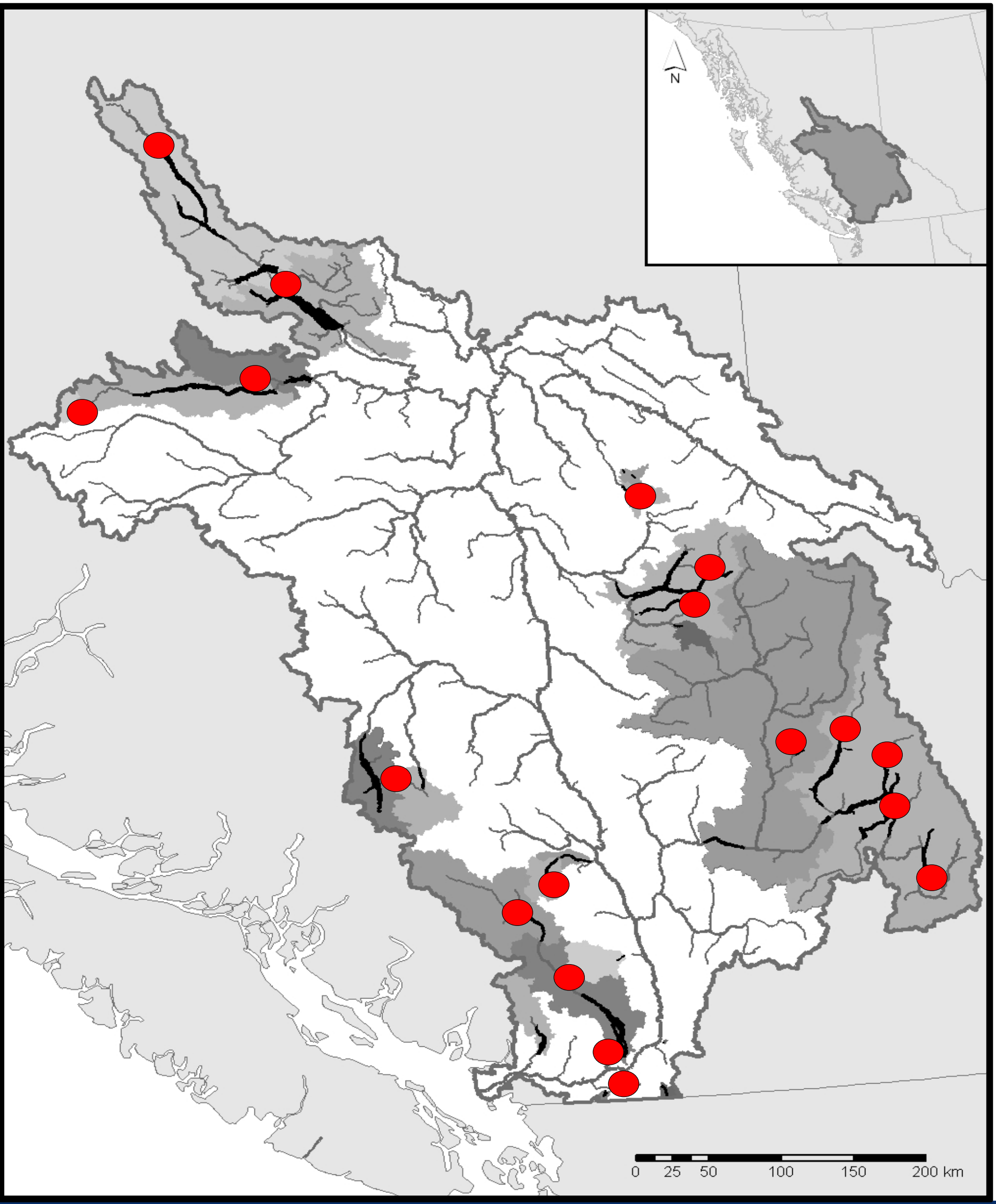
Brendan Connors

ESSA Technologies Ltd, Canada

July 9, 2014

Outline

- Research problem
- Methodological framework
- Results
- Discussion
- Limitations

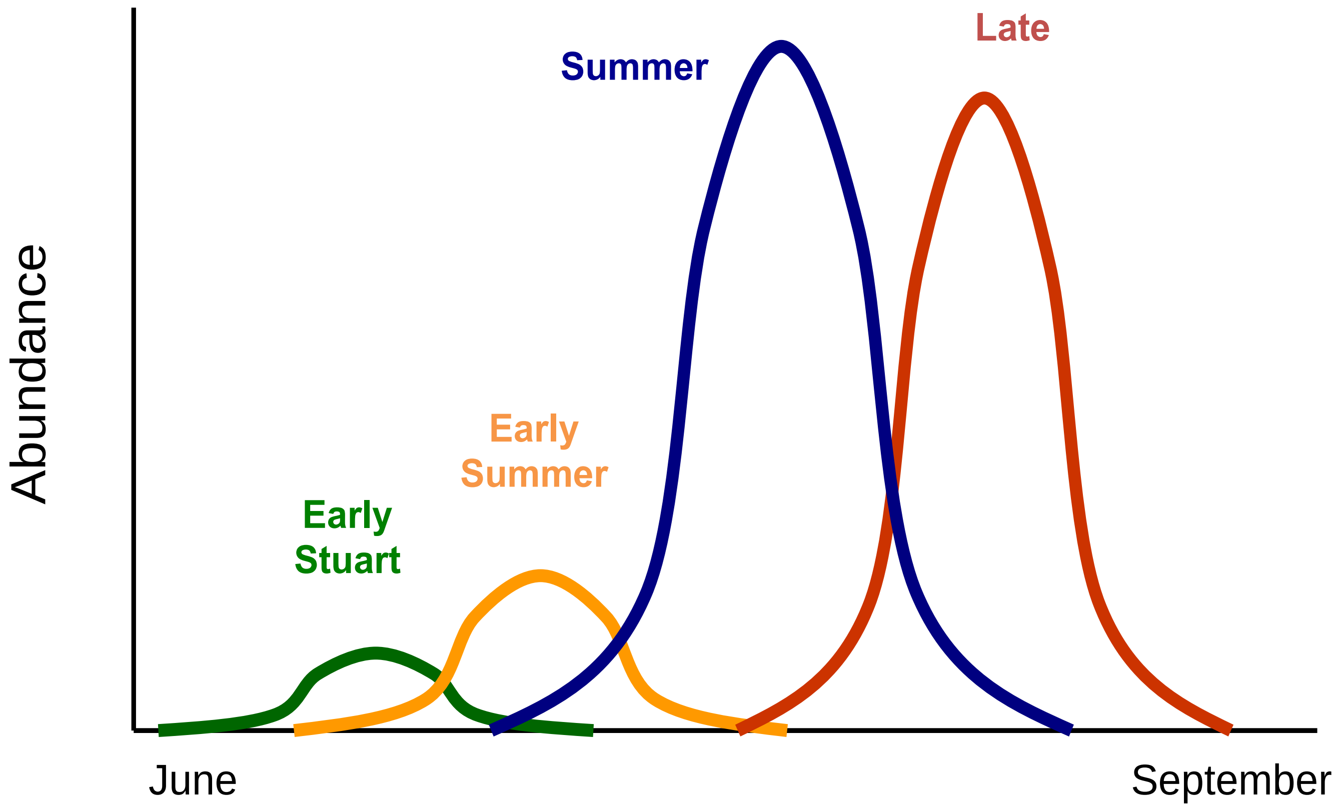


Fraser River sockeye salmon

- Ecological, social and economic importance
- 200 + spawning locations
- ● 18 stocks

Run timing

- Fishery management groups based on run timing for which target escapement and exploitation rates are set



