State Space (SS) Models for Salmon:

What we can learn and apply to Marine Species

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CAPAM Meeting on Spatial Assessments
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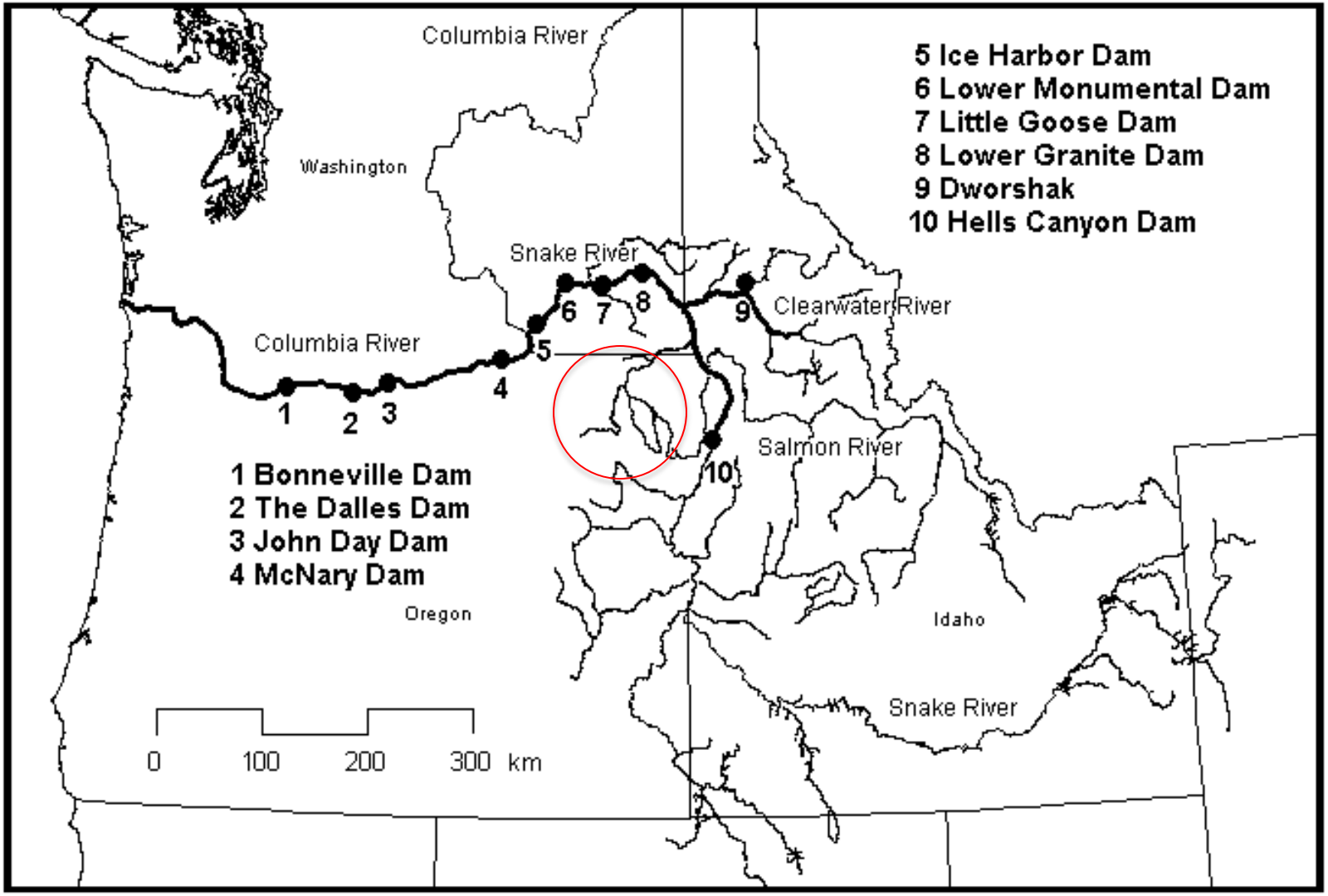
Sources

- ODFW (La Grande): Escapement, juvenile abundance and survivals, habitat mapping
- Umatilla and Nez Perce Fisheries: Escapement estimates weir counts, broodstock estimates
- CRITFC Science: Habitat mapping & fish/habitat relationships

- Data
  - Reports
    - BPA projects (http://www.cbfish.org)
    - Lower Snake Compensation Plan (website)
    - Agency data files
    - Streamnet & NWFSC links & compilations
    - Publications (e.g. Justice et al. 2016, White et. al. 2017)

Overview

- State Space Hierarchical Model
- Quantifying Habitat Change
- Building complexity-Single to Multi-population
- Resilience and Extinction Risk Quantification in projection mode
- Marine Species Comparisons

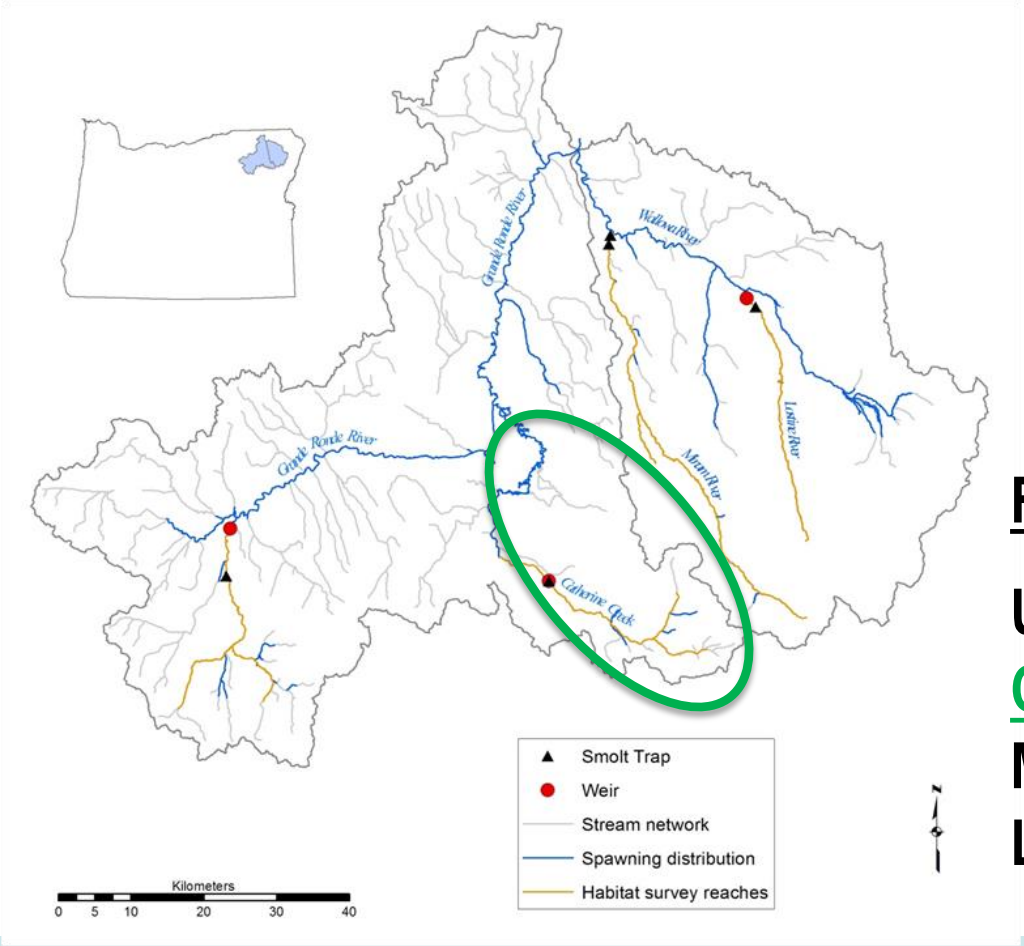

Columbia River
Washington
Snake River
Columbia River
Clearwater River
Salmon River
Idaho
Snake River
Oregon
1 Bonneville Dam
2 The Dalles Dam
3 John Day Dam
4 McNary Dam
5 Ice Harbor Dam
6 Lower Monumental Dam
7 Little Goose Dam
8 Lower Granite Dam
9 Dworshak
10 Hells Canyon Dam
1
2
3
4
5
6
7
8
9
10
0
100
200
300 km

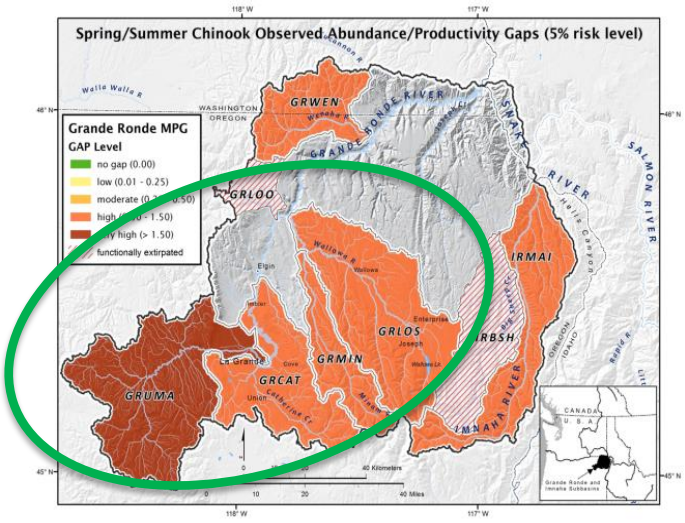
ODFW Spawner & Juvenile Studies (20+ Years)

Adult spawner estimates

Juvenile life stage abundance & survivals

Smolt parr & migrants, PIT tag survivals





Four Spring Chinook Populations

Upper Grande Ronde

Catherine Creek

Minam River

Lostine River (Lostine/Wallowa Pop.

NOAA FISHERIES

Grande Ronde/Imnaha MPG Populations

Population	Juv. Timing	Adult Timing	Habitat Actions	Supp. Hatchery	Juvenile data
Upper GR R.	Spring	Early Spr.	yes	Schedule	1993-2016+
Catherine Cr.	Spring	Early Spr	yes	Schedule	1993-2016+
Lostine/Wallowa R.	Spring	Late	yes	Schedule	1993-2016+
Minam R.	Spring	Intermed.	No	No	1993-2016+
Wenaha R.	Spring	Late??	No	No	no
Imnaha R.	Spring	Summer	Yes?	Schedule	Parr to LGR

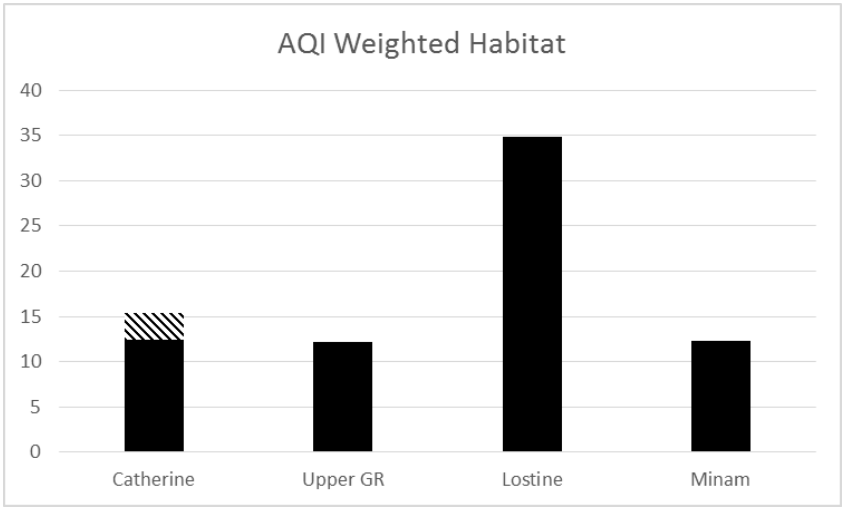
Standardizing rearing area estimates across populations

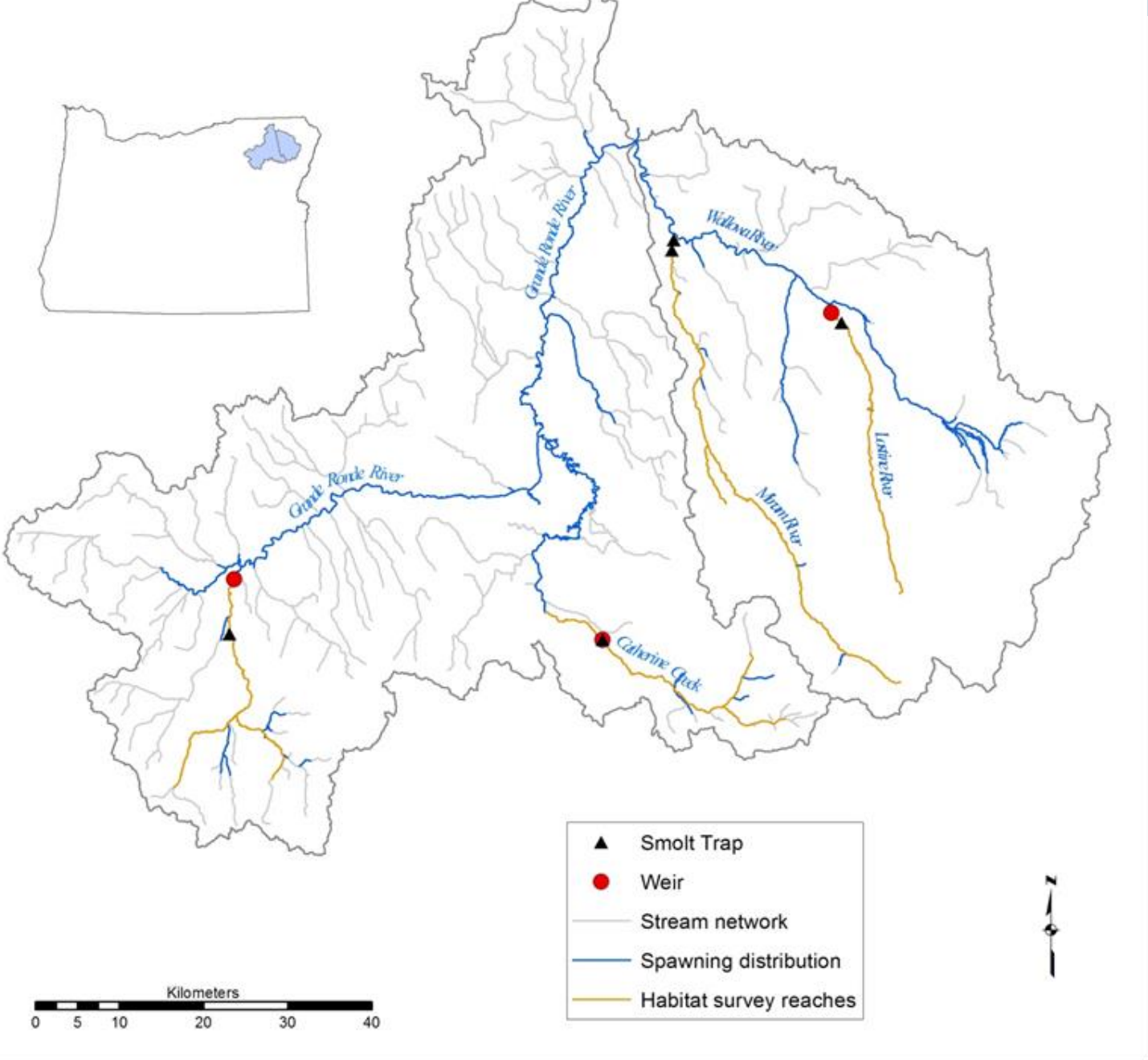
Oregon Aquatic Inventory surveys have been conducted on all four rivers. Those surveys generated reach specific estimates of stream area by category (pools, runs, fast-water) .

Summer parr density (fish per m2) data from recent surveys in study reaches within the Catherine Cr. and Upper Grande Ronde populations indicated relatively consistent ratios of densities by categories.

Standardized trap and mark recovery based **juvenile abundance** to 10,000 m2 of pool habitat equivalents

	Habitat area (X 10,000 m2)				Relative Density Index
	Catherine Creek	Upper Grande Ronde River	Lostine River	Minam River	
Pools	7.613	5.004	3.482	15.536	1.00
Runs	1.199	1.906	4.603	5.367	0.35
Fastwater	18.454	27.079	29.764	29.764	0.24
Total	27.266	33.989	37.849	50.667	
Weighted Total	12.44	12.13	12.21	24.53	



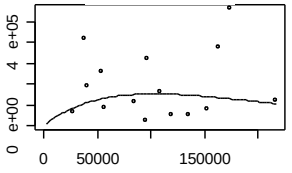

Grande Ronde River
Wallowa River
Grande Ronde River
Minam River
Lostine River
Catherine Creek
Smolt Trap
Weir
Stream network
Spawning distribution
Habitat survey reaches
N
Kilometers
0 5 10 20 30 40

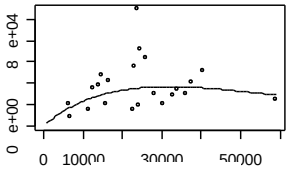
$$N_{parr} = \frac{N_s}{\frac{1}{prod_{parr}} + \frac{N_s}{cap_{parr}}}$$

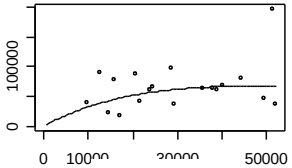
$$cap_{parr} = \alpha PEU$$

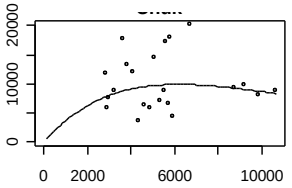
$$N_{smolts} = N_{parr} * \text{logit}(a + b(N_{parr}/PEU))$$

A Hierarchical Modeling Approach







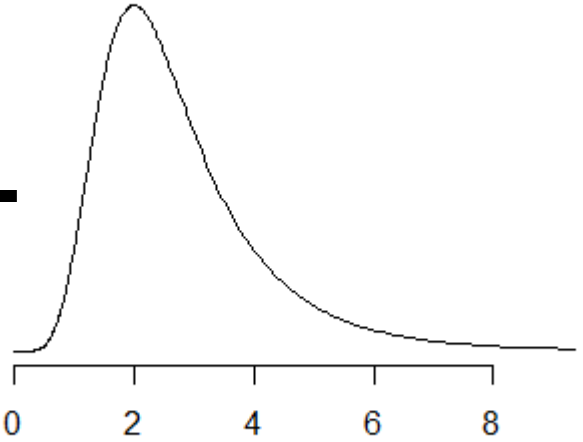


$prod_1$

$prod_2$

$prod_3$

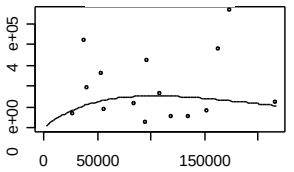
$prod_4$

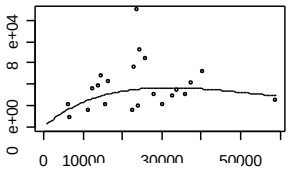


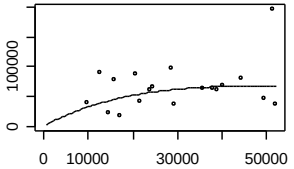
$$prod \sim N(\mu_{prod}, \sigma_{prod})$$

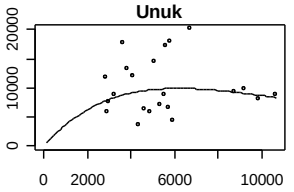
log(prod[j]) ~ dnorm(logProdMu, logProdTau)

A Hierarchical Modeling Approach







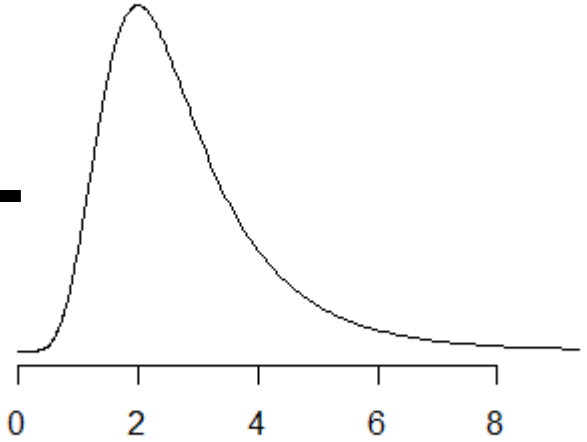


cap_1

cap_2

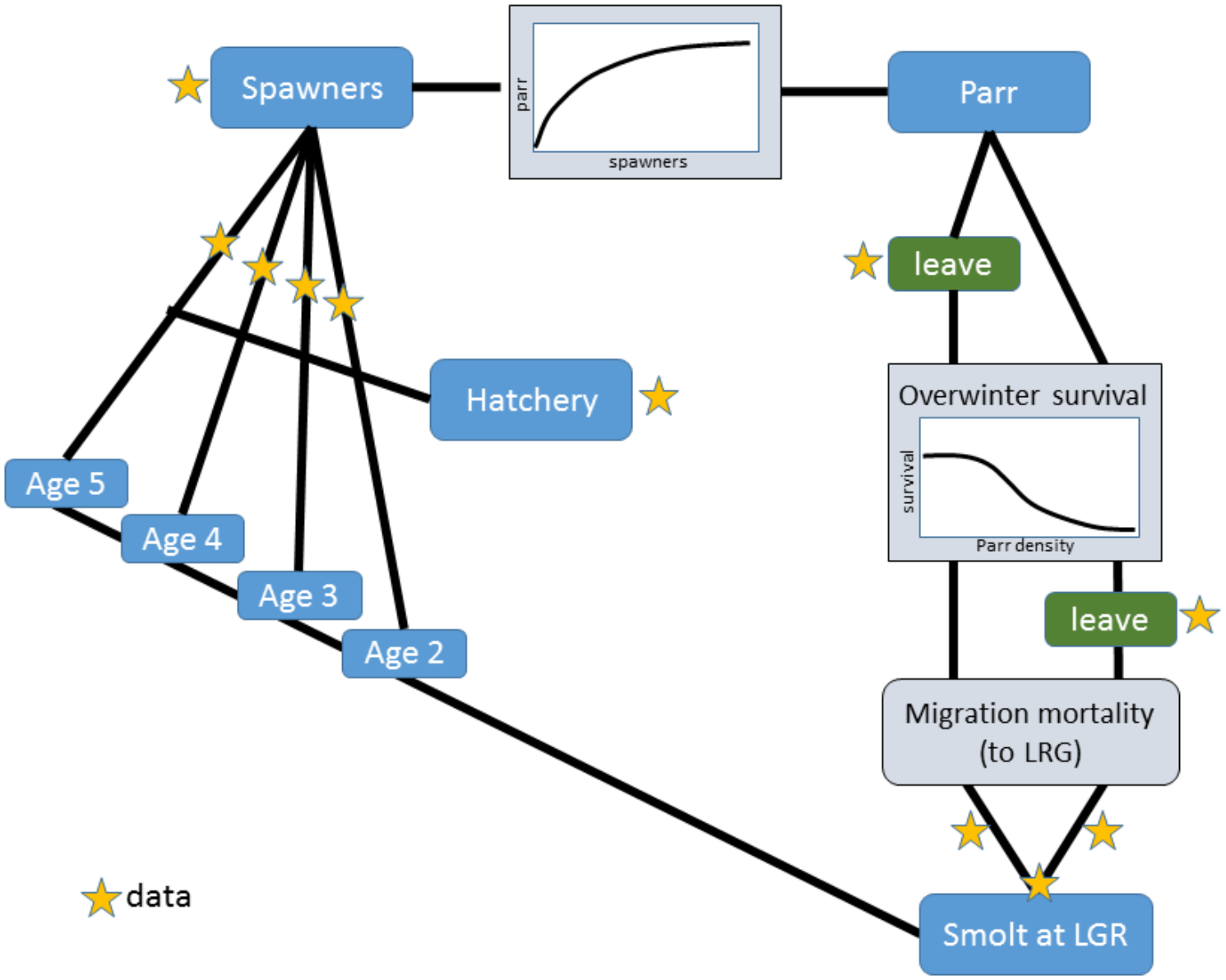
cap_3

cap_4



$$cap \sim N(\alpha PEU, \sigma_{cap})$$

log(cap[j]) ~ dnorm(log(capSlope*habVar[j]),logCapTau)

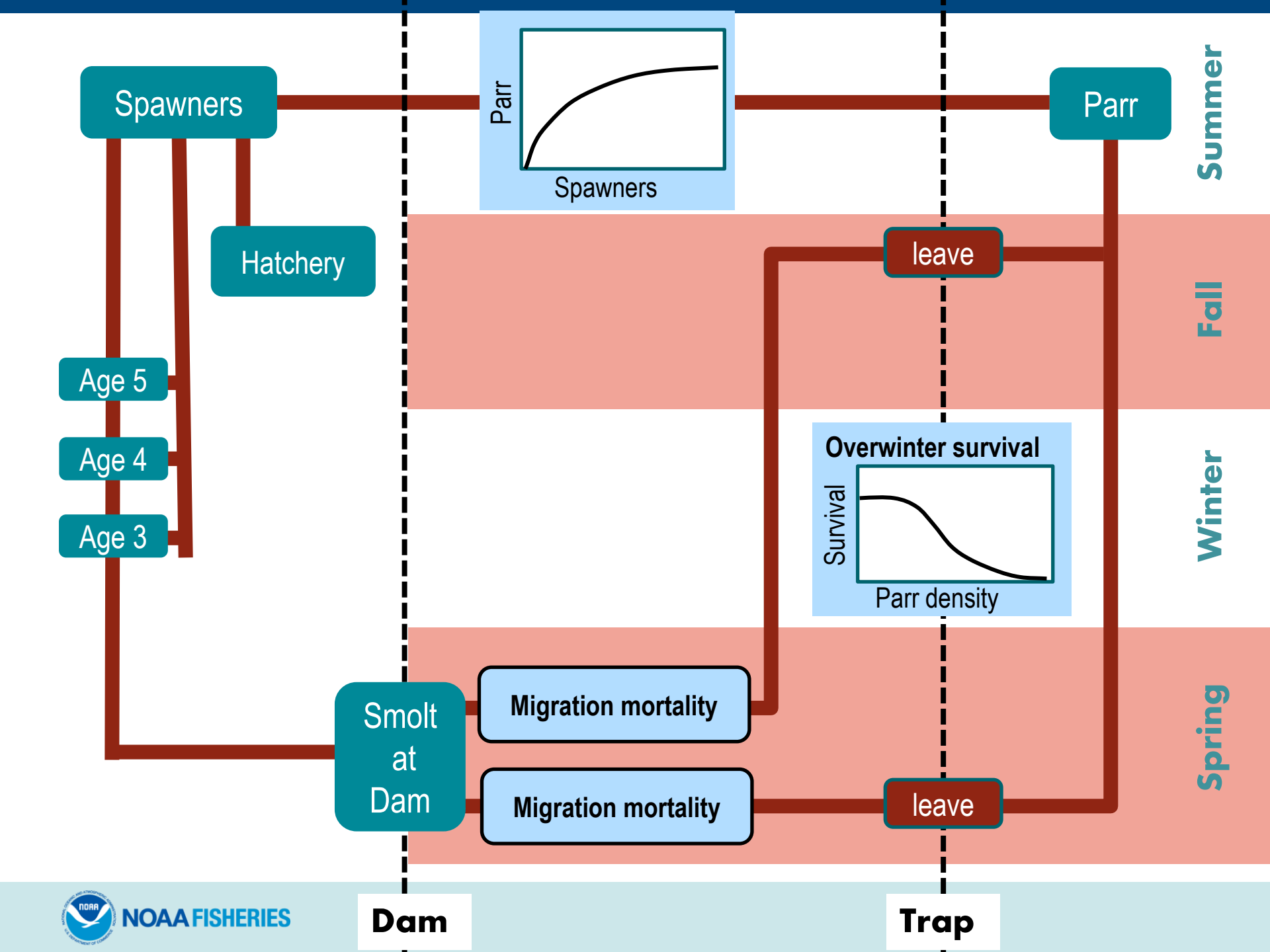

Spawners
parr
spawners
Parr
leave
Hatchery
Overwinter survival
survival
Parr density
Age 5
Age 4
Age 3
Age 2
leave
Migration mortality
(to LRG)
data
Smolt at LGR

Process Model

Observation Model

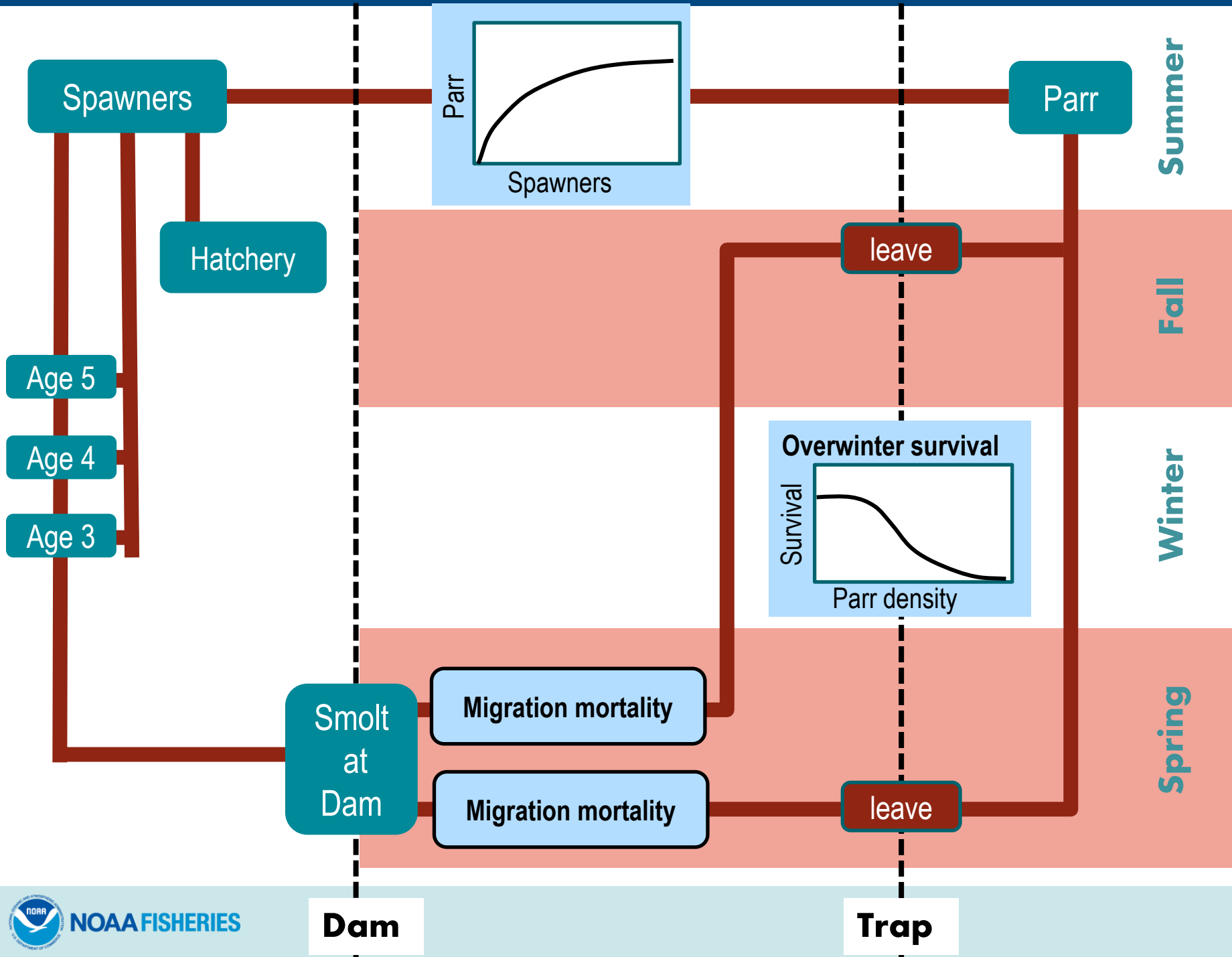
Process Model

Observation Model


Spawners
Hatchery
Age 5
Age 4
Age 3
Parr
Spawners
Parr
Summer
leave
Fall
Overwinter survival
Survival
Parr density
Winter
Smolt at Dam
Migration mortality
Migration mortality
leave
Spring
NOAA FISHERIES
Dam
Trap