Harvest

USA

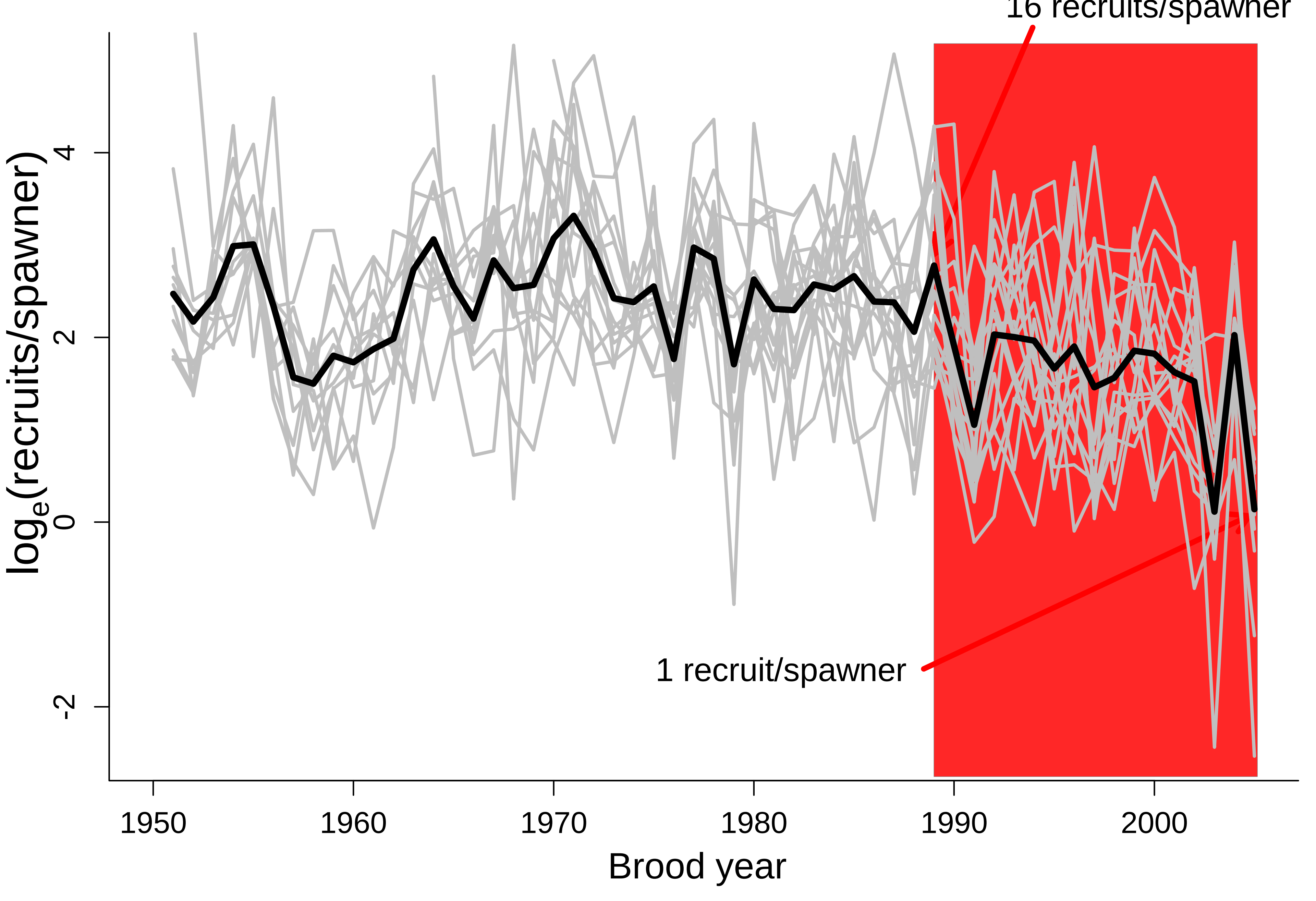
→ First Nation (food, culture & ceremony)

→ Recreational fishing

→ First Nation (econ. Opportunity)