Process Model

Observation Model


Spawners
Hatchery
Age 5
Age 4
Age 3
Parr
Spawners
Parr
Summer
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Parr density
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leave
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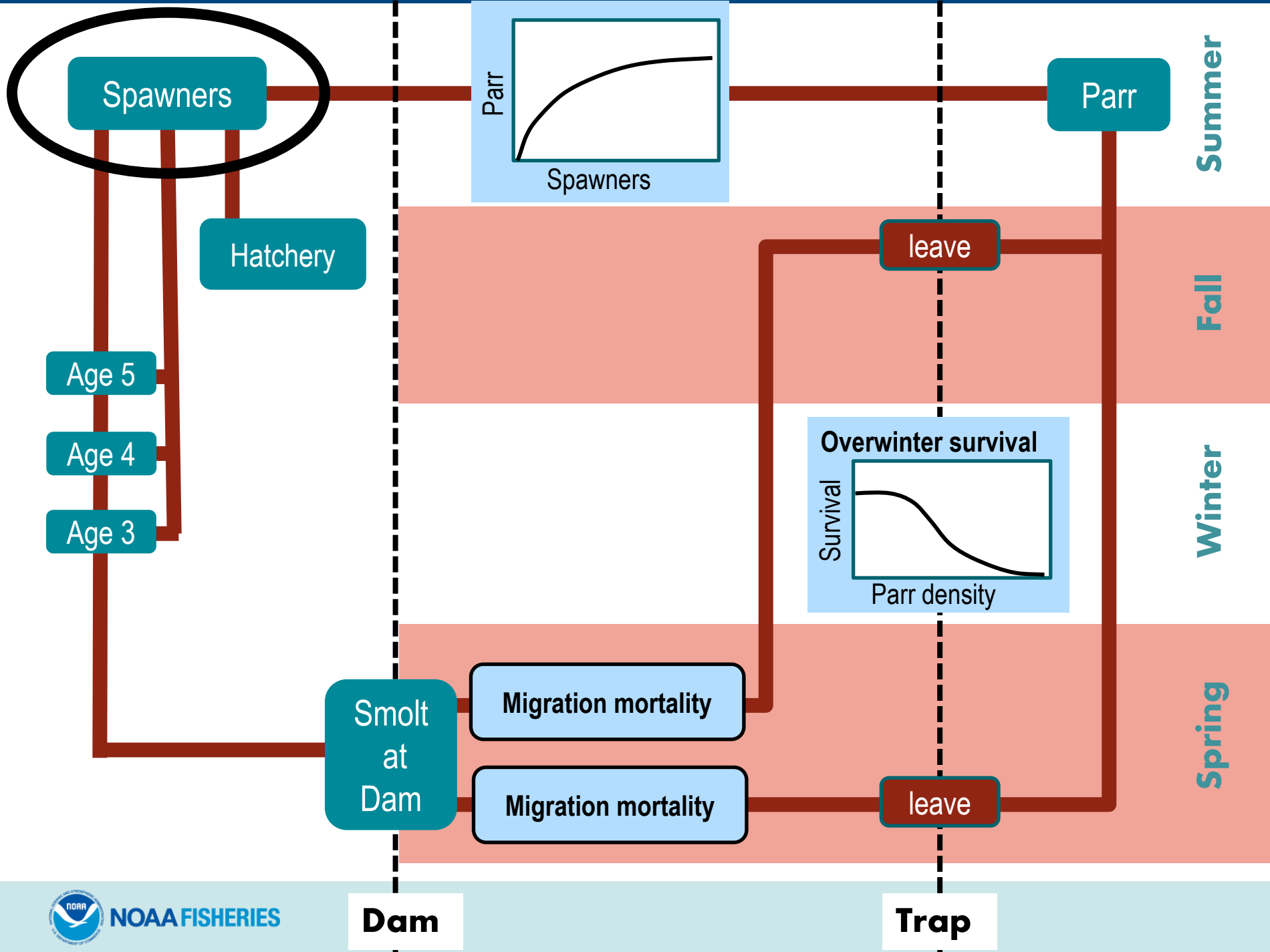
Spawners
Hatchery
Age 5
Age 4
Age 3
Parr
Spawners
Parr
Summer
leave
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Overwinter survival
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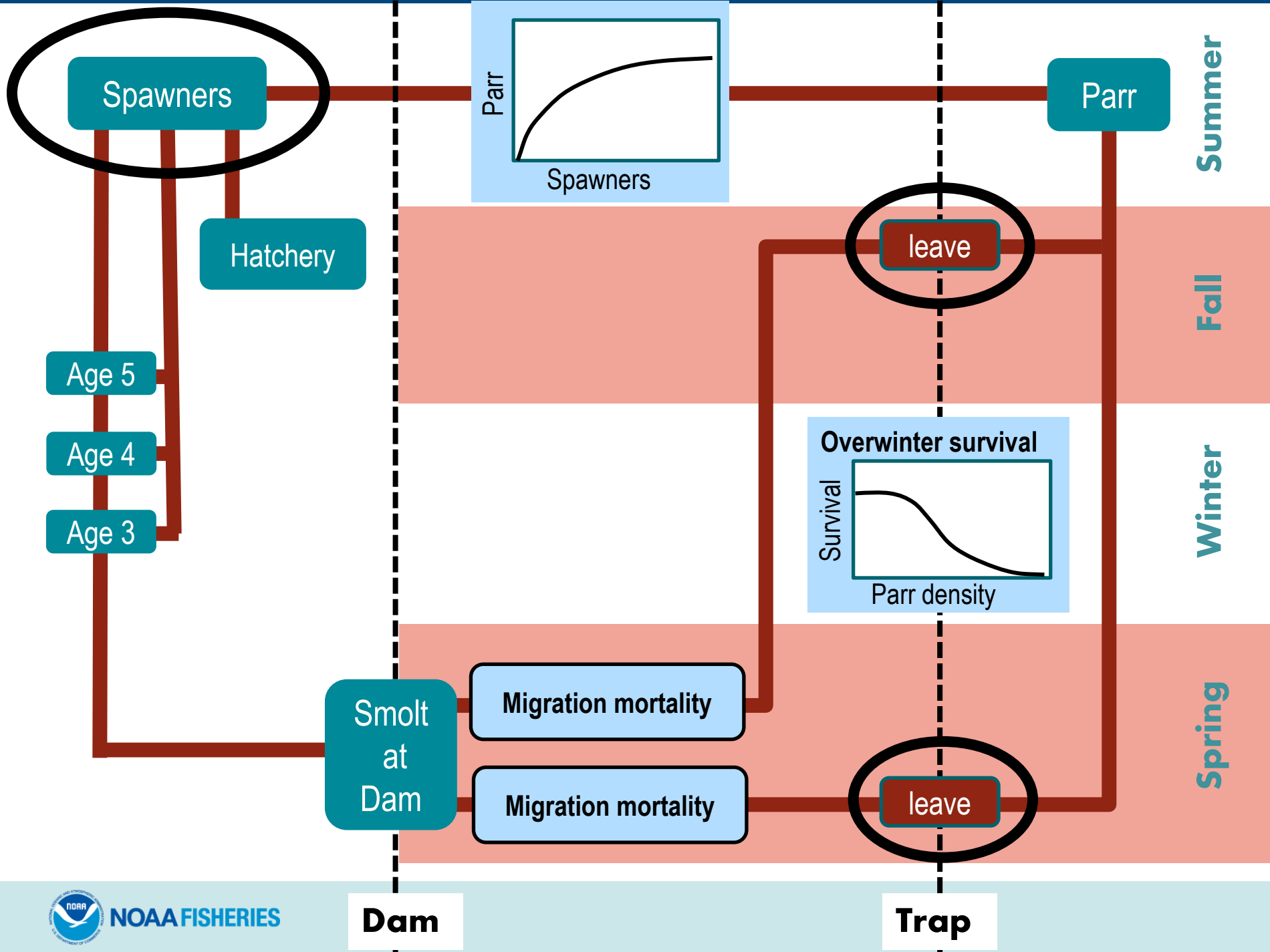
Spawners
Hatchery
Age 5
Age 4
Age 3
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Spawners
Parr
Summer
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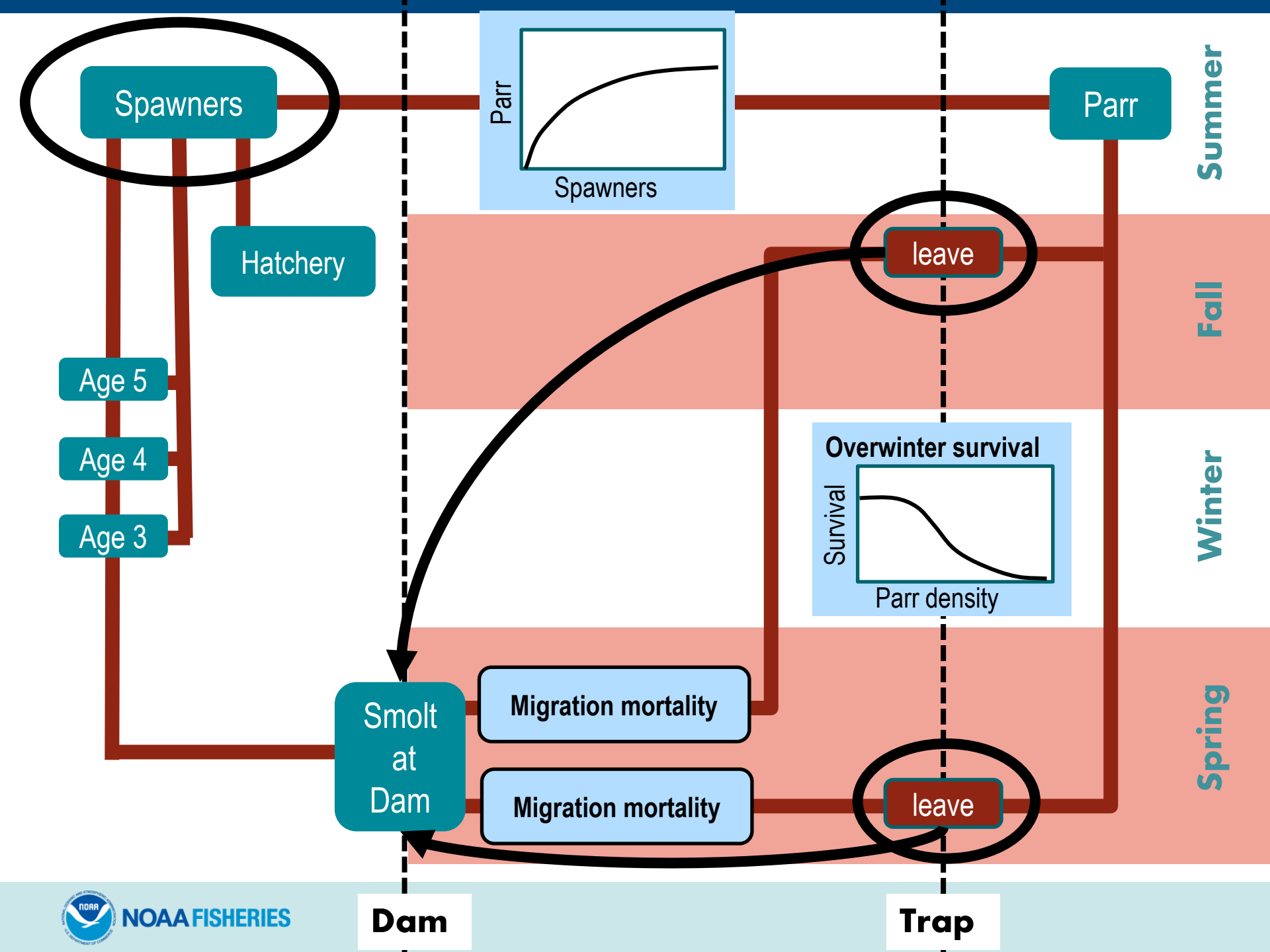
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Hatchery
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Age 4
Age 3
Parr
Spawners
Parr
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leave
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Overwinter survival
Survival
Parr density
Winter
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Spring
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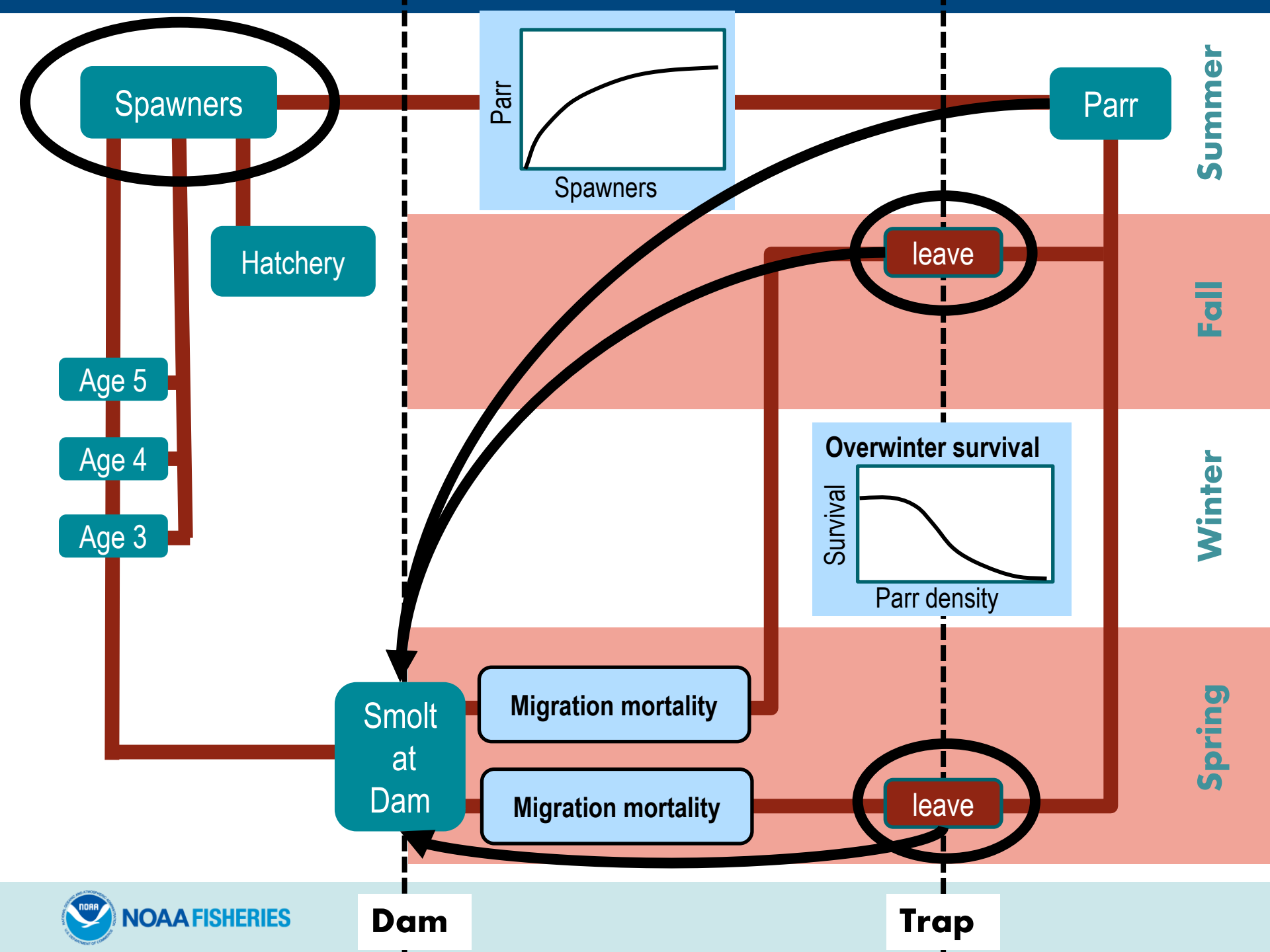
Dam
Trap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Spawners
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Summer
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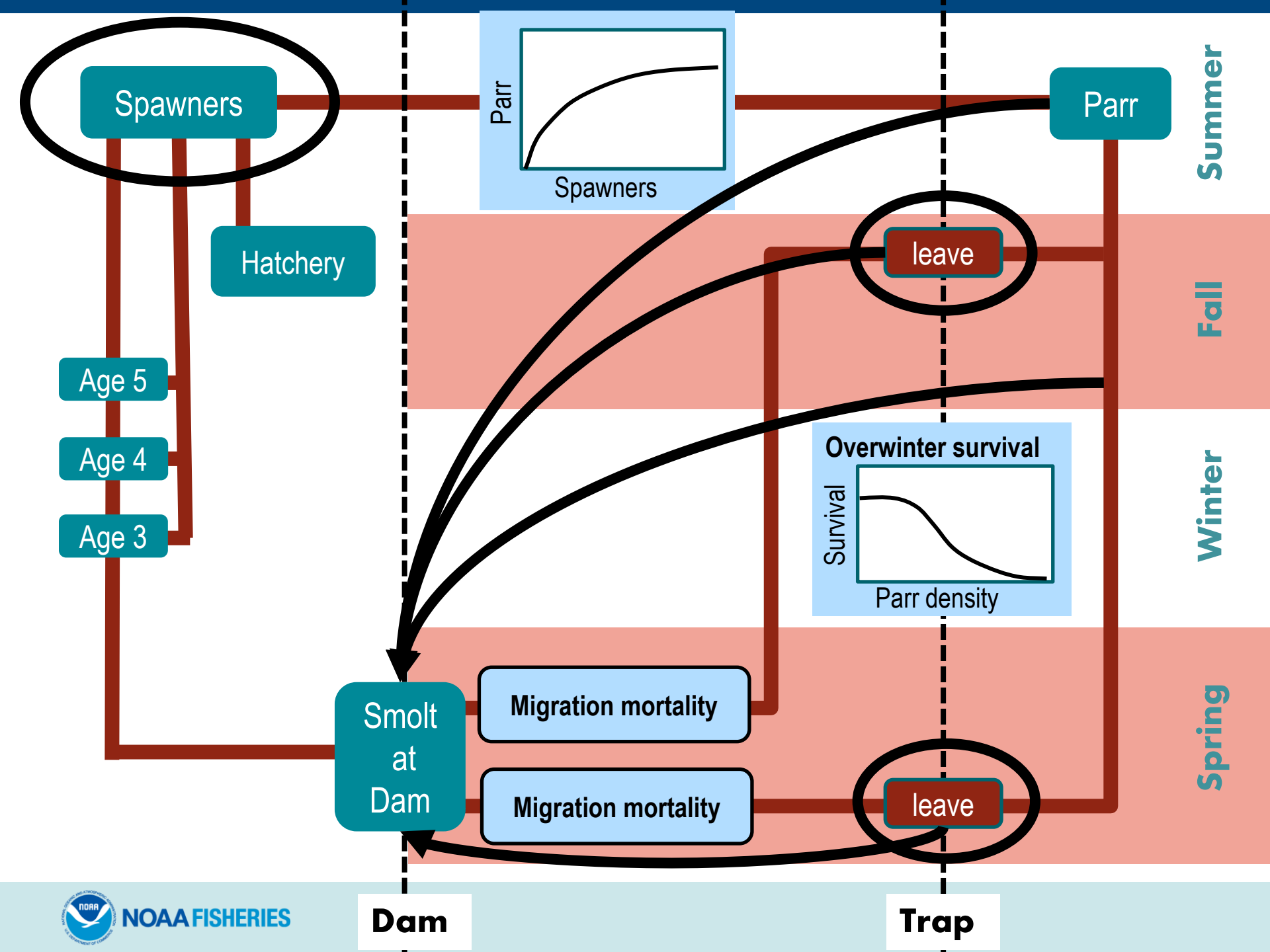
Trap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Hatchery
Age 5
Age 4
Age 3
Parr
Spawners
Parr
Summer
leave
Fall
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Parr density
Winter
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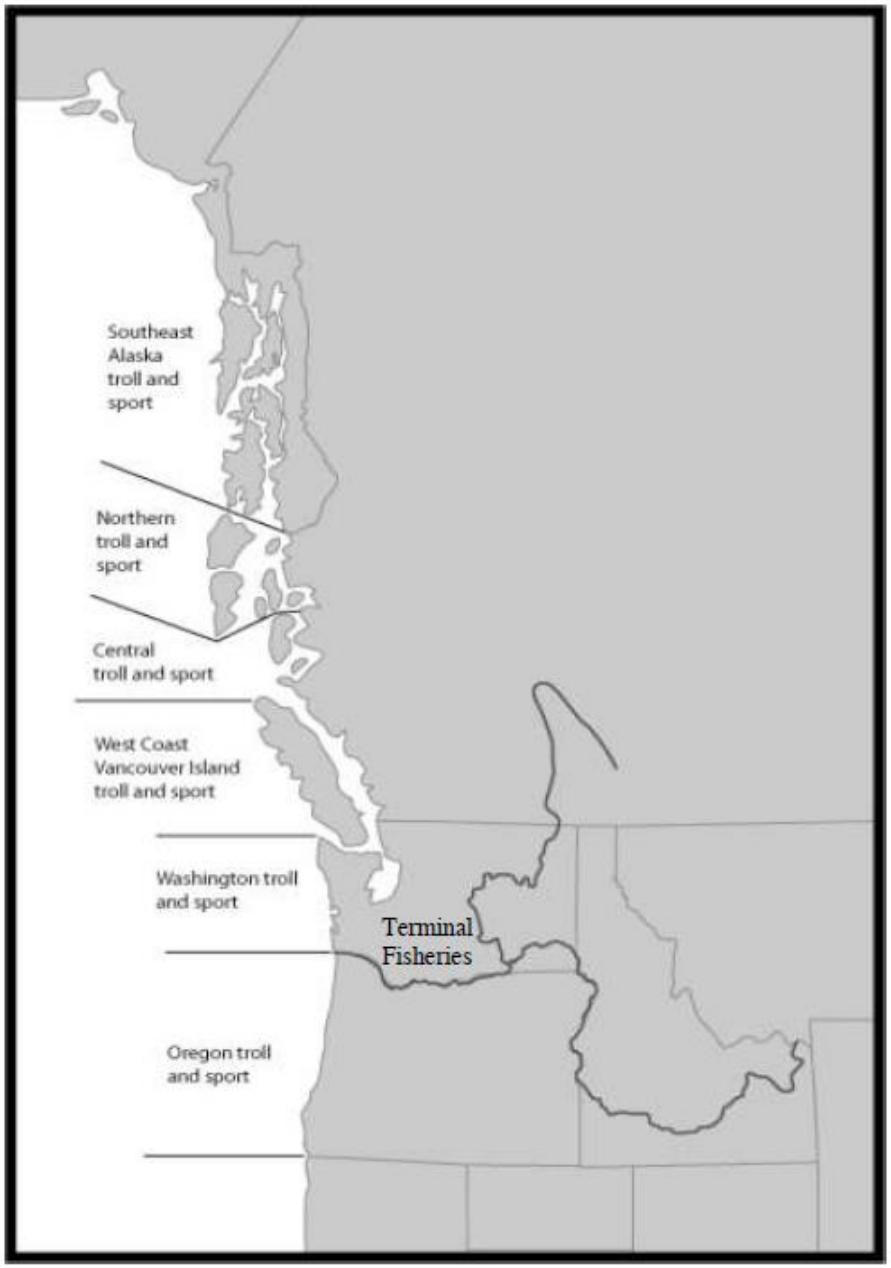
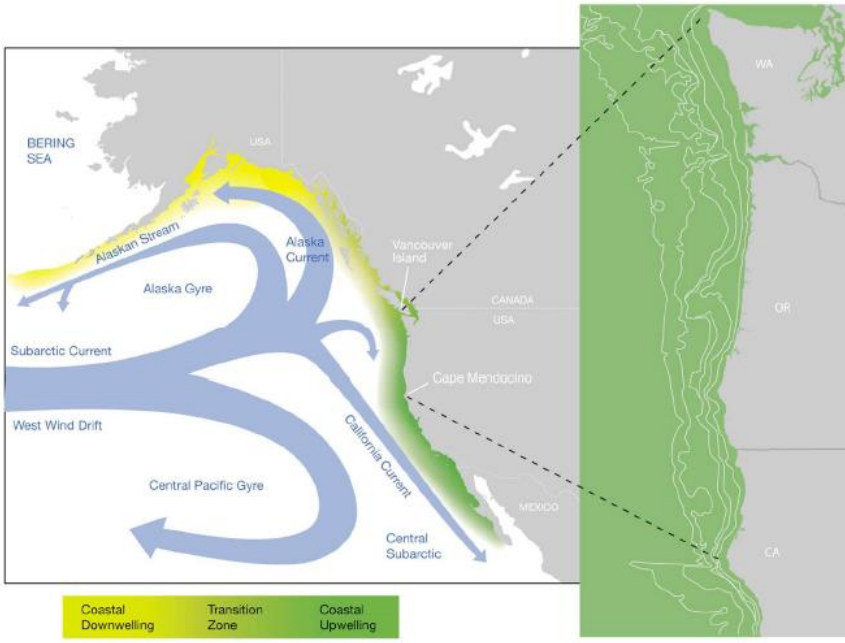
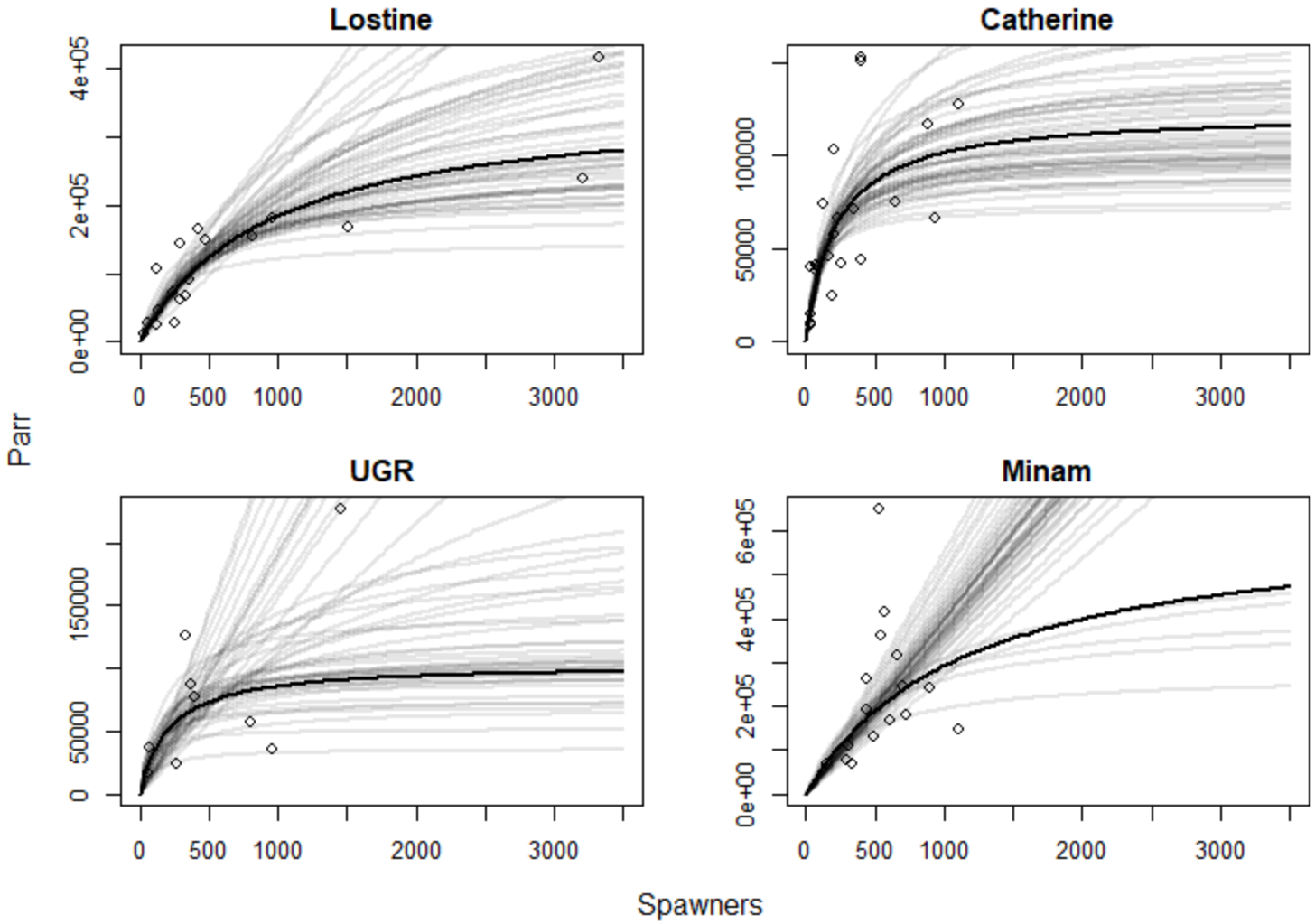
leave
Spring
NOAA FISHERIES
Dam
Trap


Southeast Alaska troll and sport
Northern troll and sport
Central troll and sport
West Coast Vancouver Island troll and sport
Washington troll and sport
Terminal Fisheries
Oregon troll and sport


BERING SEA
USA
Alaskan Stream
Alaska Current
Vancouver Island
Alaska Gyre
CANADA
USA
Subarctic Current
Cape Mendocino
West Wind Drift
California Current
Central Pacific Gyre
MEXICO
Central Subarctic
Coastal Downwelling
Transition Zone
Coastal Upwelling
WA
OR
CA