→ Commercial fishing

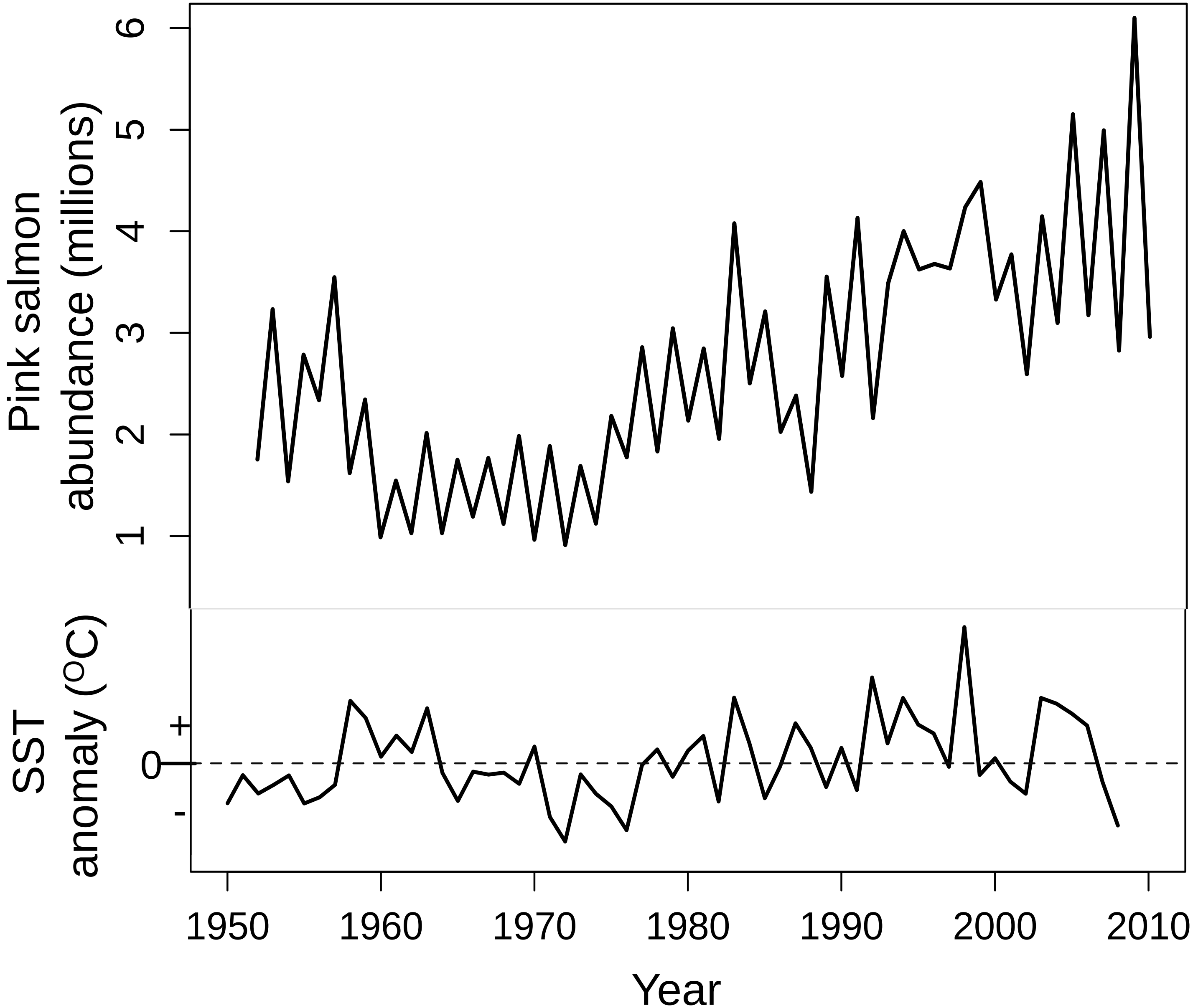
The problem

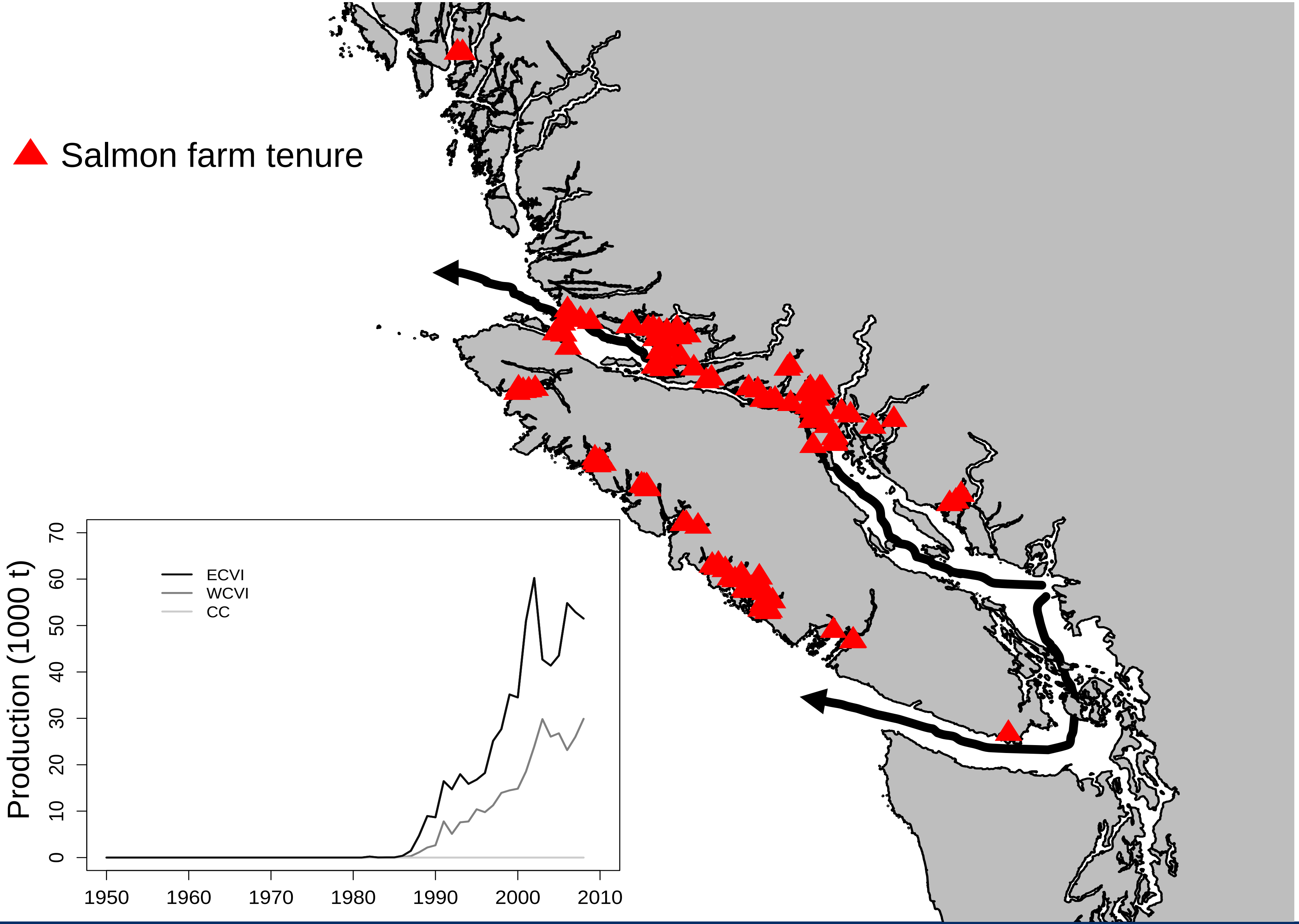


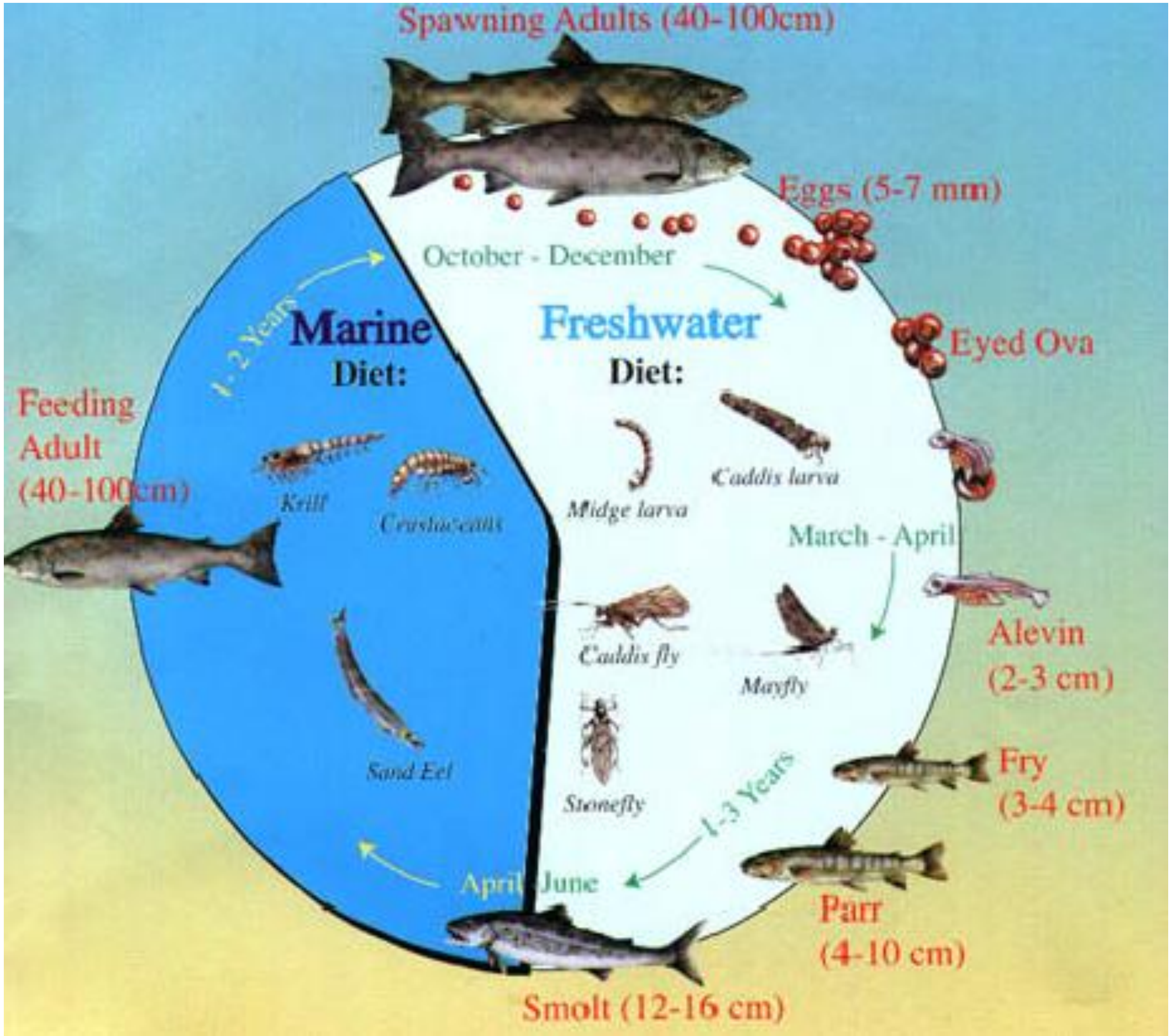
16 recruits/spawner
1 recruit/spawner
$\log_e$(recruits/spawner)
4
2
0
-2
1950
1960
1970
1980
1990
2000
Brood year

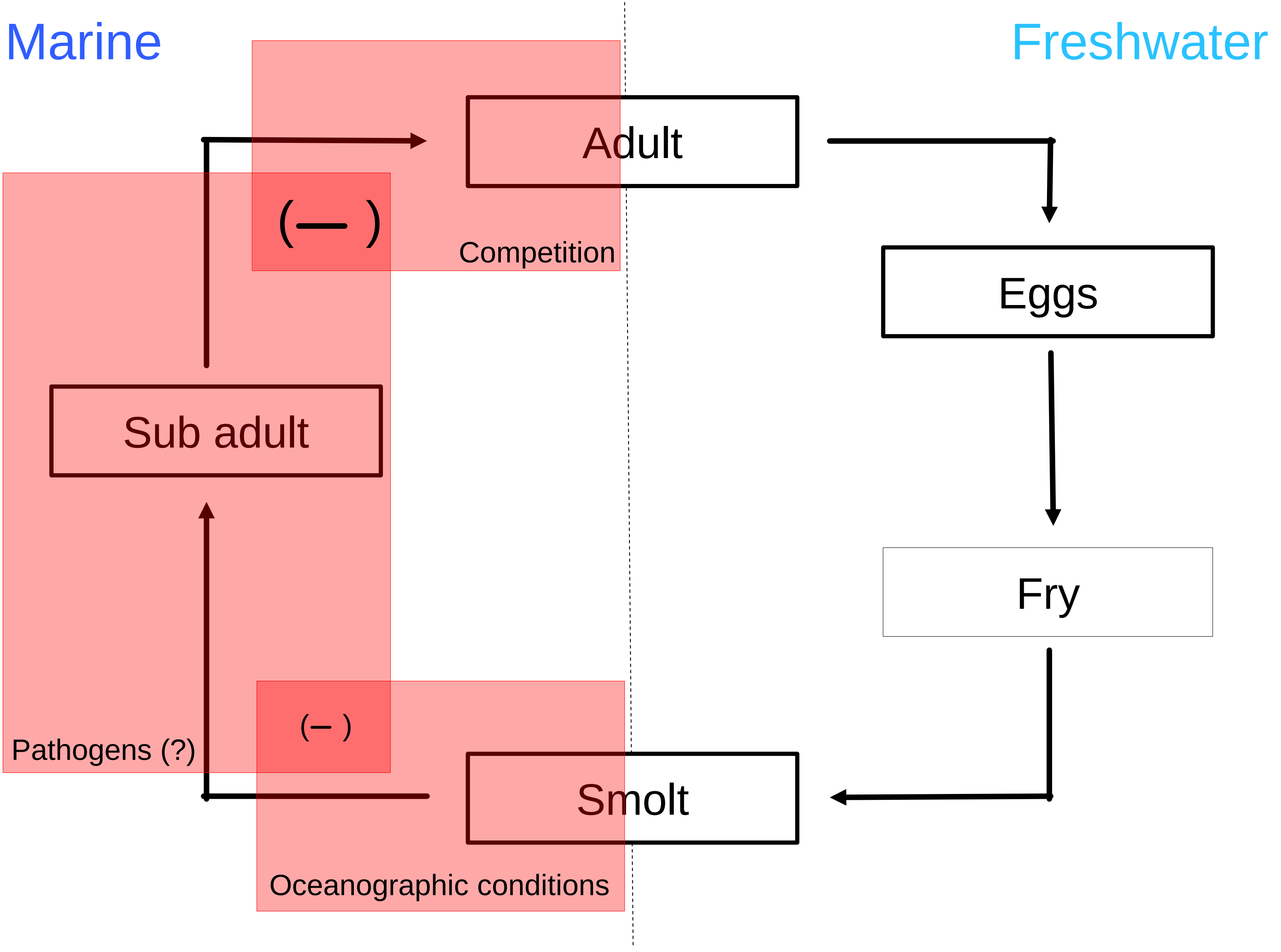
Causes

- ❖ Ocean conditions - SST
- ❖ Prey competition – Pink salmon
- ❖ Aquaculture – pathogens (?)


Pink salmon
abundance (millions)
1
2
3
4
5
6
SST
anomaly (°C)
+
0
-
1950
1960
1970
1980
1990
2000
2010
Year


Salmon farm tenure
Production (1000 t)
0
10
20
30
40
50
60
70
1950
1960
1970
1980
1990
2000
2010
ECVI
WCVI
CC


Spawning Adults (40-100cm)
Eggs (5-7 mm)
October - December
Marine
Diet:
Freshwater
Diet:
Eyed Ova
1 - 2 Years
Feeding
Adult
(40-100cm)
Krill
Crustaceans
Midge larva
Caddis larva
March - April
Caddis fly
Mayfly
Alevin
(2-3 cm)
Sand Eel
Stonefly
1-3 Years
Fry
(3-4 cm)
April - June
Parr
(4-10 cm)
Smolt (12-16 cm)

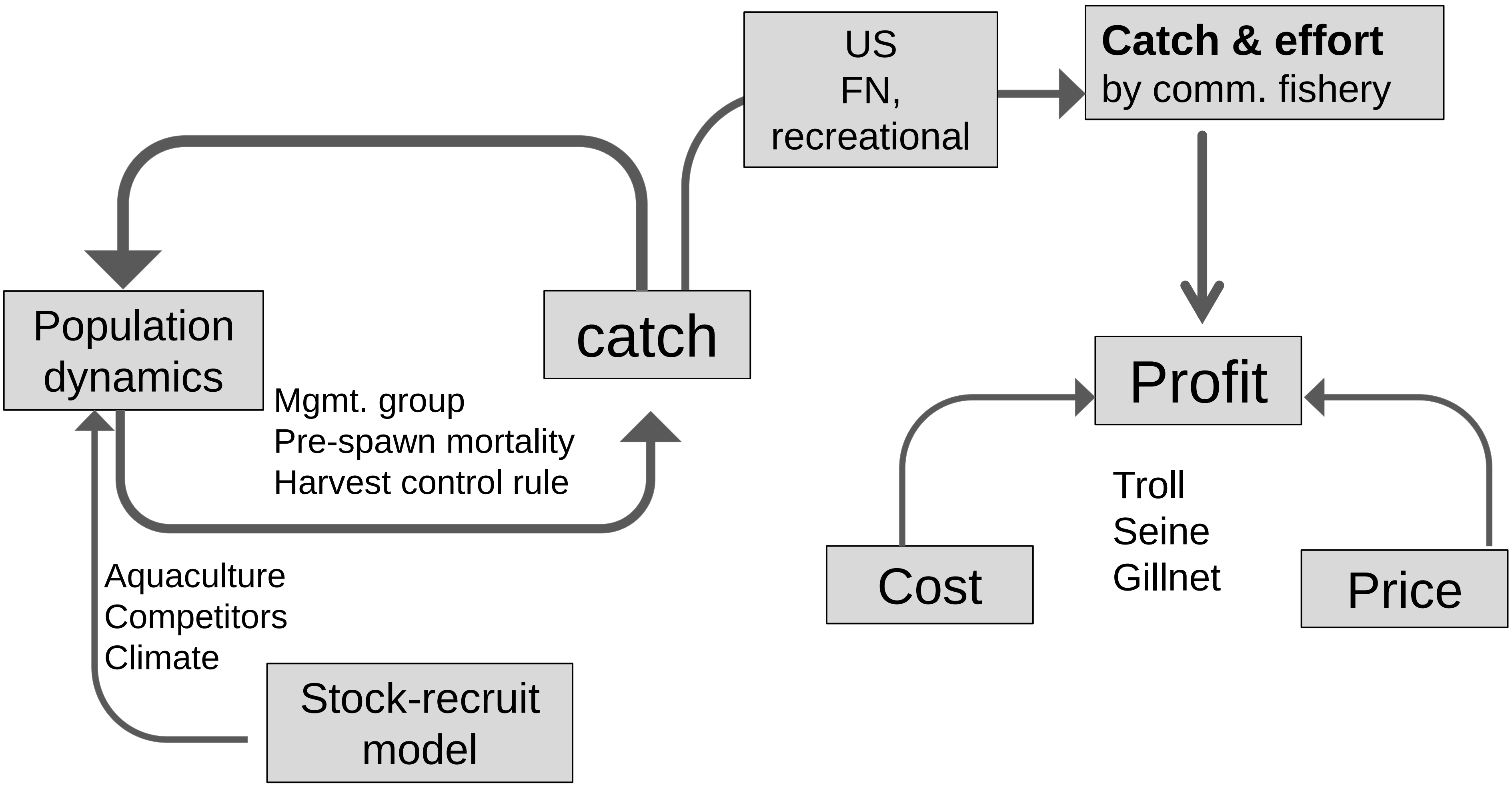


Marine
Freshwater
Adult
Eggs
Fry
Smolt
Sub adult
(—)
Competition
(–)
Pathogens (?)
Oceanographic conditions

Objectives

- Explore potential future influence of climate, competition and aquaculture on sockeye salmon in Fraser River;
- Examine the economic consequences of these stressors;

Model framework



Model framework

1) Built a salmon population model to generate future spawner-recruit time series with added environmental and anthropogenic factors;

$$\log_e\left(\frac{R_{i,t}}{S_{i,t}}\right) = \alpha_i + b_i S_{i,t} + b_{1,i} S_{i,t} + b_{2,i} S_{i,t} + b_{3,i} S_{i,t} + \delta_{i,j} E_{i,j,t+x} + \varepsilon_{i,t}$$