Iterative testing

- Single population Bayesian Models
- Adding additional data on survivals in Process models.
- Full Hierarchical Model
- Evaluations


Lostine
Catherine
UGR
Minam
Parr
Spawners
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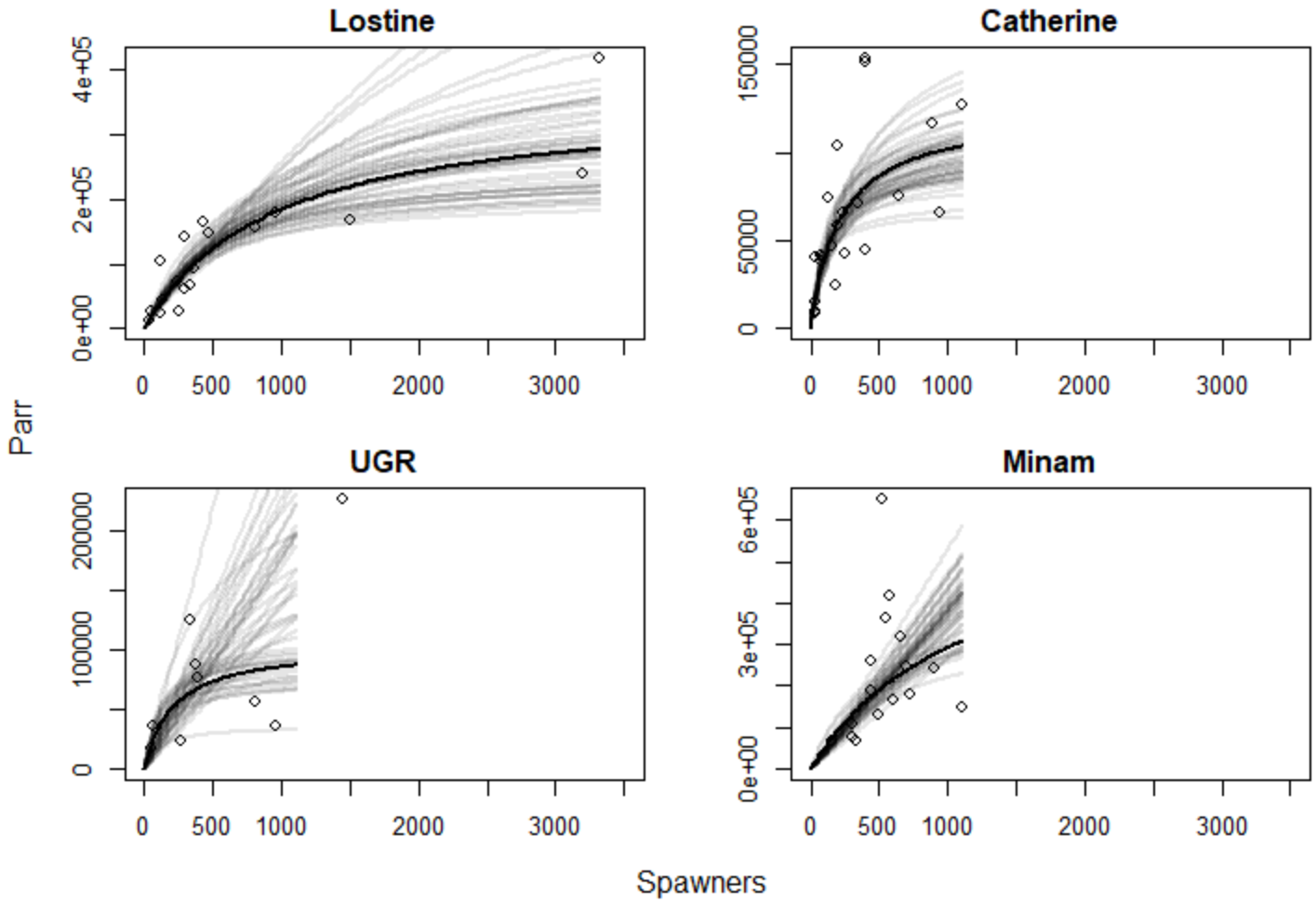
2e+05
4e+05
0
50000
100000
150000
6e+05
0
500
1000
2000
3000


Lostine
Catherine
UGR
Minam
Parr
Spawners
0e+00
2e+05
4e+05
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50000
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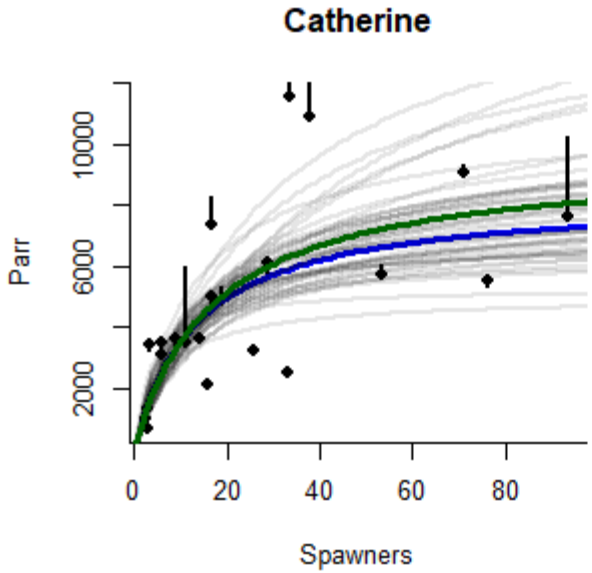
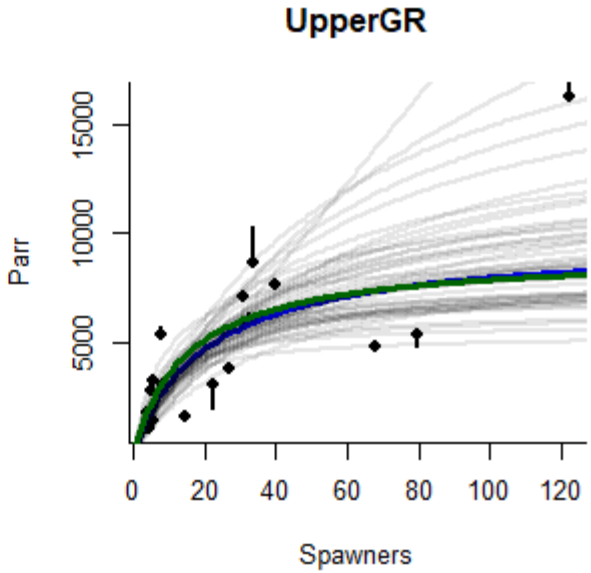
100000
200000
3e+05
6e+05
0
500
1000
2000
3000


Catherine
Parr
2000
6000
10000
0
20
40
60
80
Spawners


UpperGR
Parr
5000
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15000
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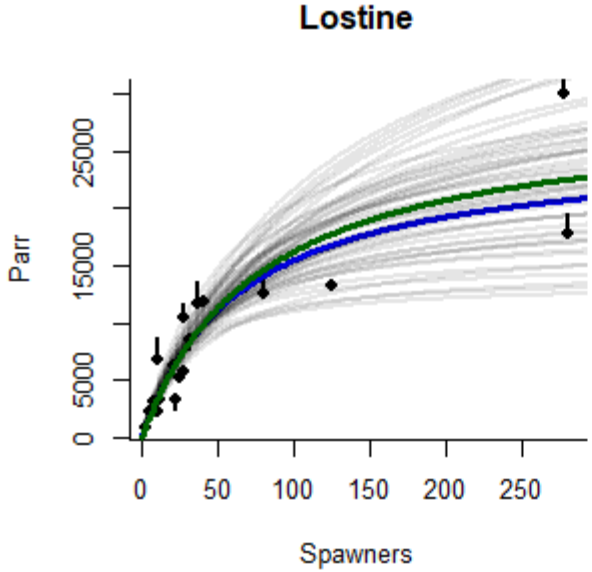
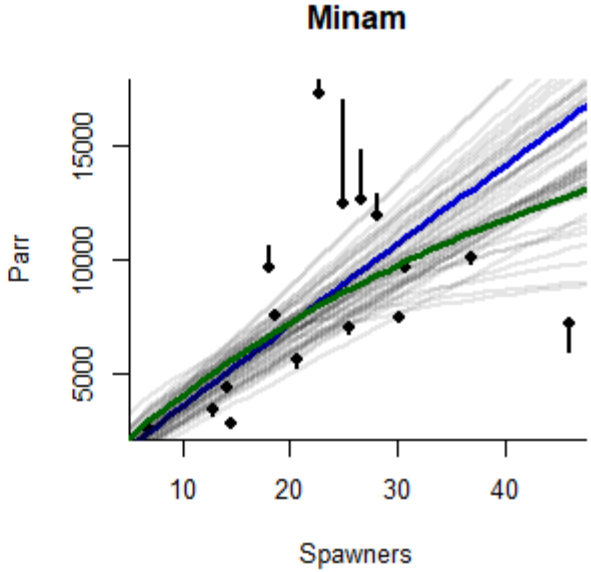
80
100
120
Spawners


Lostine
Parr
0
5000
15000
25000
0
50
100
150
200
250
Spawners


Minam
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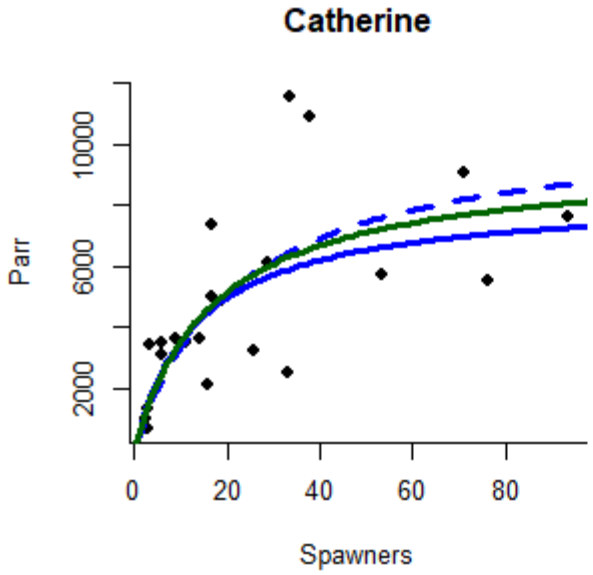
Spawners


Catherine
Parr
Spawners
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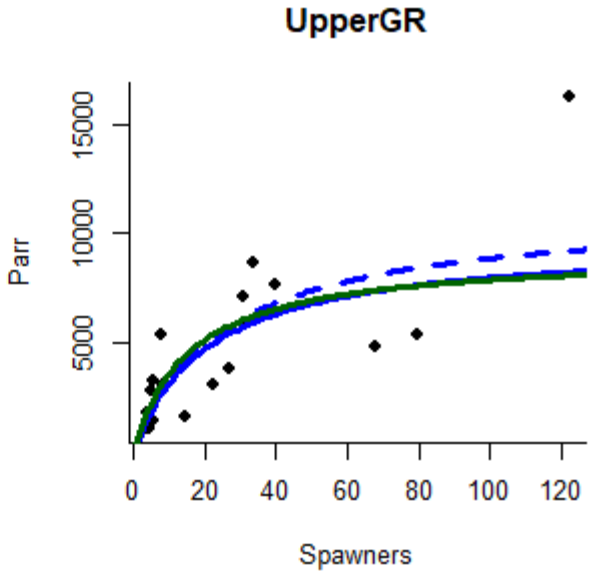
UpperGR
Parr
Spawners
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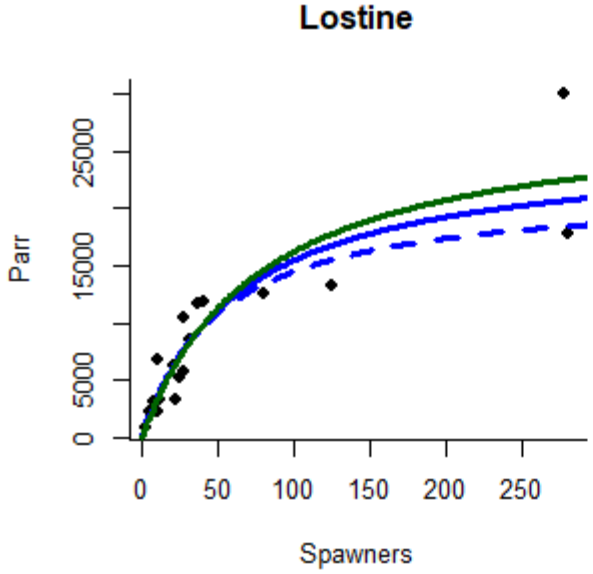
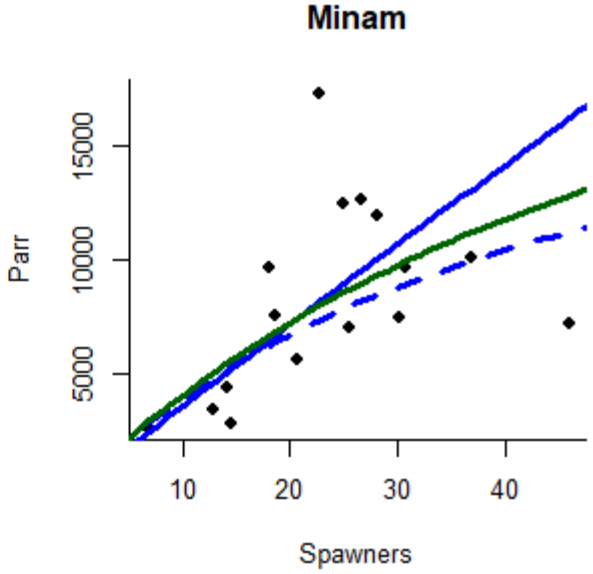
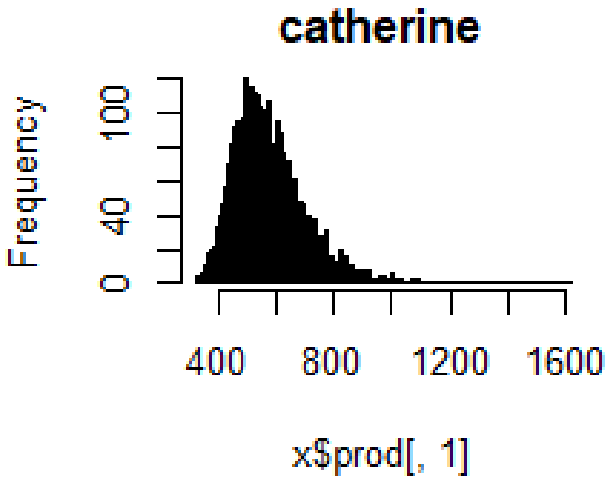
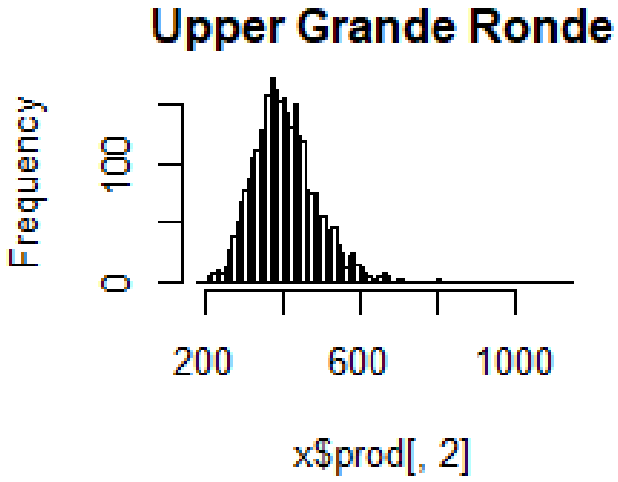
120