2) Estimated the potential influence of region-wide shared responses to SST, pink salmon abundance and aquaculture by fitting a modified hierarchical mixed-effects;

$$\log_e\left(\frac{R_{i,t}}{S_{i,t}}\right) = (\mu_\alpha + \alpha_i) + b_i S_{i,t} + (\mu_\phi + \delta_{i,j}) E_{i,j,t+x} + \varepsilon_{i,t}$$

3) Estimated catch and effort

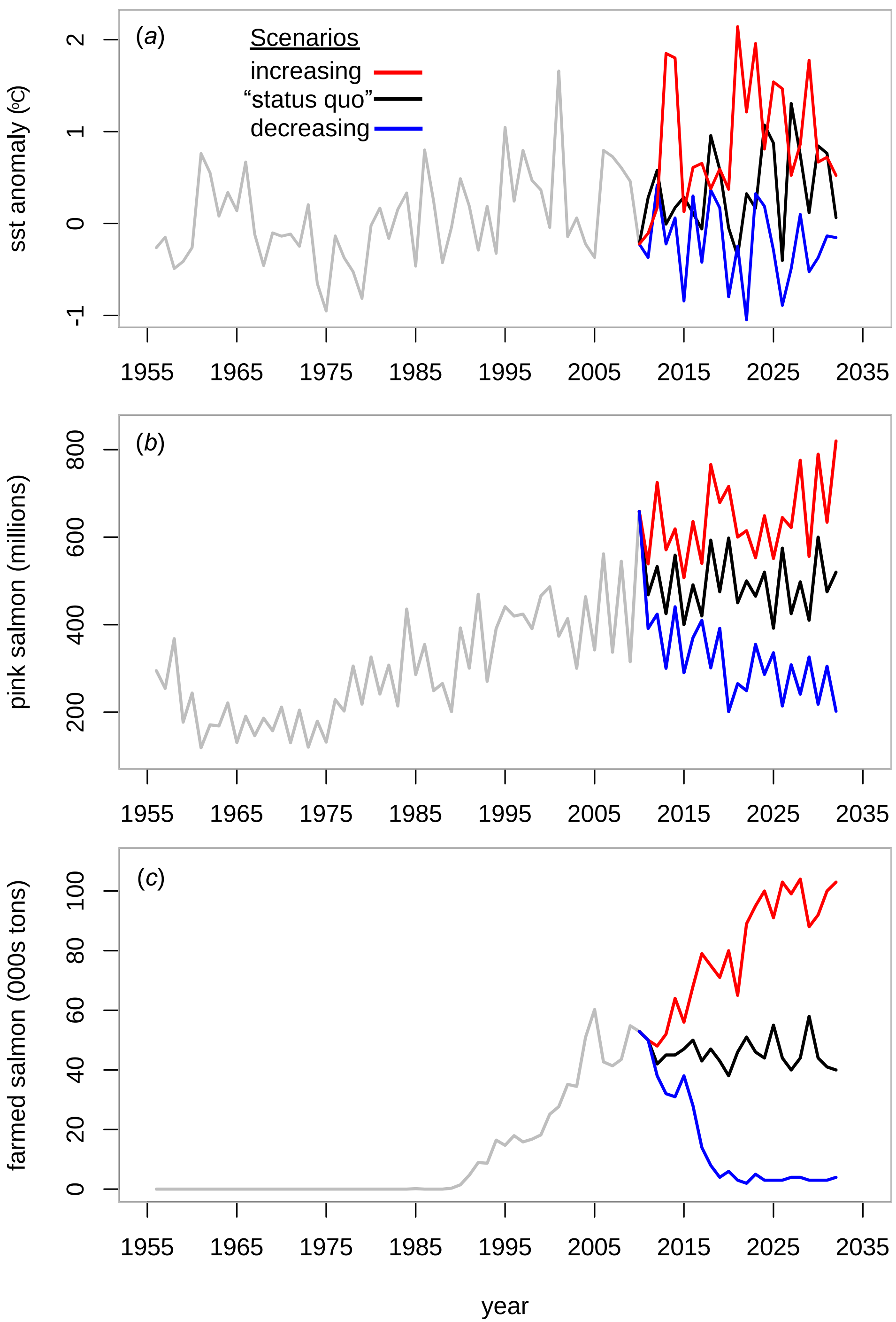
$$\log_e(E_{i,t}) = \frac{\phi + \log_e(Y_{i,t}) - \theta t - \gamma \log_e(R_t) + \delta_i}{\beta}$$

4) Measured profit

$$P_{i,t} = (\rho_i Y_{i,t} - (E_{i,t} \omega_i) - l_i)(1 - \upsilon)$$

Simulation Scenarios

Factor	Scenario	Description
Climate (represented by SST at the ocean entry point in the winter preceding marine entry)	Status quo Increasing Decreasing	1980-2010 average SST and interannual variability. SST under a high emission scenario (a1b_MIROCmed). Decline in SST to 1960-1980 average.
Competition (represented by the abundance of potential North Pacific pink salmon competitors in the second year of marine life)	Status quo Increasing Decreasing	2000-2010 average North Pacific pink salmon abundance and interannual variability. Gradual increase to 1.5 x 2000-2010 average North Pacific pink salmon abundance and interannual variability. Decline in North Pacific pink salmon abundance and interannual variability to competitors to 1980-1985 average.
Aquaculture (represented by farmed-salmon production along sockeye early marine migration routes)	None Status quo Increasing Decreasing	No farmed salmon production along early marine sockeye migration routes. 2005-2010 average aquaculture production and interannual variability. Increase to two x 2005-2010 average aquaculture production by 2025[1] and interannual variability after. Sharp decline to ~ no aquaculture production.



(a)
Scenarios
increasing
"status quo"
decreasing
sst anomaly (ºC)
-1
0
1
2
1955
1965
1975
1985
1995
2005
2015
2025
2035
(b)
pink salmon (millions)
200
400
600
800
(c)
farmed salmon (000s tons)
0
20
40
60
80
100
year

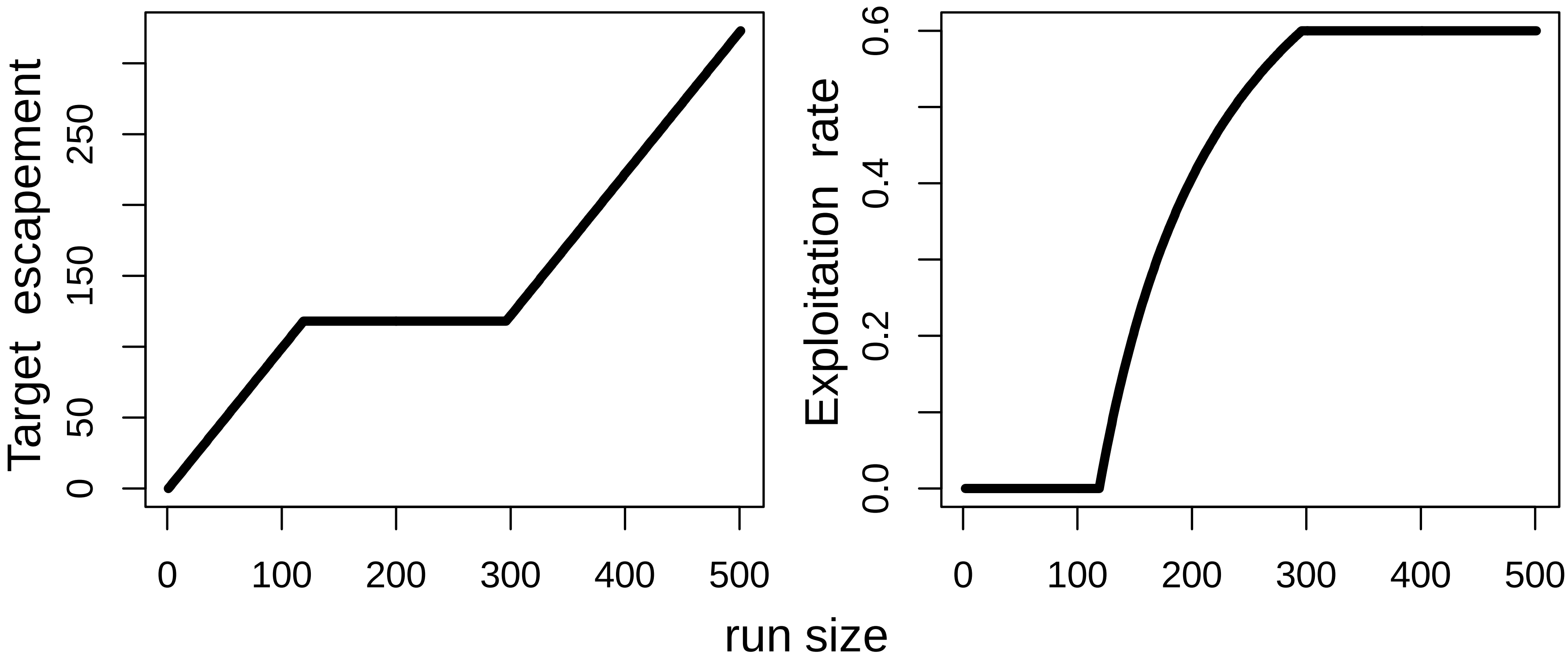
Harvest rule and catch

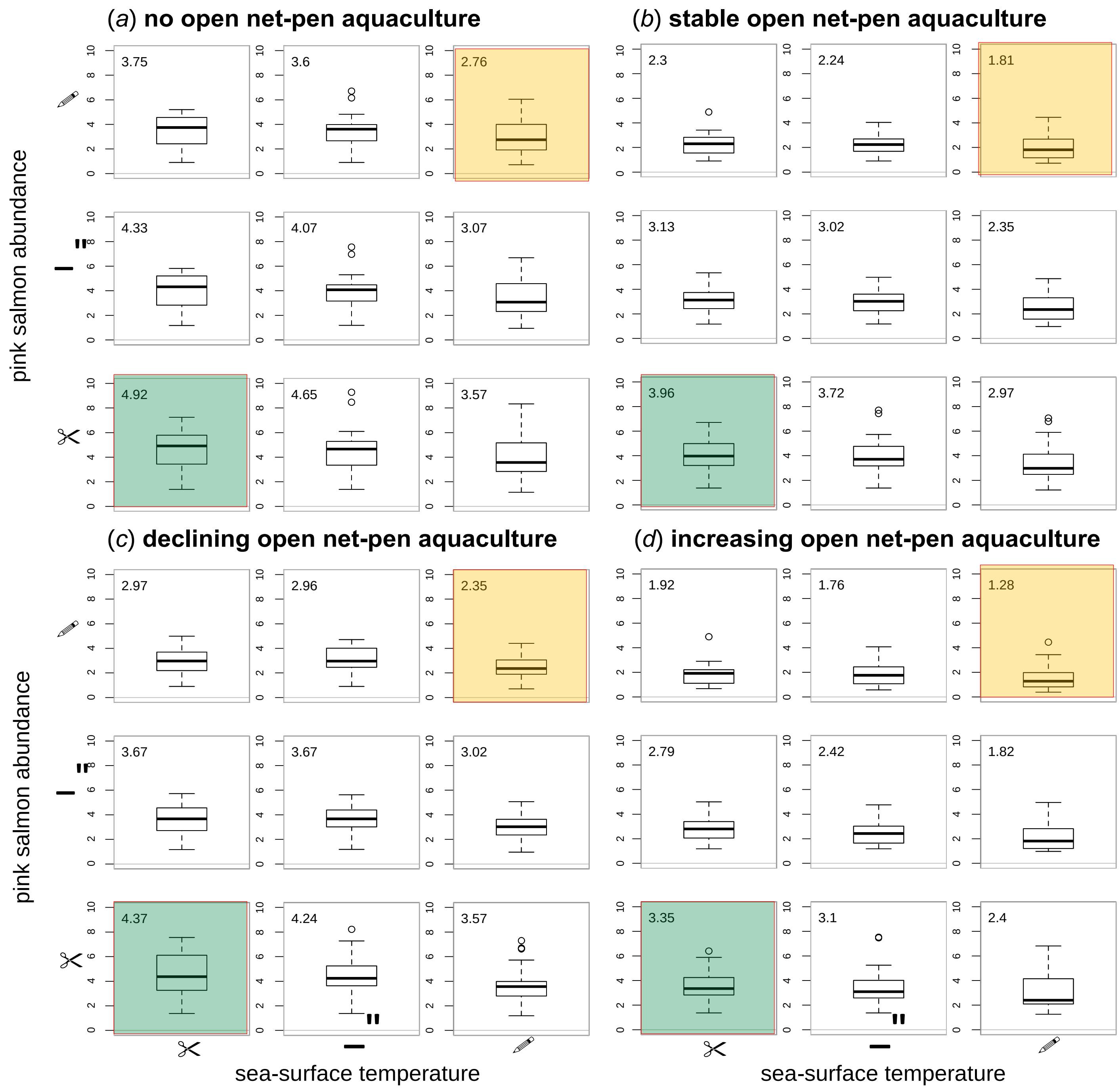
Harvest rule / mgt adjustment	Early Stuart	Early Summer	Summer	Late
ER floor [1]	0.1	0.1	0.1	0.2
TAM cap [2]	0.6	0.6	0.6	0.6
Target escapement	118 000	200 000	592 000	673 000
Management adjustment	0.623± 0.022	0.436± 0.054	0.078± 0.015	log(0.31± 1.03)

- USA
  - 16.5%
- First Nation (food, culture & ceremony)
  - 1 Million
- Recreational fishing
  - 5%
- First Nation (econ. Opportunity)
  - 3.7%
- Commercial fishing
  - Troll (5%)
  - Seine (46.5%)
  - Gillnet(48.5)

Harvest control rule

- Too ensure target escapement is met and weak stocks are protected





Recruitment

Greatest:

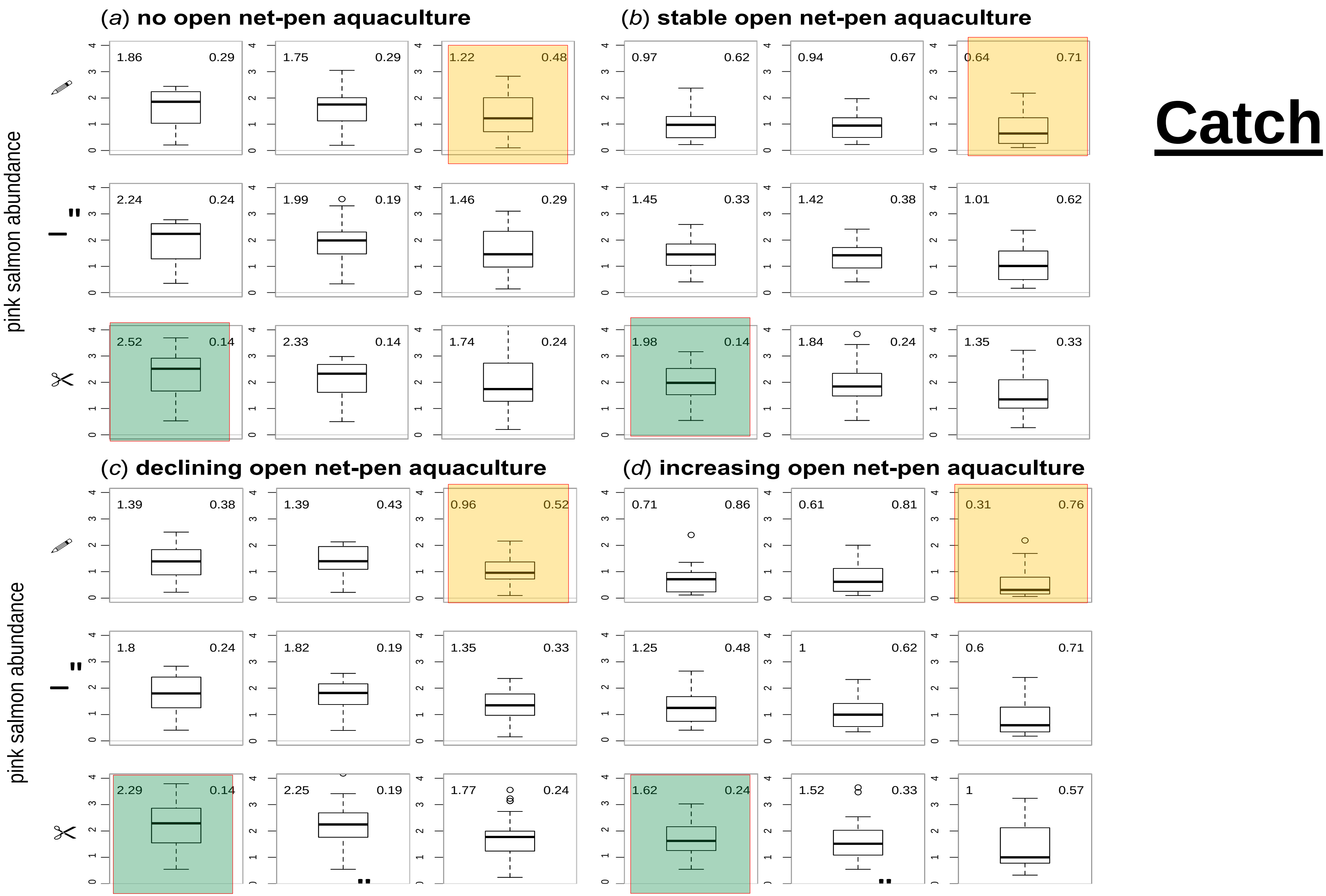
- Low competitors
- Low SST
- No aquaculture