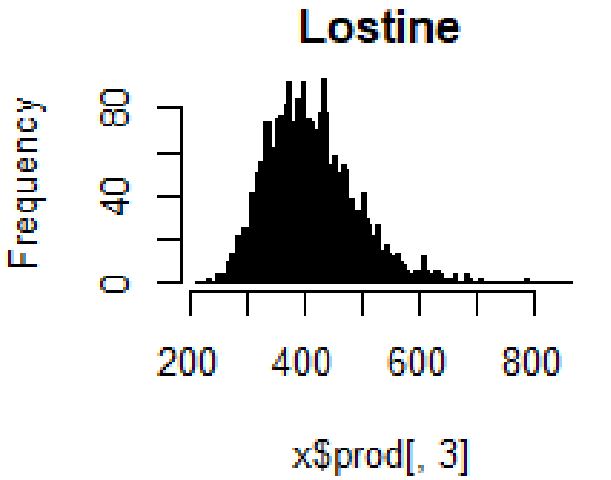

Lostine
Parr
Spawners
0
5000
15000
25000
0
50
100
150
200
250

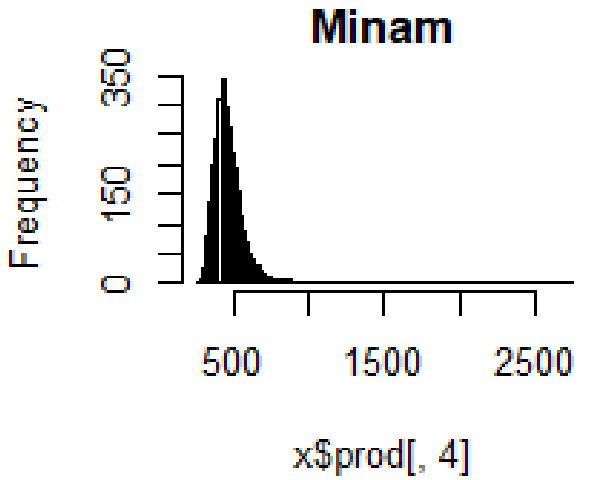

Minam
Parr
Spawners
5000
10000
15000
10
20
30
40

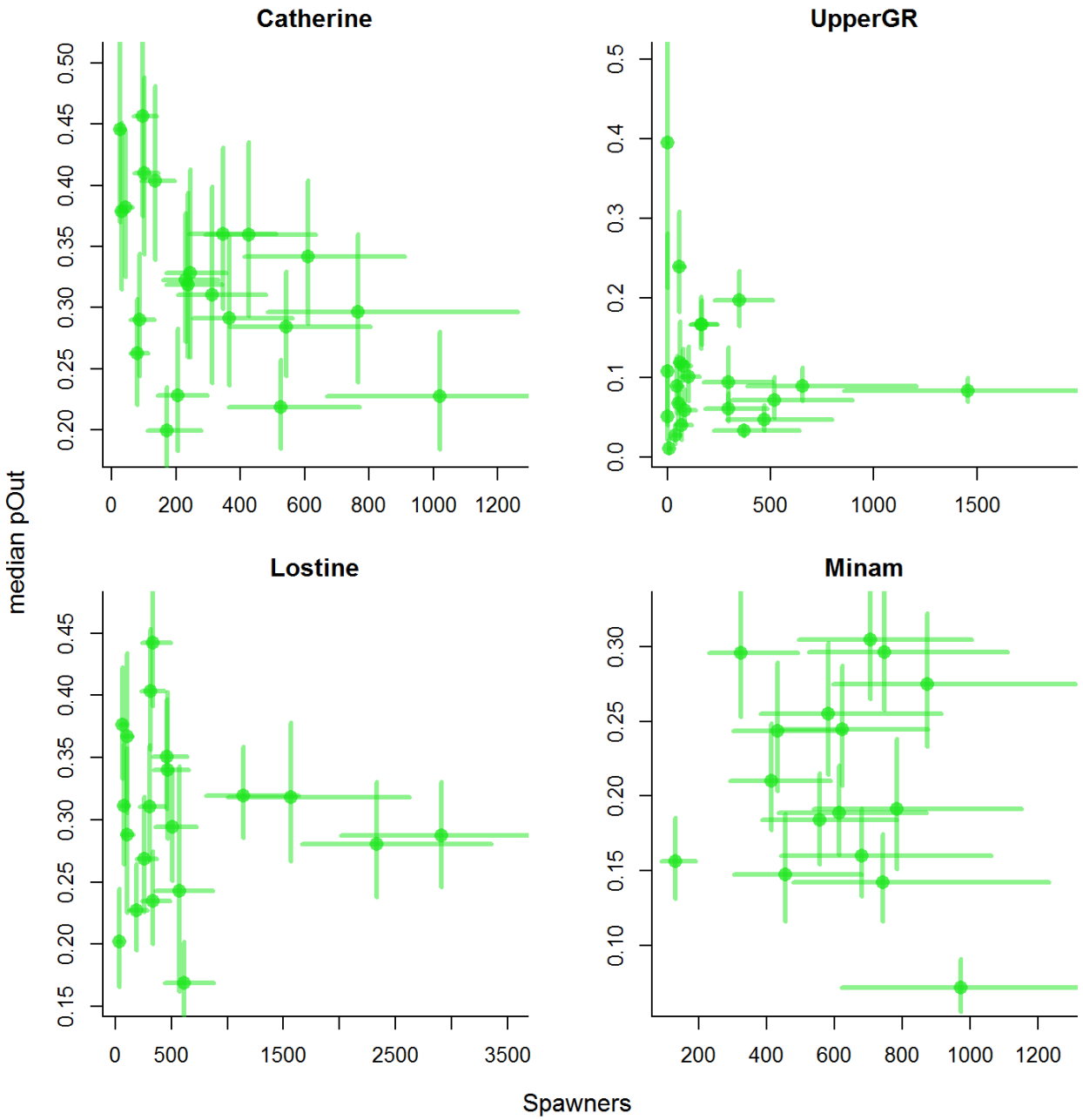
Full Hierarchical

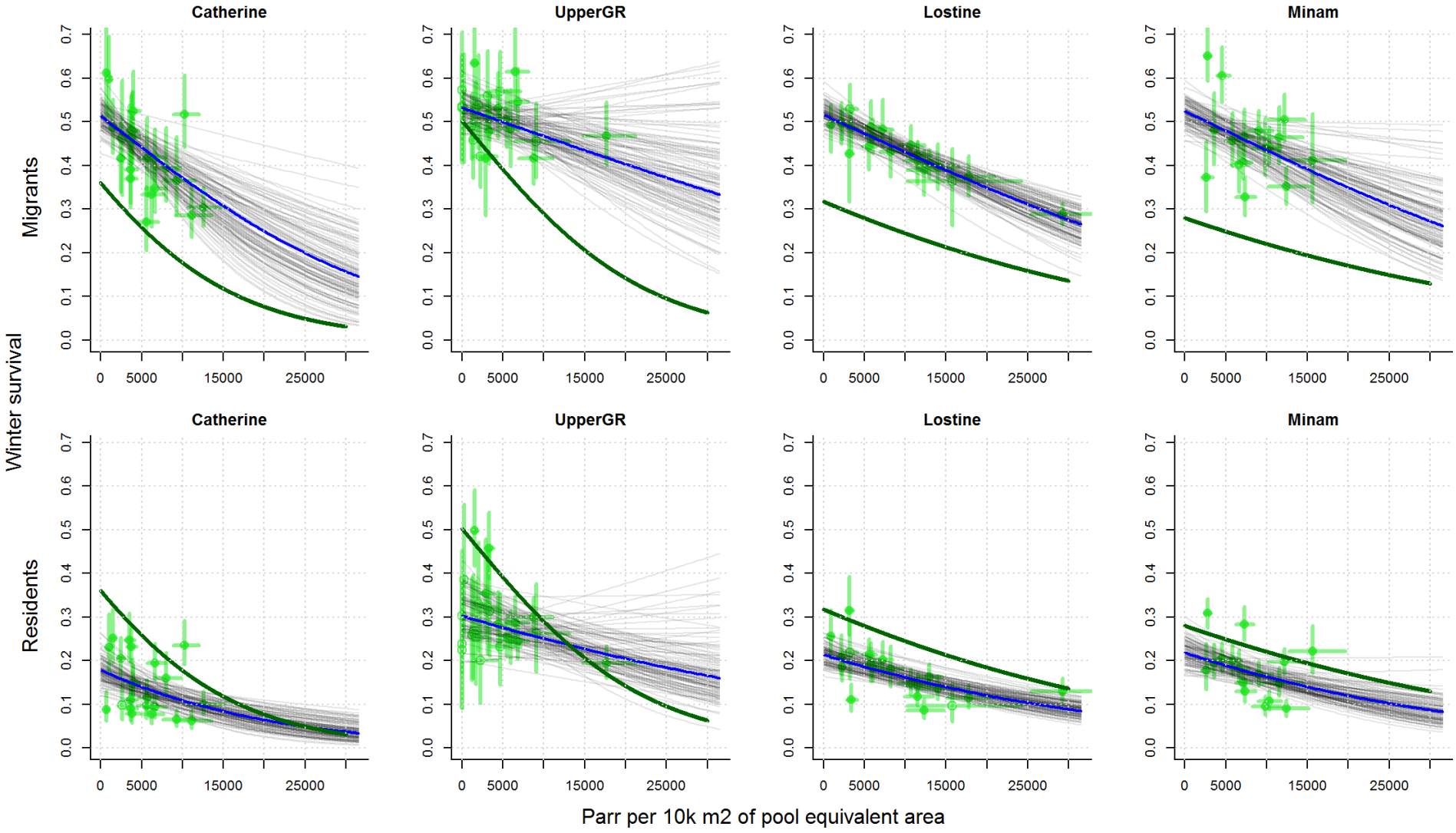


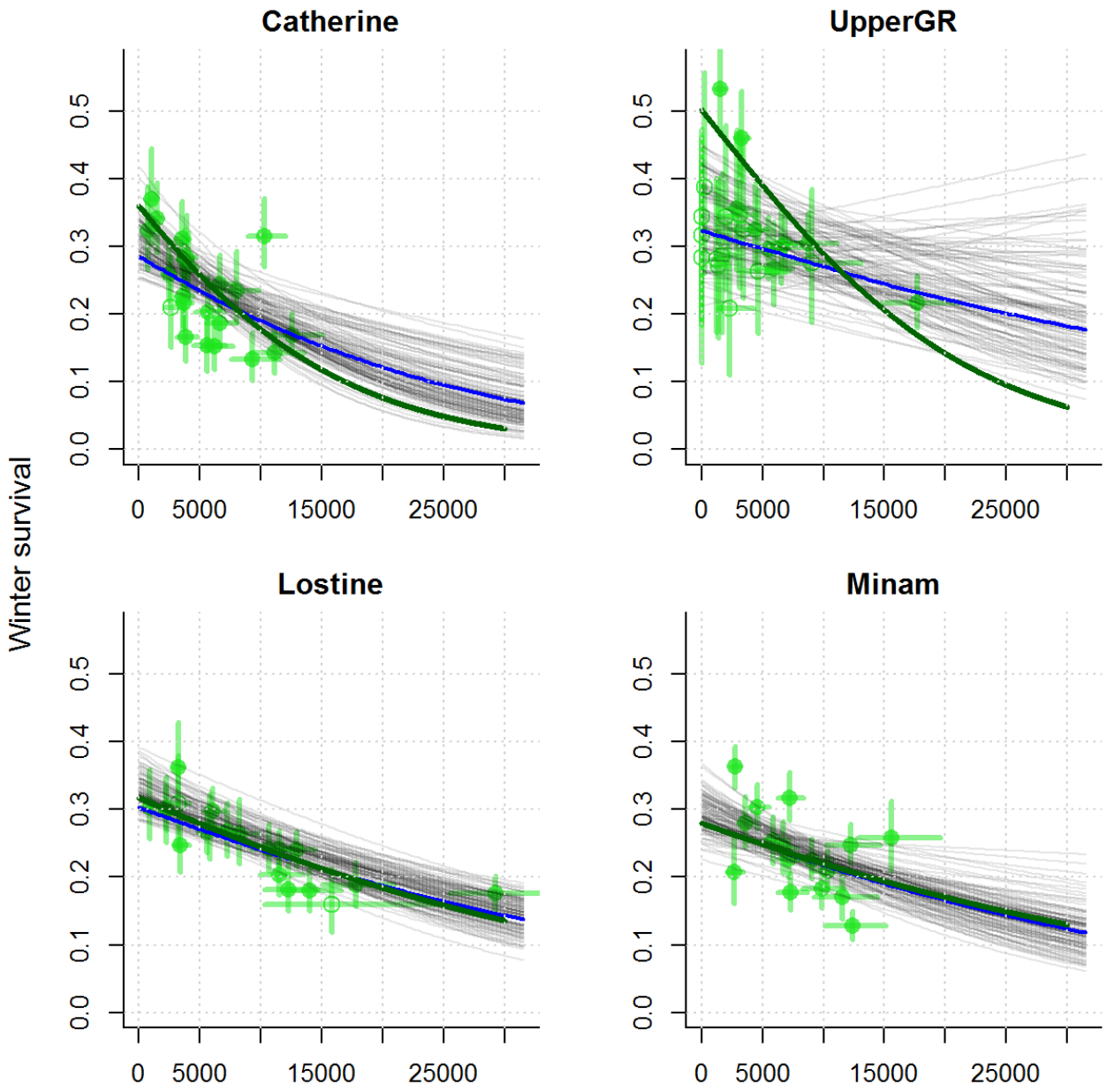


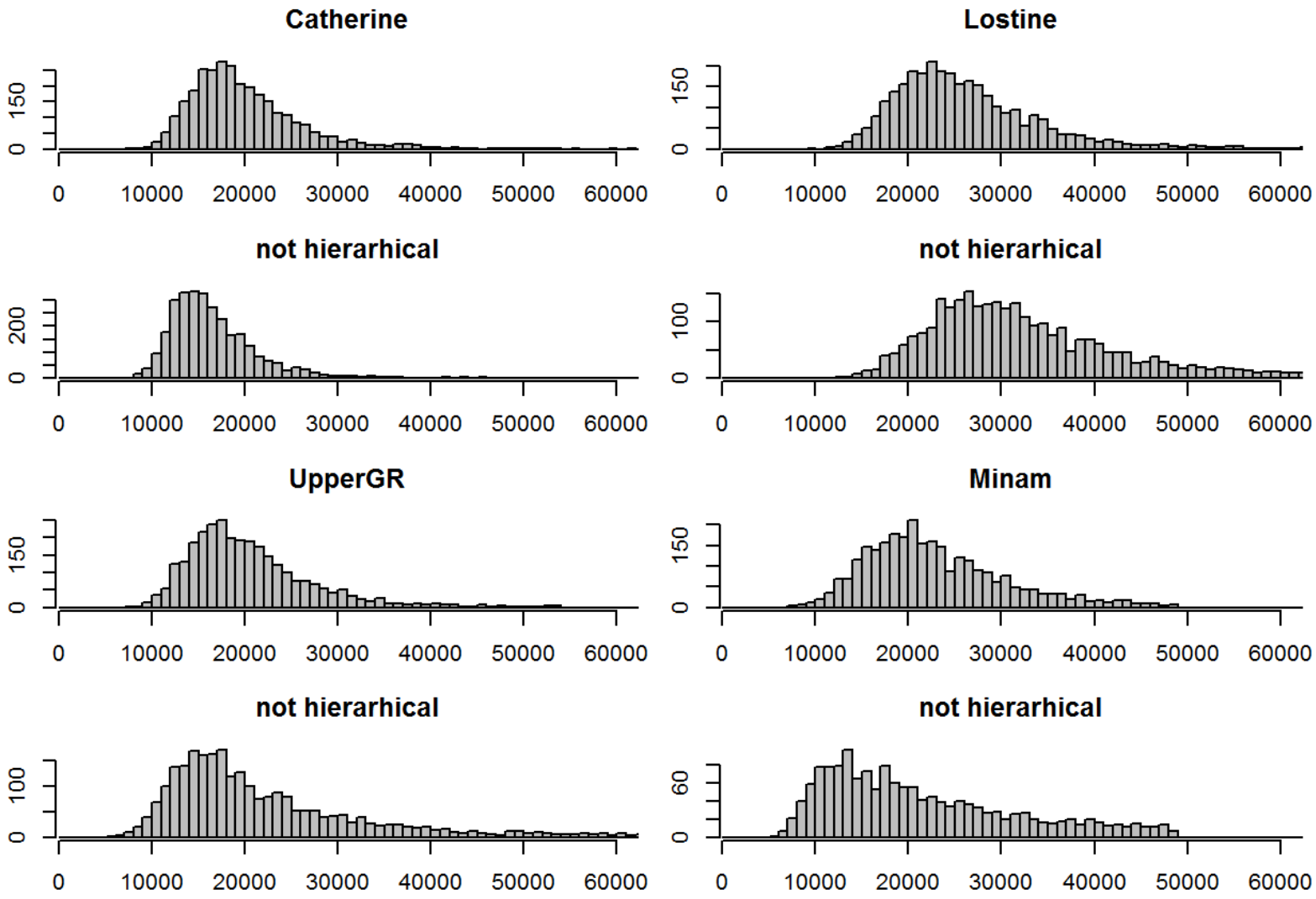


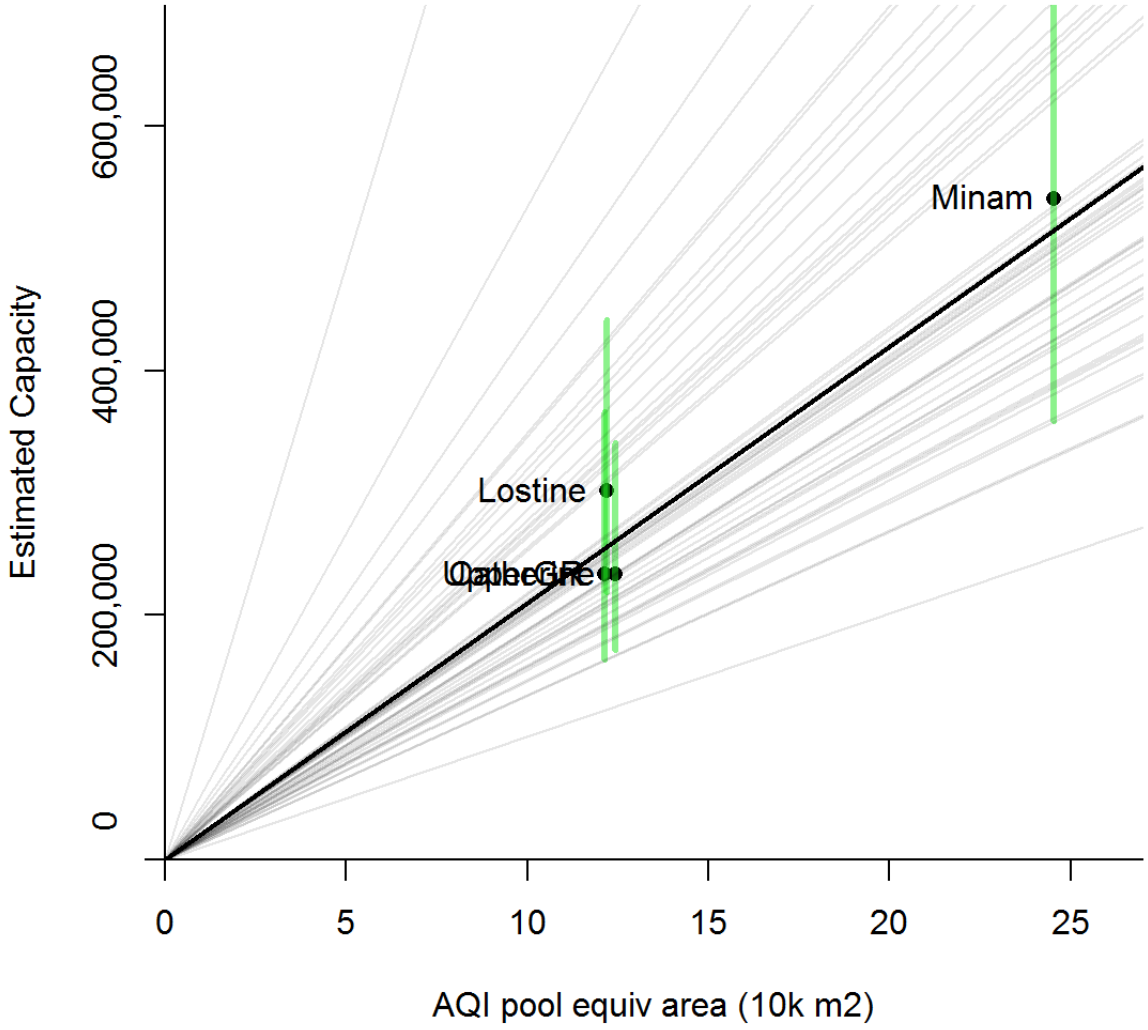



Catherine
UpperGR
Lostine
Minam
median pOut
Spawners
0.20 0.25 0.30 0.35 0.40 0.45 0.50
0 200 400 600 800 1000 1200
0.0 0.1 0.2 0.3 0.4 0.5
0 500 1000 1500
0.15 0.20 0.25 0.30 0.35 0.40 0.45
0 500 1500 2500 3500
0.10 0.15 0.20 0.25 0.30
200 400 600 800 1000 1200

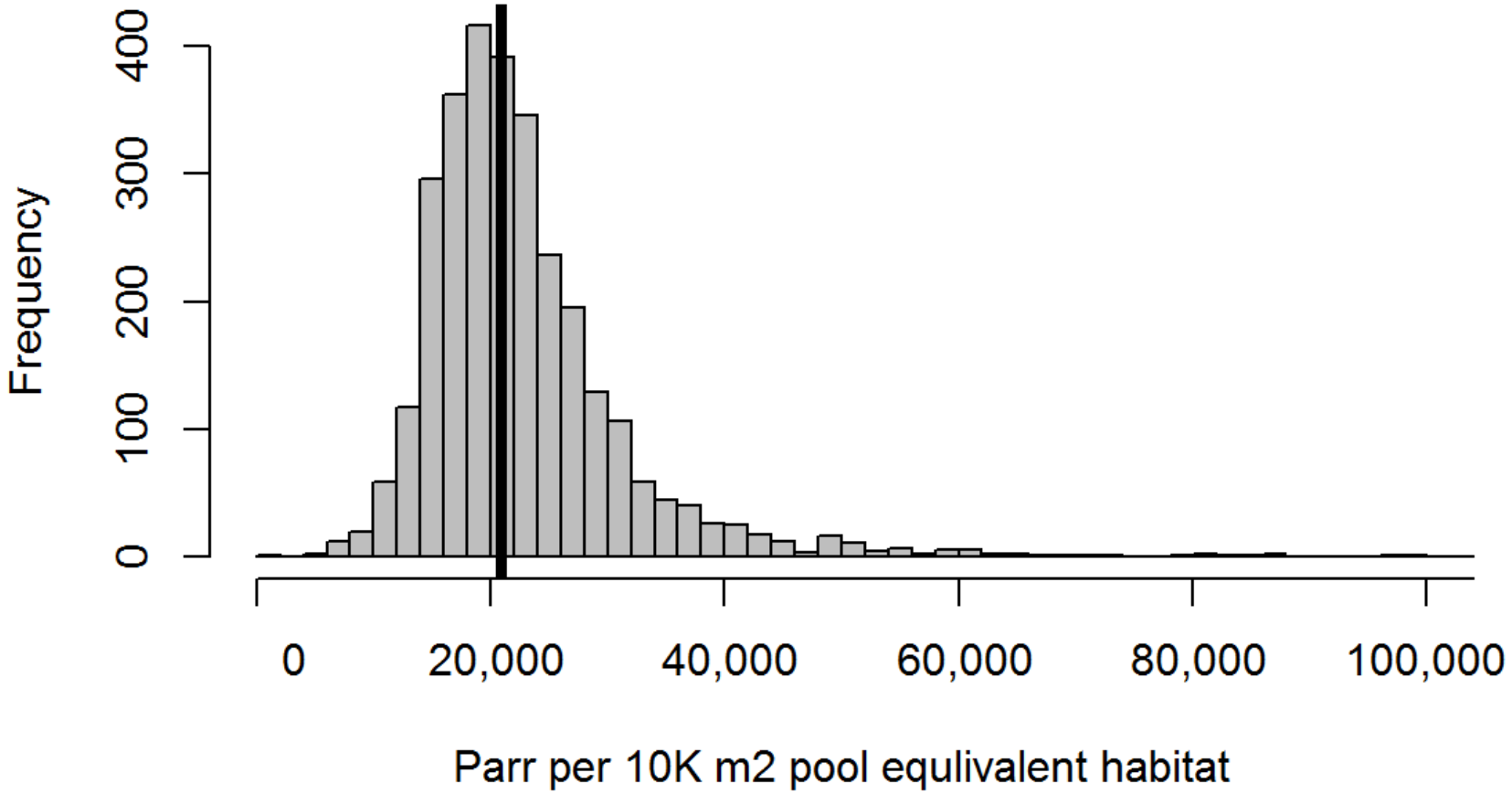

Catherine
UpperGR
Lostine
Minam
Migrants
Residents
Winter survival
Parr per 10k m2 of pool equivalent area
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
5000
15000
25000