Lowest:

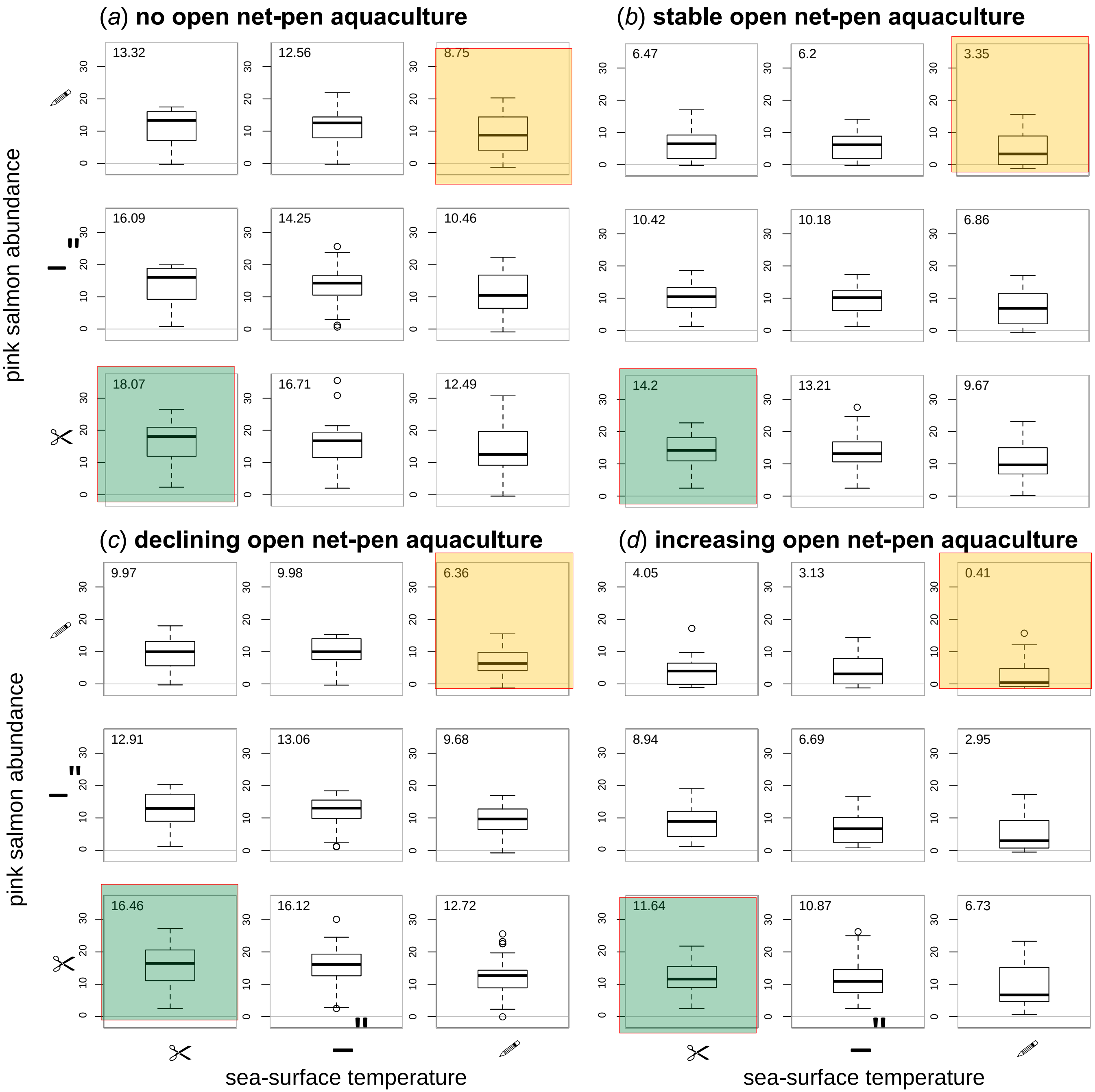
- High SST
- High competitors
- Increasing aquaculture production

Increasing competitors *vs*. low SST

Increasing SST *vs*. low competitors



(a) no open net-pen aquaculture
(b) stable open net-pen aquaculture
(c) declining open net-pen aquaculture
(d) increasing open net-pen aquaculture
Catch
pink salmon abundance
1.86 0.29
1.75 0.29
1.22 0.48
0.97 0.62
0.94 0.67
0.64 0.71
2.24 0.24
1.99 0.19
1.46 0.29
1.45 0.33
1.42 0.38
1.01 0.62
2.52 0.14
2.33 0.14
1.74 0.24
1.98 0.14
1.84 0.24
1.35 0.33
1.39 0.38
1.39 0.43
0.96 0.52
0.71 0.86
0.61 0.81
0.31 0.76
1.8 0.24
1.82 0.19
1.35 0.33
1.25 0.48
1 0.62
0.6 0.71
2.29 0.14
2.25 0.19
1.77 0.24
1.62 0.24
1.52 0.33
1 0.57



Profit

Greatest:

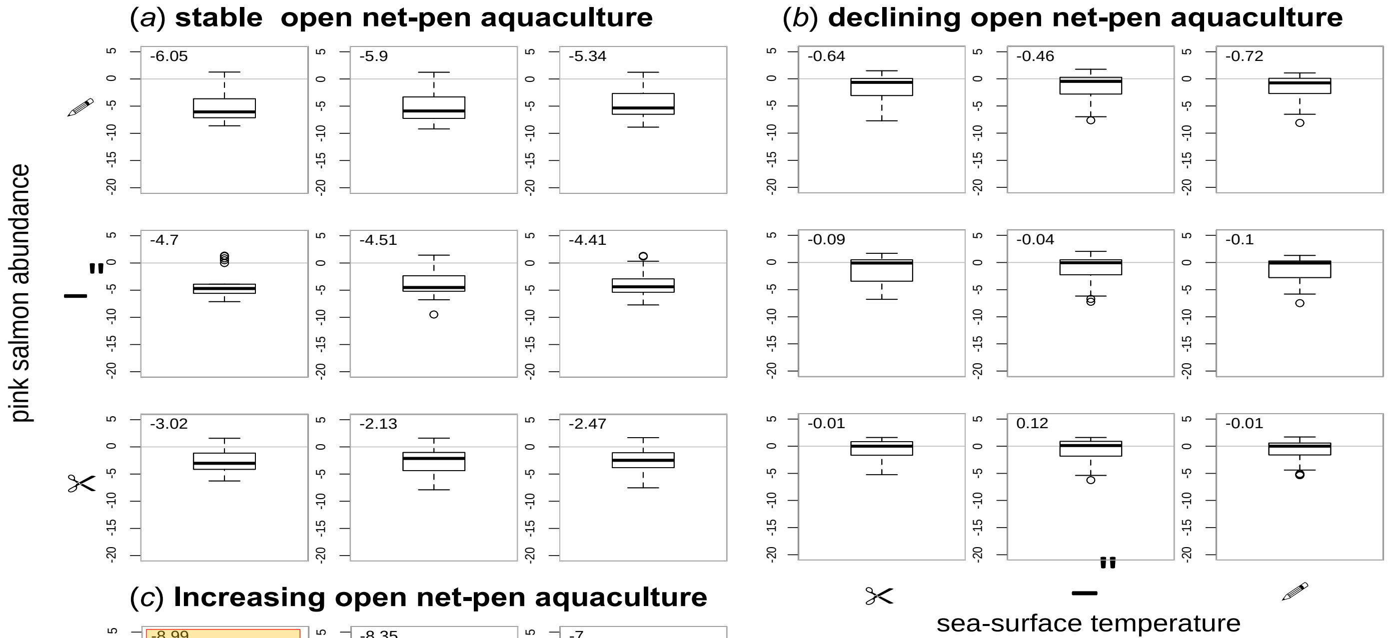
- Low competitors
- Low SST
- No aquaculture