Catherine
UpperGR
Lostine
Minam
Winter survival
0.0
0.1
0.2
0.3
0.4
0.5
0
5000
15000
25000
Parr per 10k m2 of pool equivalent area

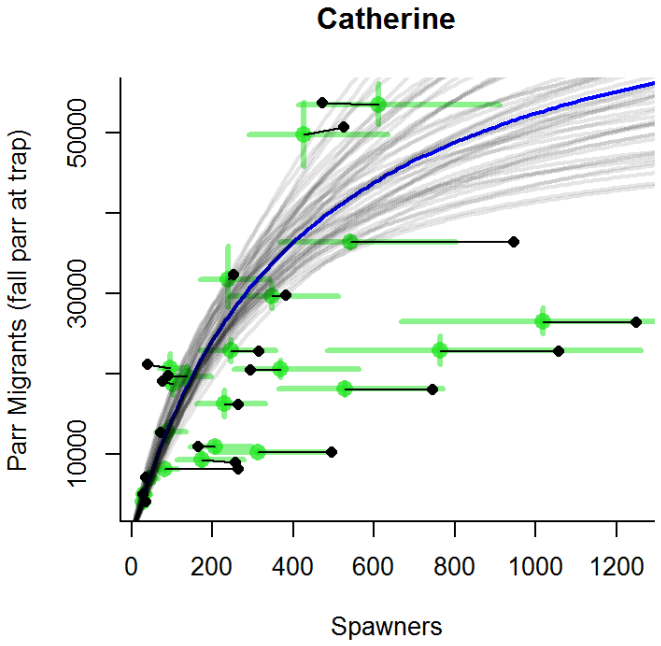

Catherine
Lostine
not hierarhical
not hierarhical
UpperGR
Minam
not hierarhical
not hierarhical
0
10000
20000
30000
40000
50000
60000
Log capacity / poolEquivUnits

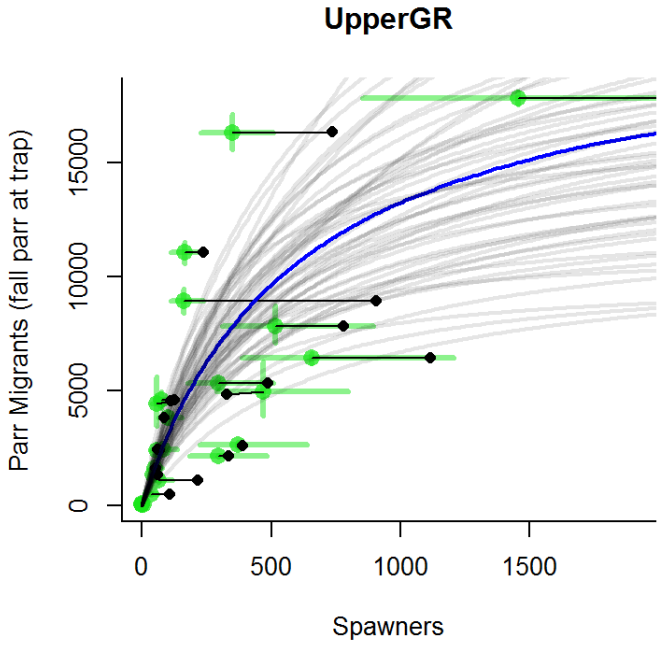

Estimated Capacity
0
200,000
400,000
600,000
0
5
10
15
20
25
AQI pool equiv area (10k m2)
Minam
Lostine

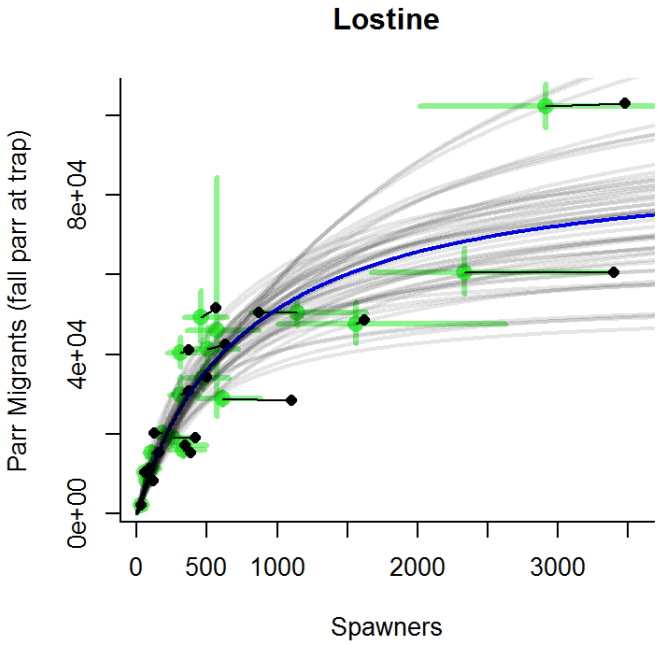
Parr at capacity per pool equivalent area

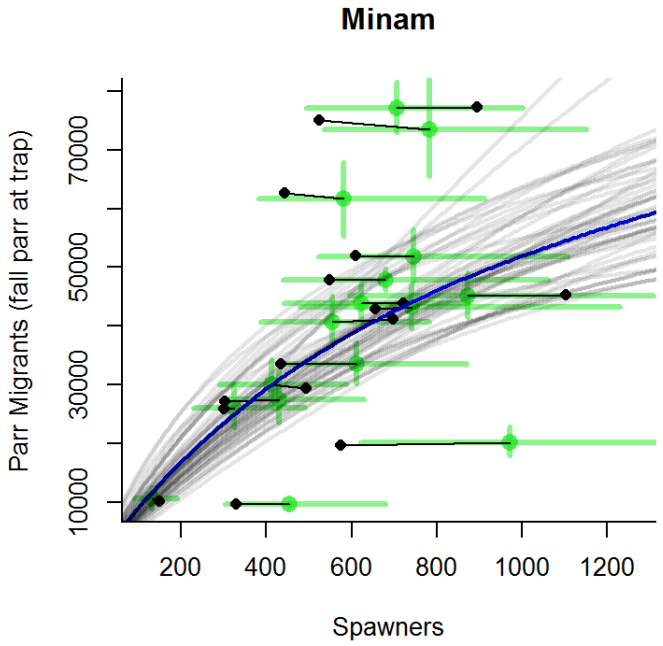


Spawner to Parr









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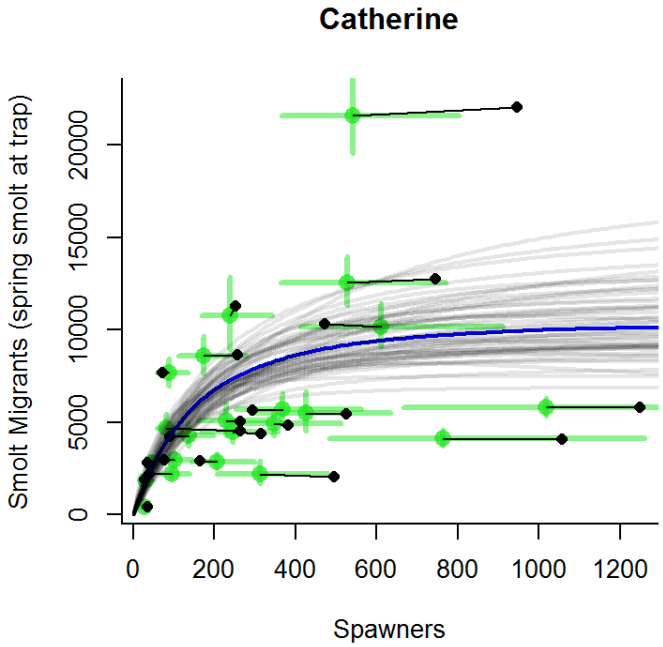
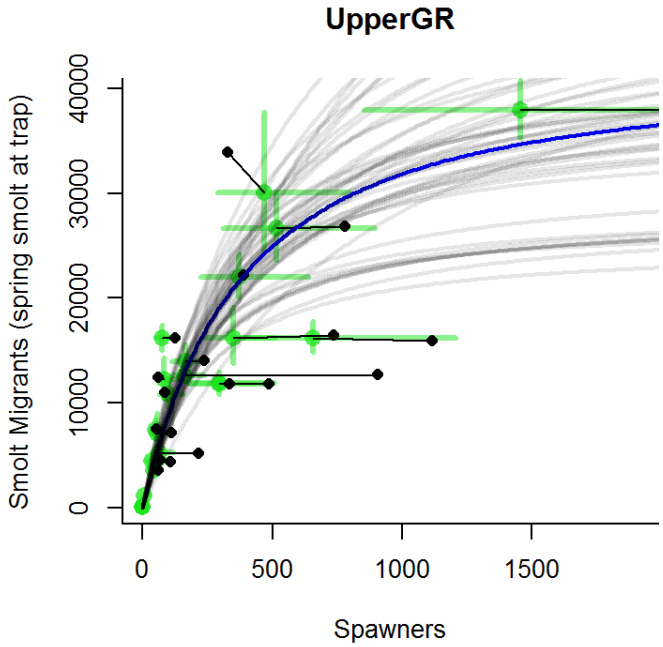
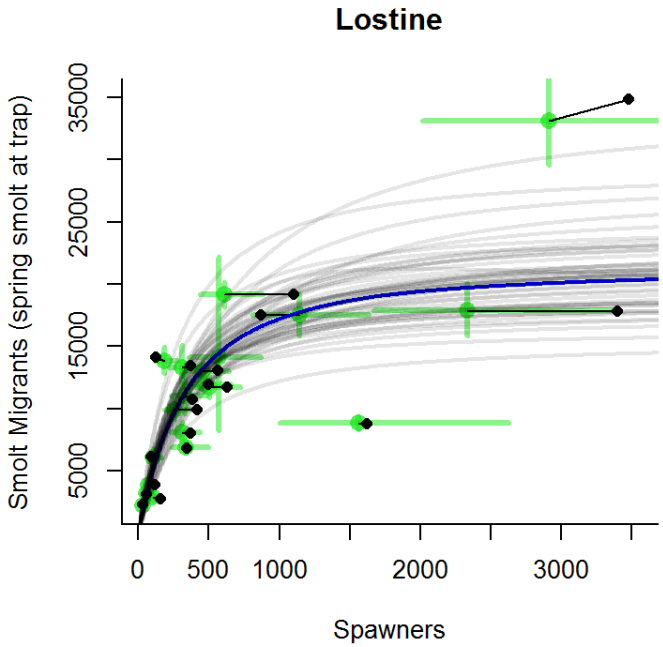
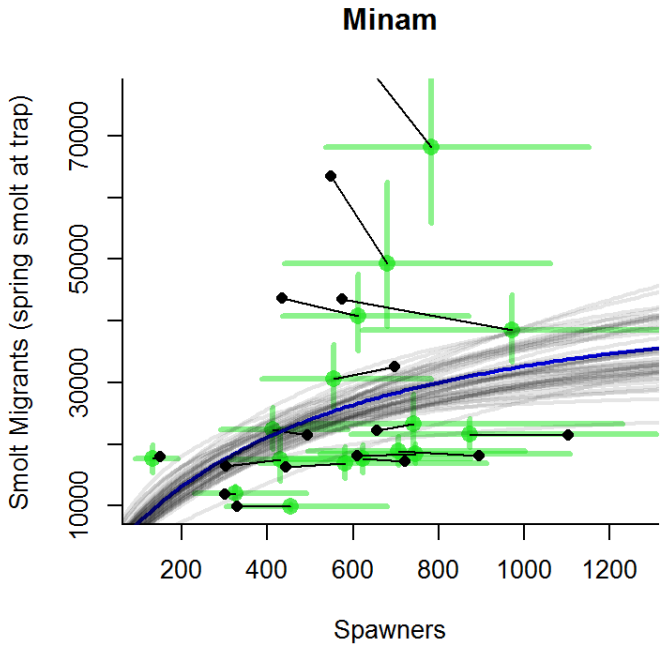
Spawner to Smolt

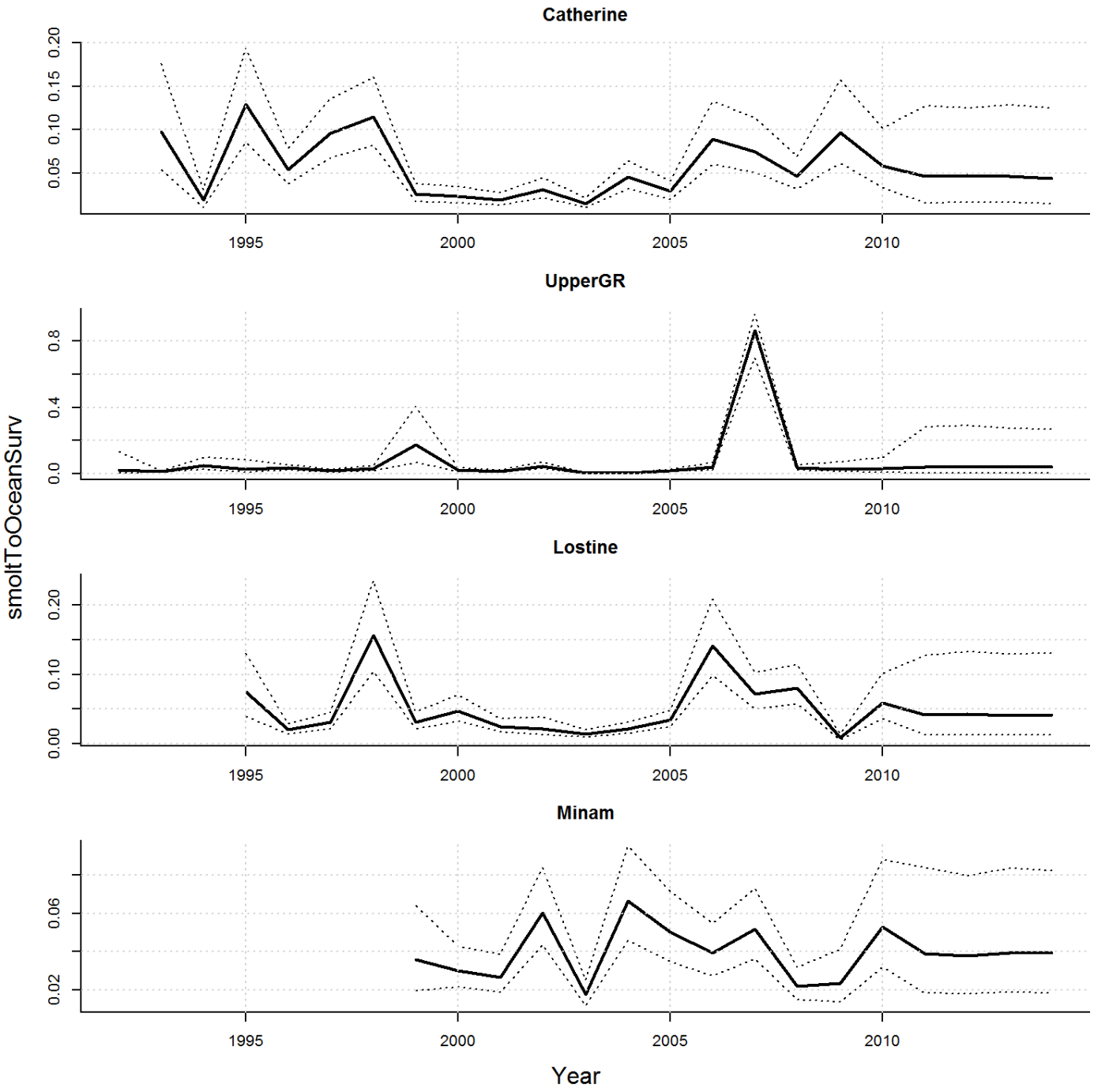








Dam to Ocean Survival



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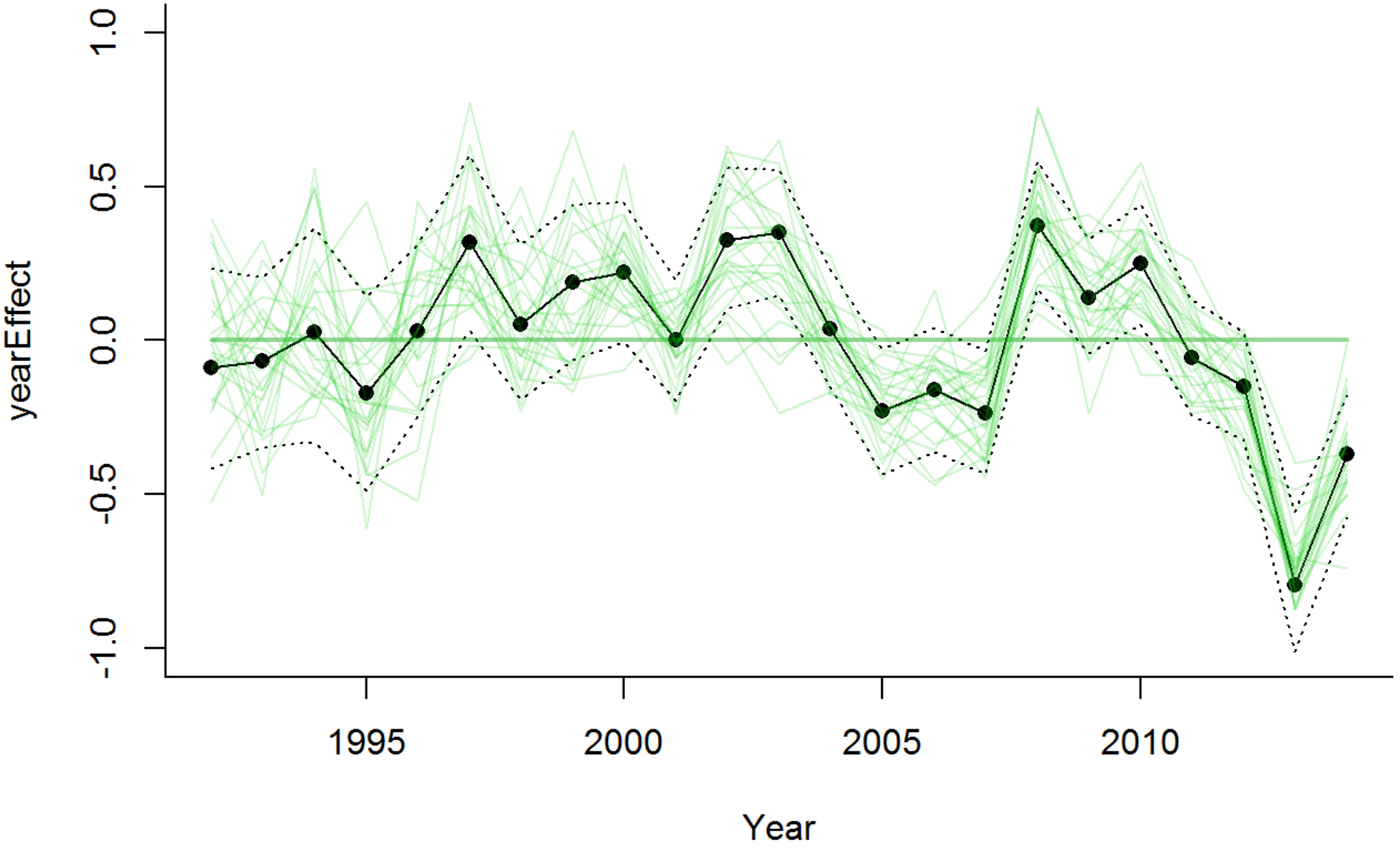
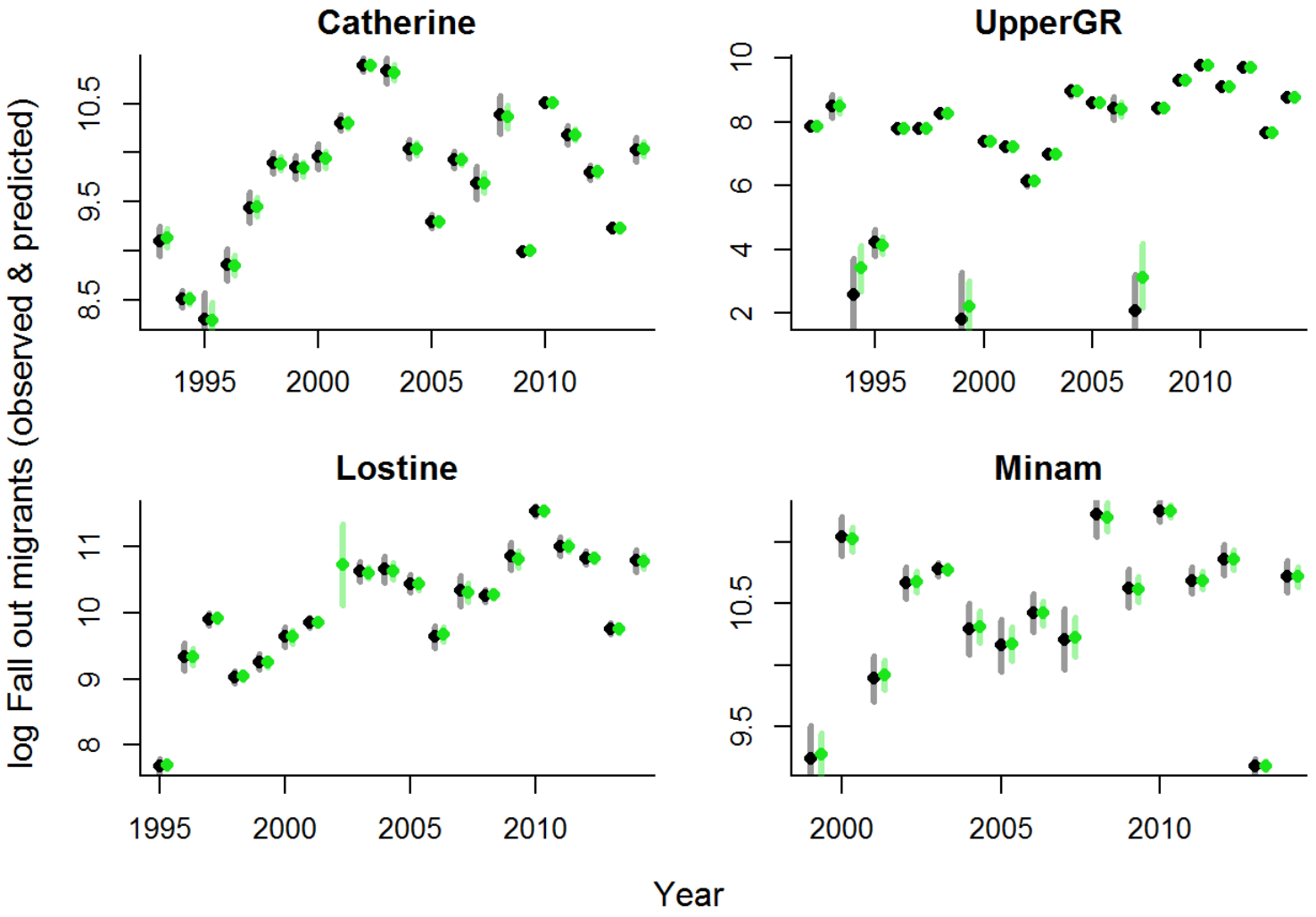
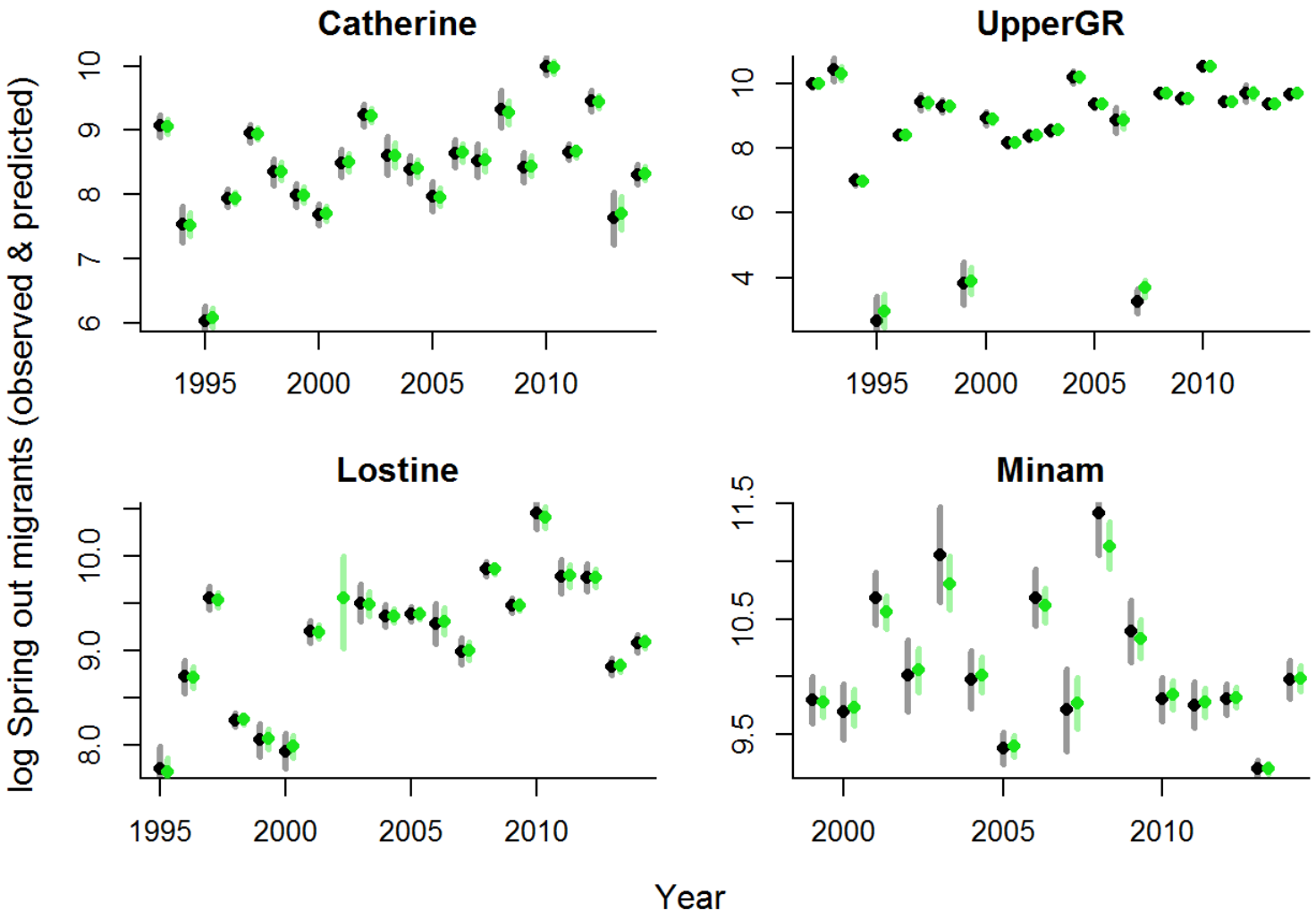
Year Effect



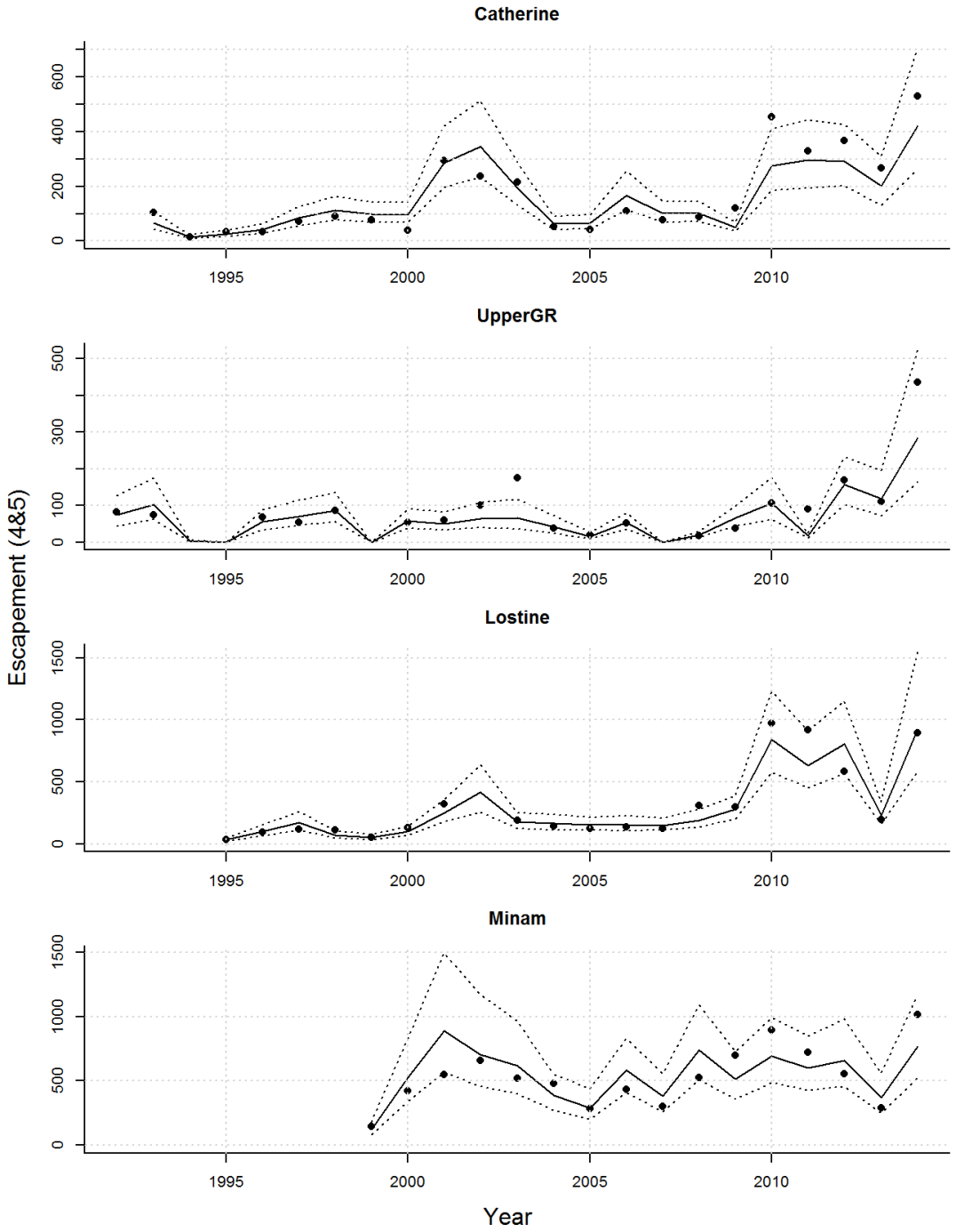
Fits to data-I (Fall Out Migrants)



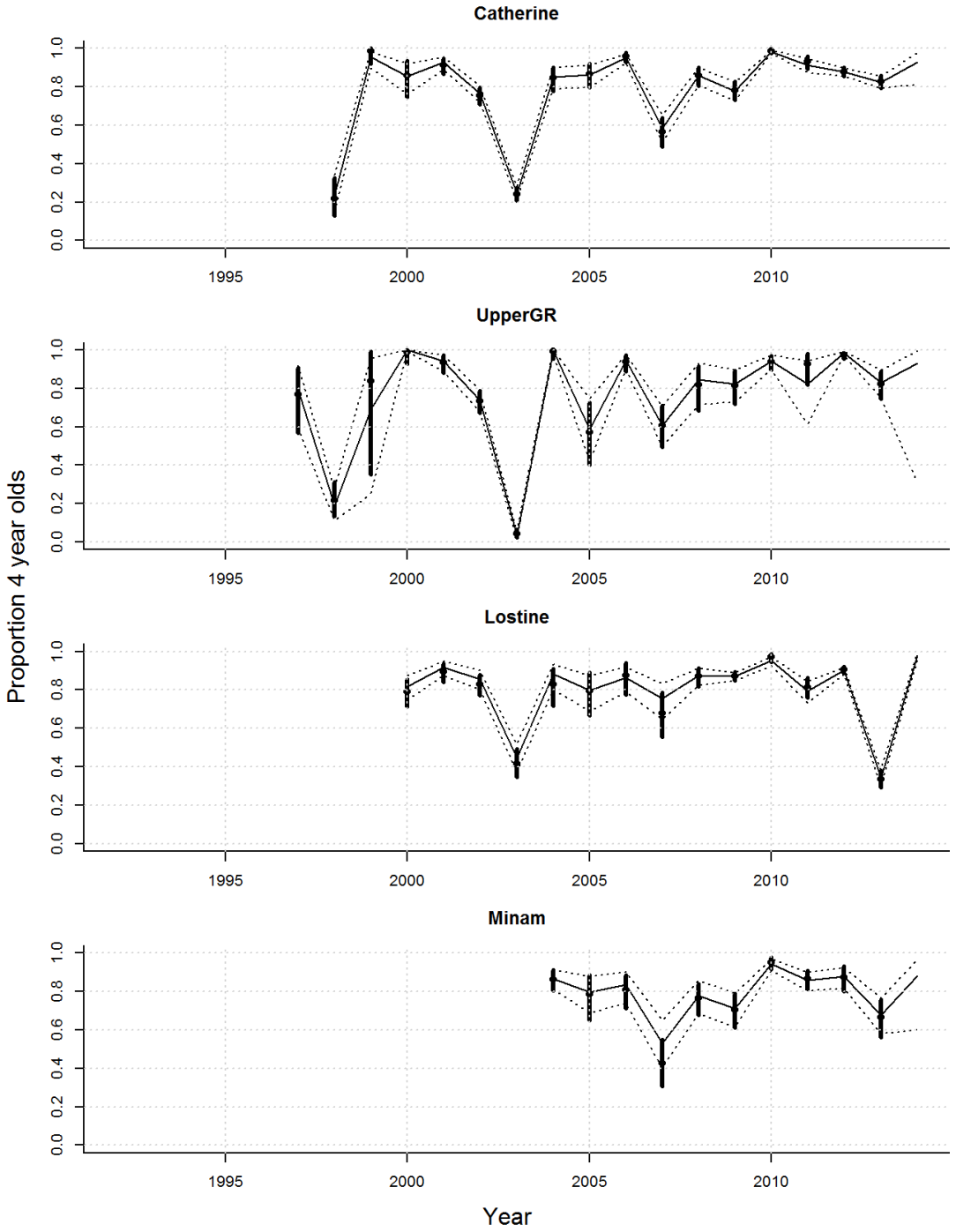
Fits to data-II (Spring Outmigrants)