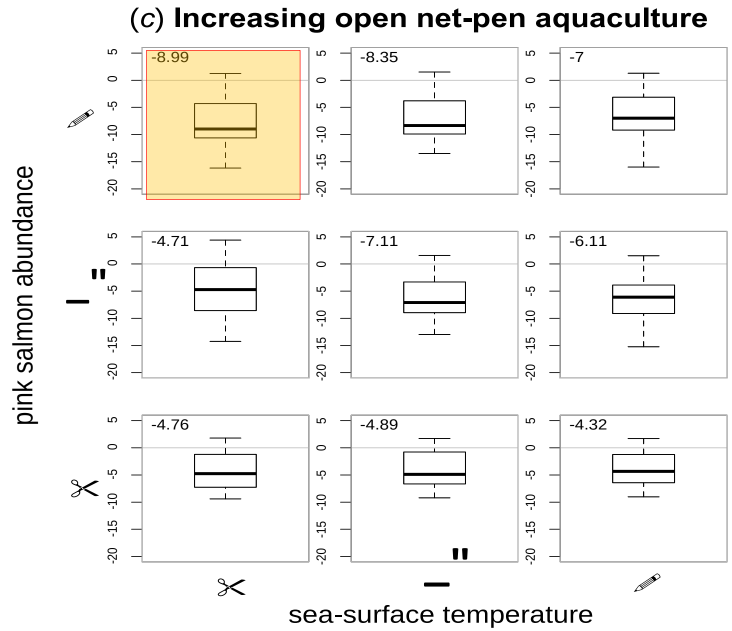
Lowest:

- High SST
- High competitors
- Increasing aquaculture production

Increasing competitors *vs*. low SST

Increasing SST *vs*. low competitors





<u>Profit loss</u>

i) Greatest profit losses associated with salmon aquaculture when:

- The ocean was cool and
- Both an increasing competitors and salmon farms.

ii) Impacts on profit: competition **>** SST **>** aquaculture

Concluding remarks

Greatest impacts on recruitment, catch and profit when:

- the ocean early in marine life is **warm**,
- the number of salmon competitors later in marine life were **high** and
- there was **increasing** open net-pen salmon aquaculture production along juvenile sockeye salmon migration routes.

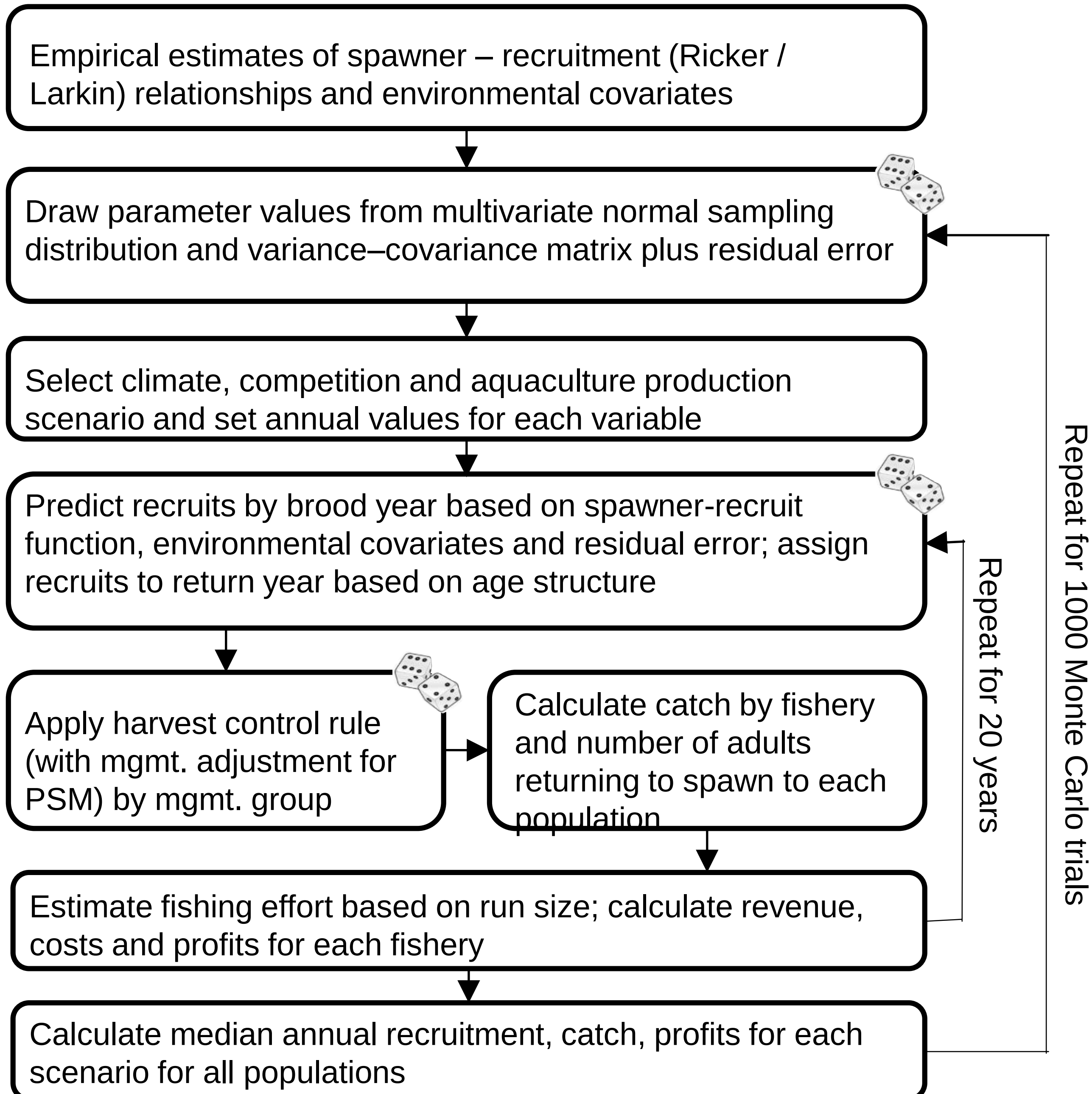
- Competition has the strongest impact
- Implications for policy and management:
  - Wild salmon fisheries
  - Aquaculture industry and its development

Limitations

- High uncertainties

- Fixed harvest rules used:
  - Conservation goal: overestimated
  - Social-economic goal: underestimated

- Fixed costs and prices
- No discounting
- Underestimated FN and recreational values
  - As food fish


Empirical estimates of spawner – recruitment (Ricker / Larkin) relationships and environmental covariates
Draw parameter values from multivariate normal sampling distribution and variance–covariance matrix plus residual error
Select climate, competition and aquaculture production scenario and set annual values for each variable
Predict recruits by brood year based on spawner-recruit function, environmental covariates and residual error; assign recruits to return year based on age structure
Apply harvest control rule (with mgmt. adjustment for PSM) by mgmt. group
Calculate catch by fishery and number of adults returning to spawn to each population
Estimate fishing effort based on run size; calculate revenue, costs and profits for each fishery
Calculate median annual recruitment, catch, profits for each scenario for all populations
Repeat for 20 years
Repeat for 1000 Monte Carlo trials