Predicted and observed escapement



Predicted and observed proportion age 4



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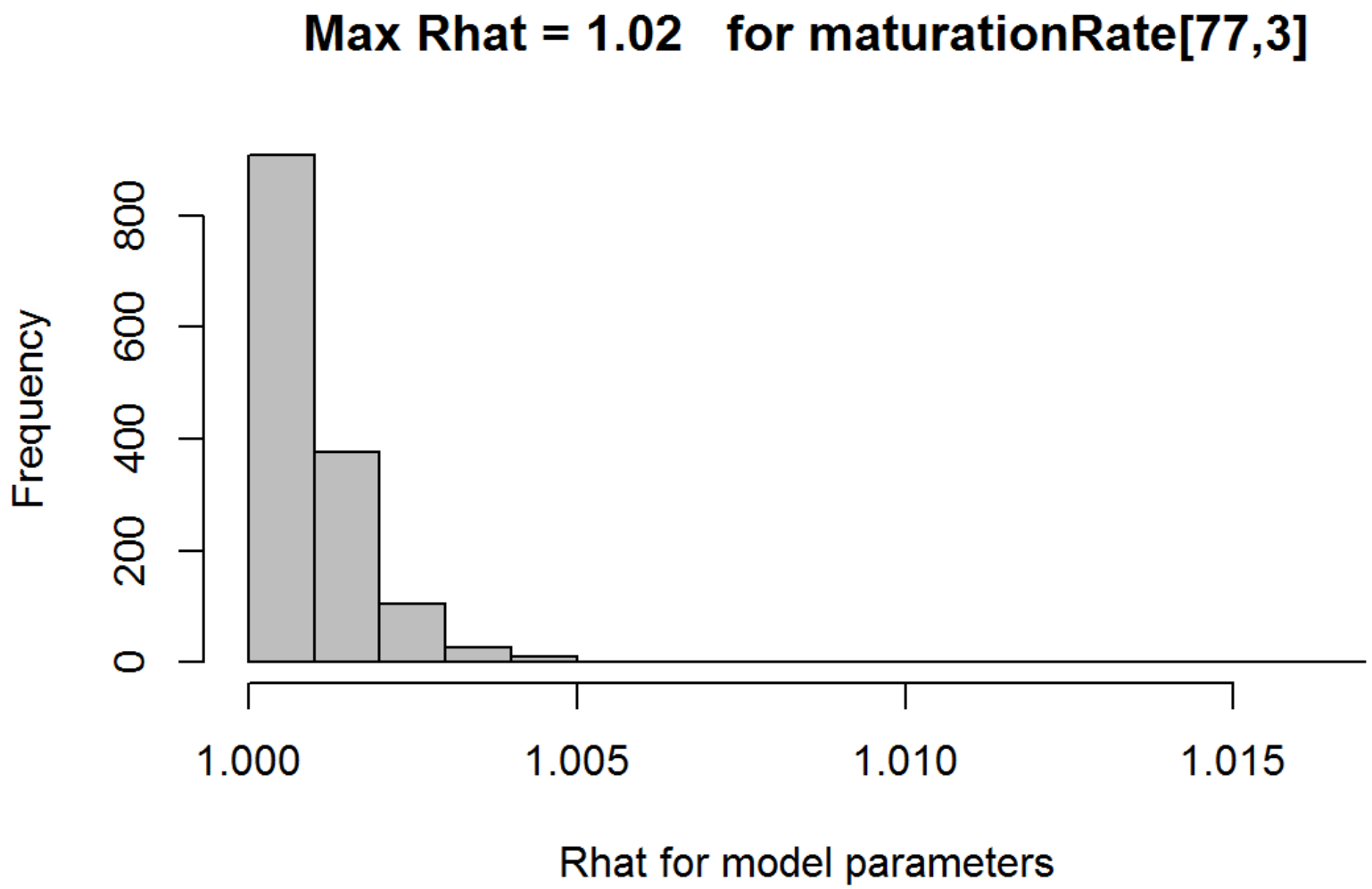
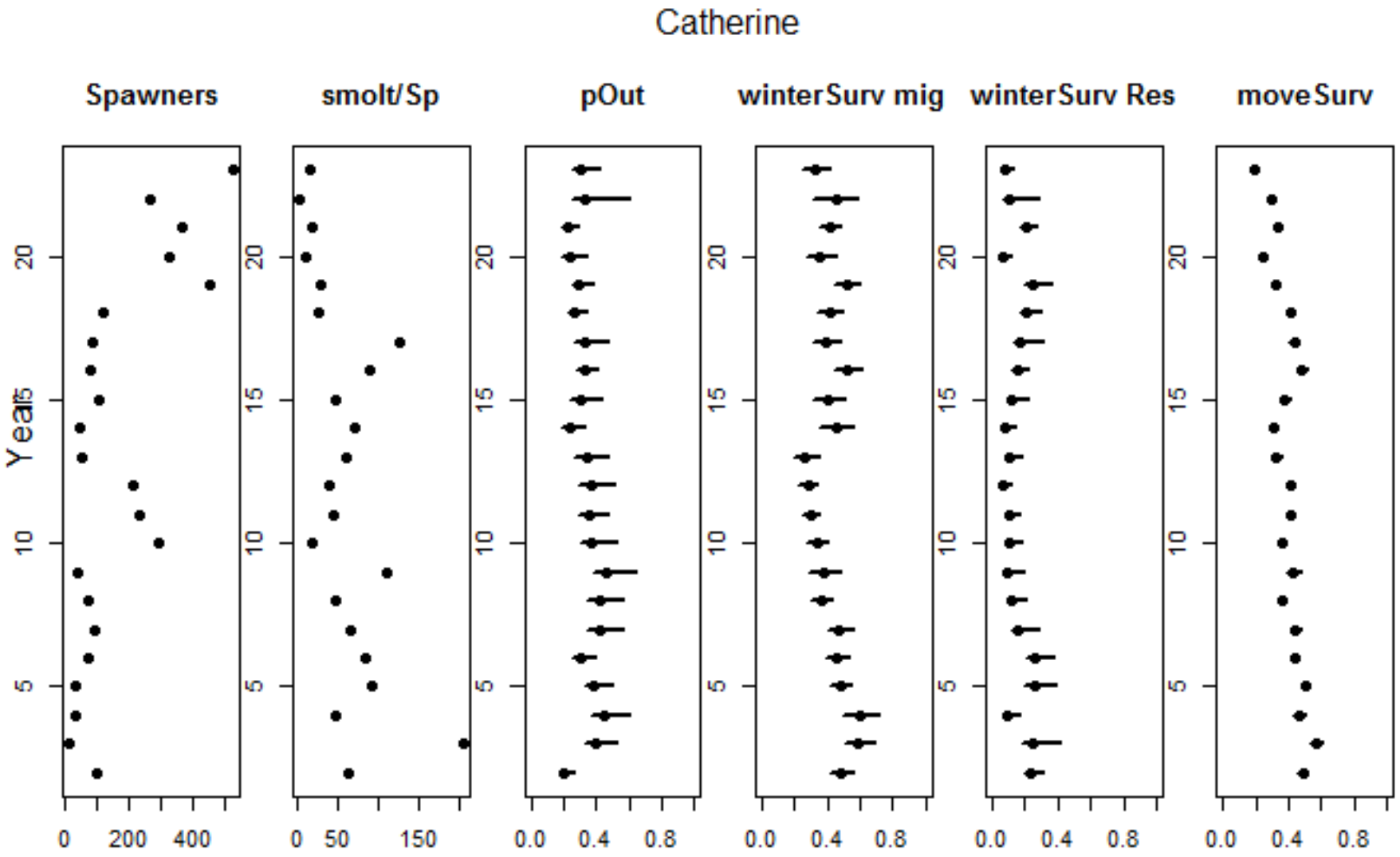
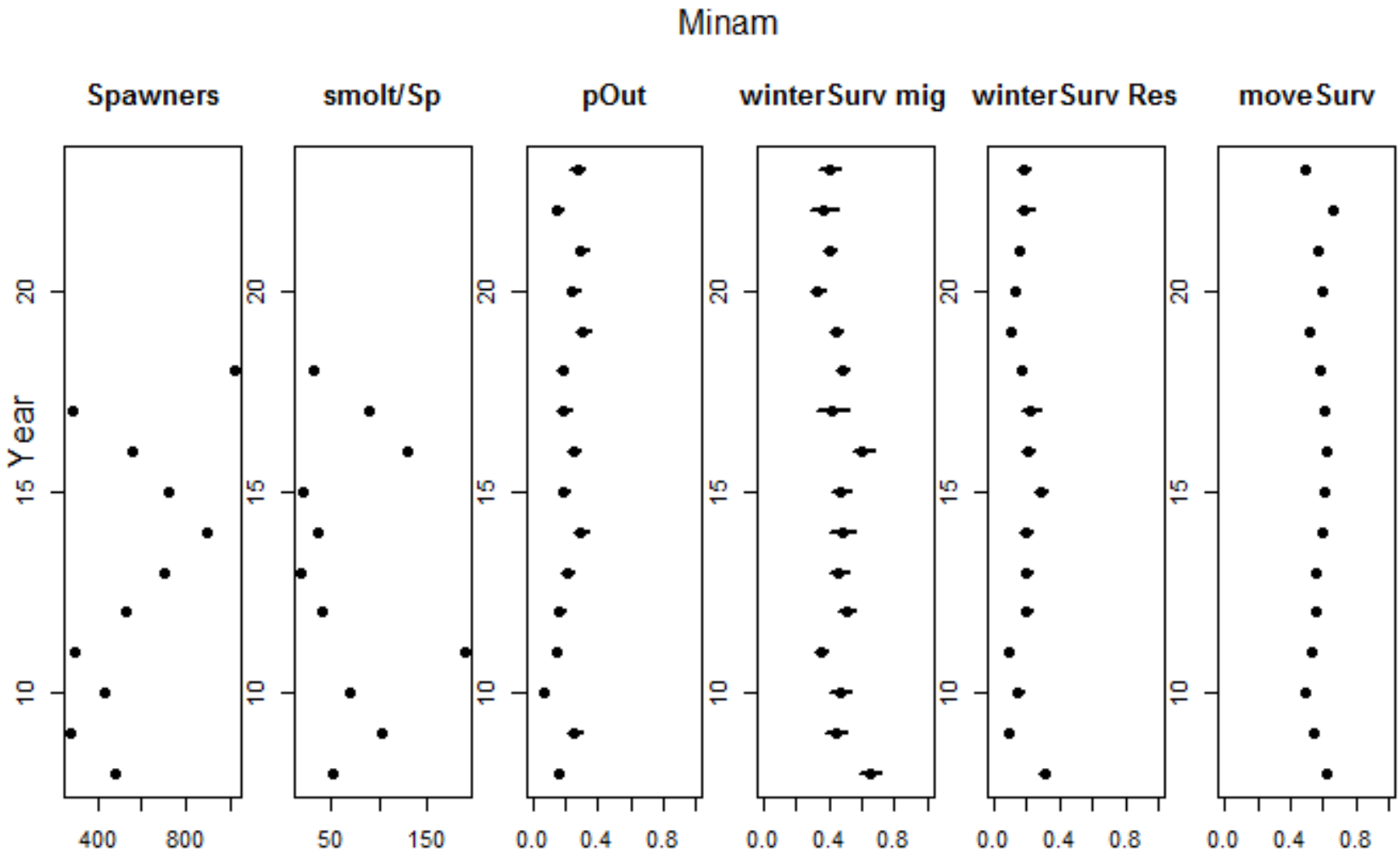
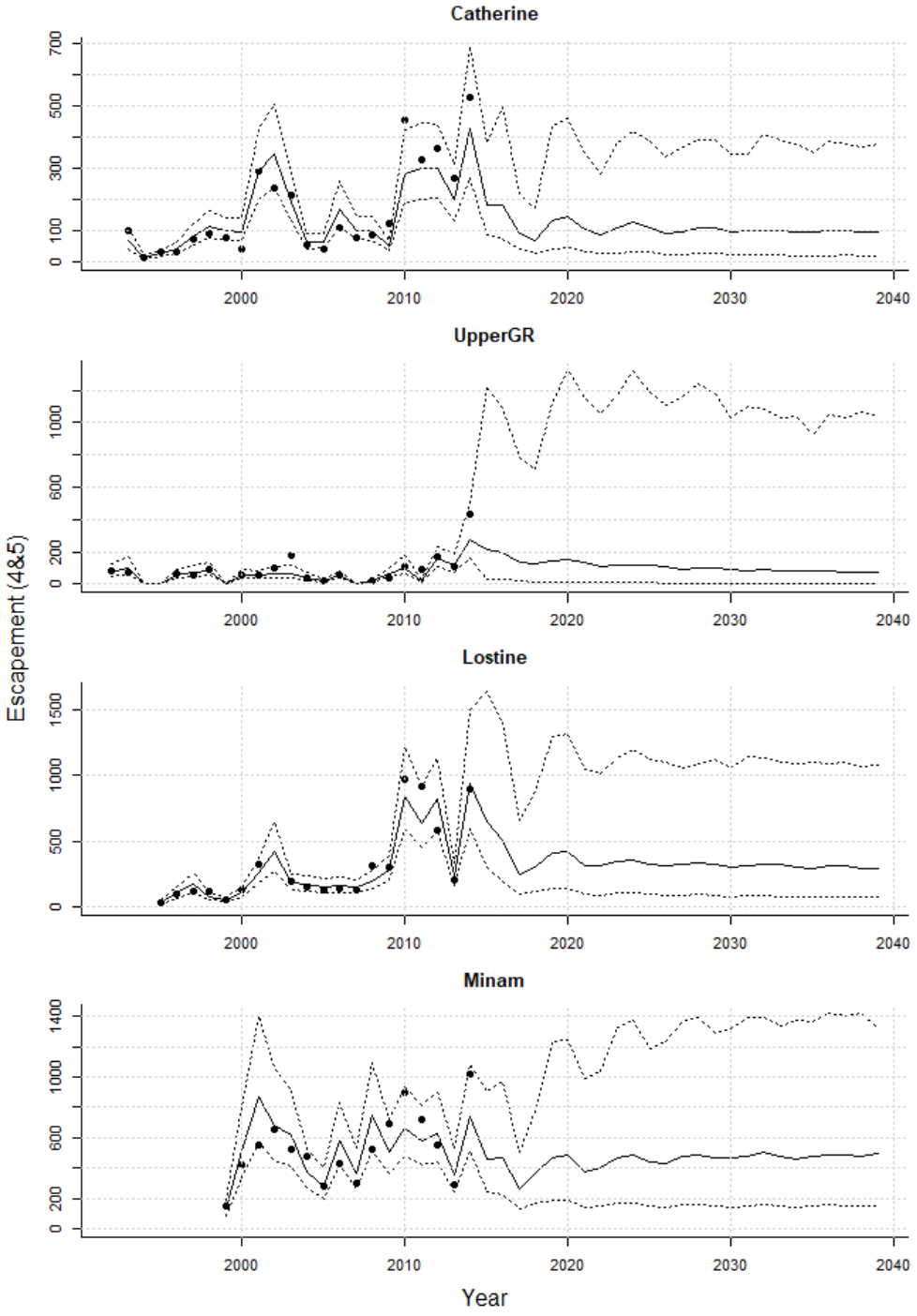
Convergence Criteria

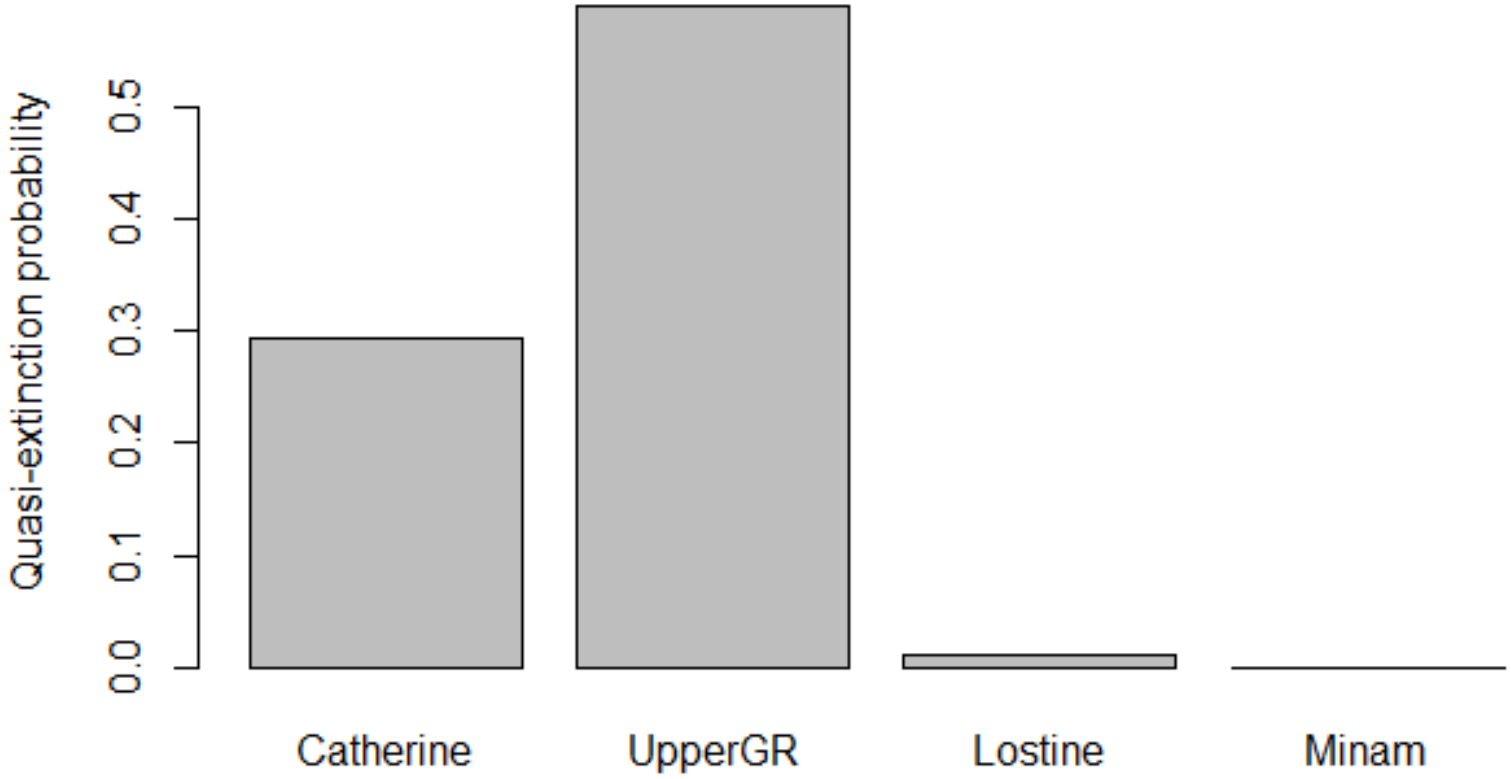



Catherine
Spawners
smolt/Sp
pOut
winterSurv mig
winterSurv Res
moveSurv
Years
5
10
15
20
0
200
400
0
50
150
0.0
0.4
0.8


Minam
Spawners
smolt/Sp
pOut
winterSurv mig
winterSurv Res
moveSurv
Year
10
15
20
400
800
50
150
0.0
0.4
0.8

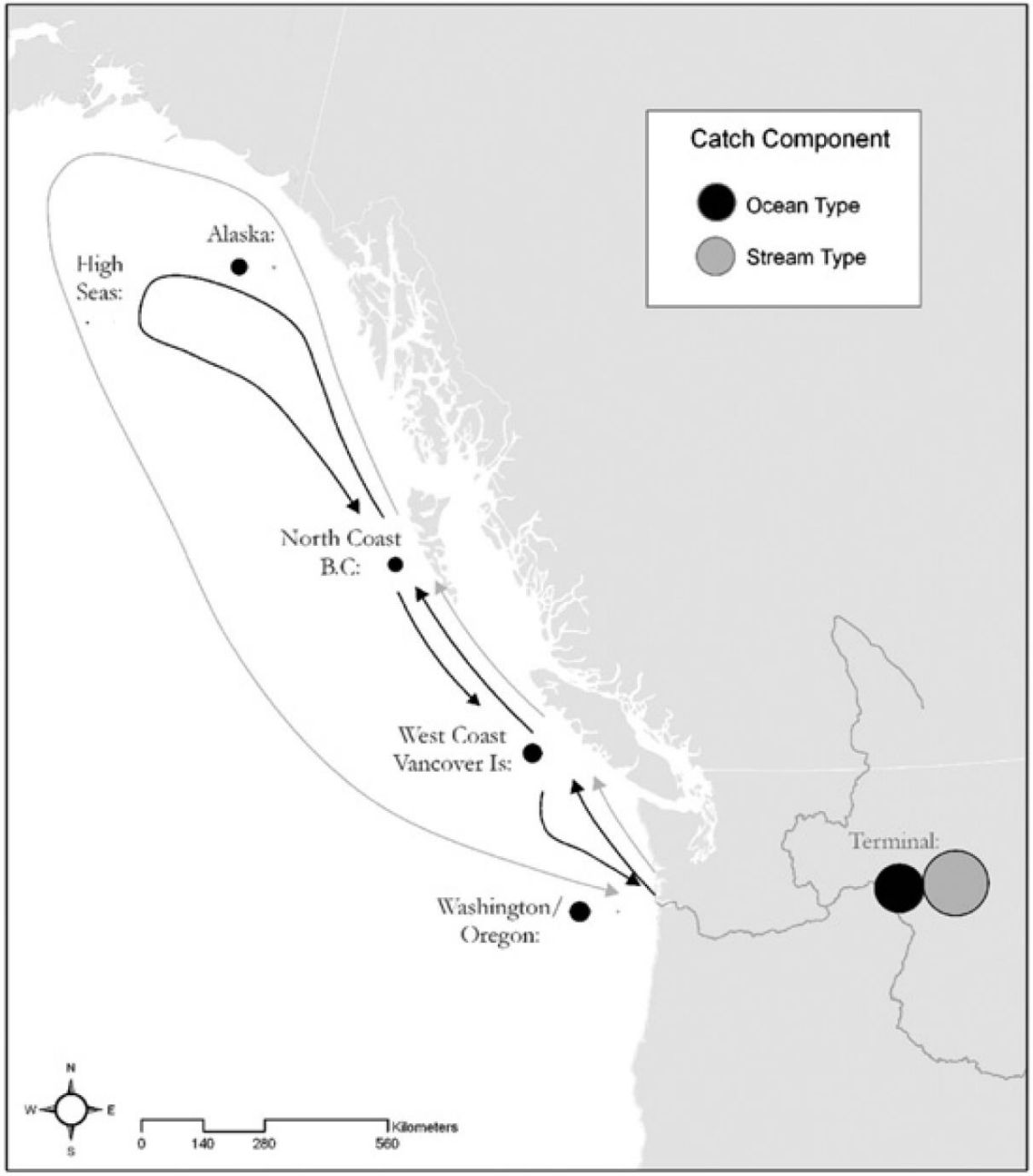
Projections and Quasi Extinction



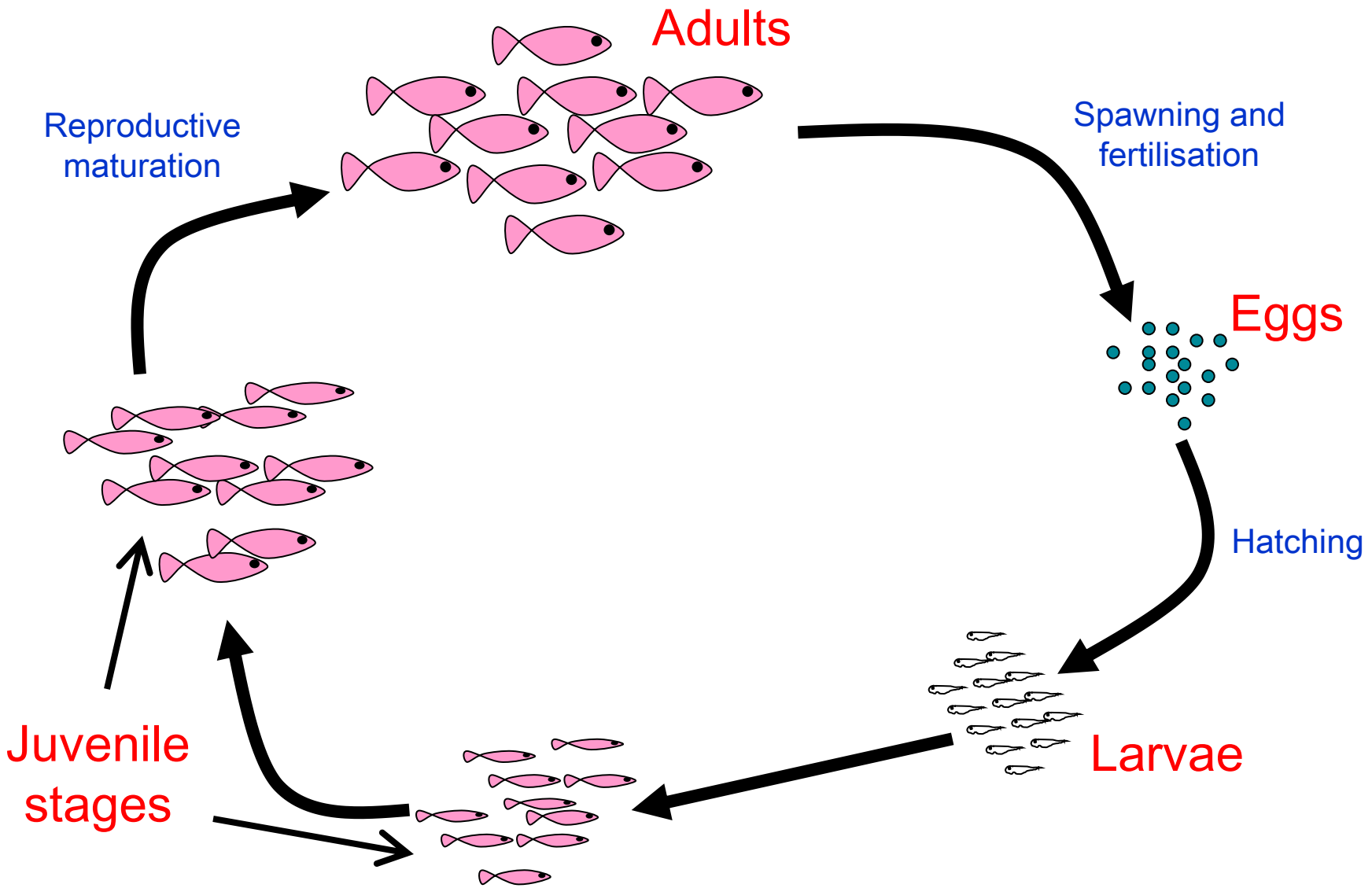

Quasi-extinction probability
0.0
0.1
0.2
0.3
0.4
0.5
Catherine
UpperGR
Lostine
Minam

Differences between marine and anadromous fisheries

Movement – Chinook vs Marine Species

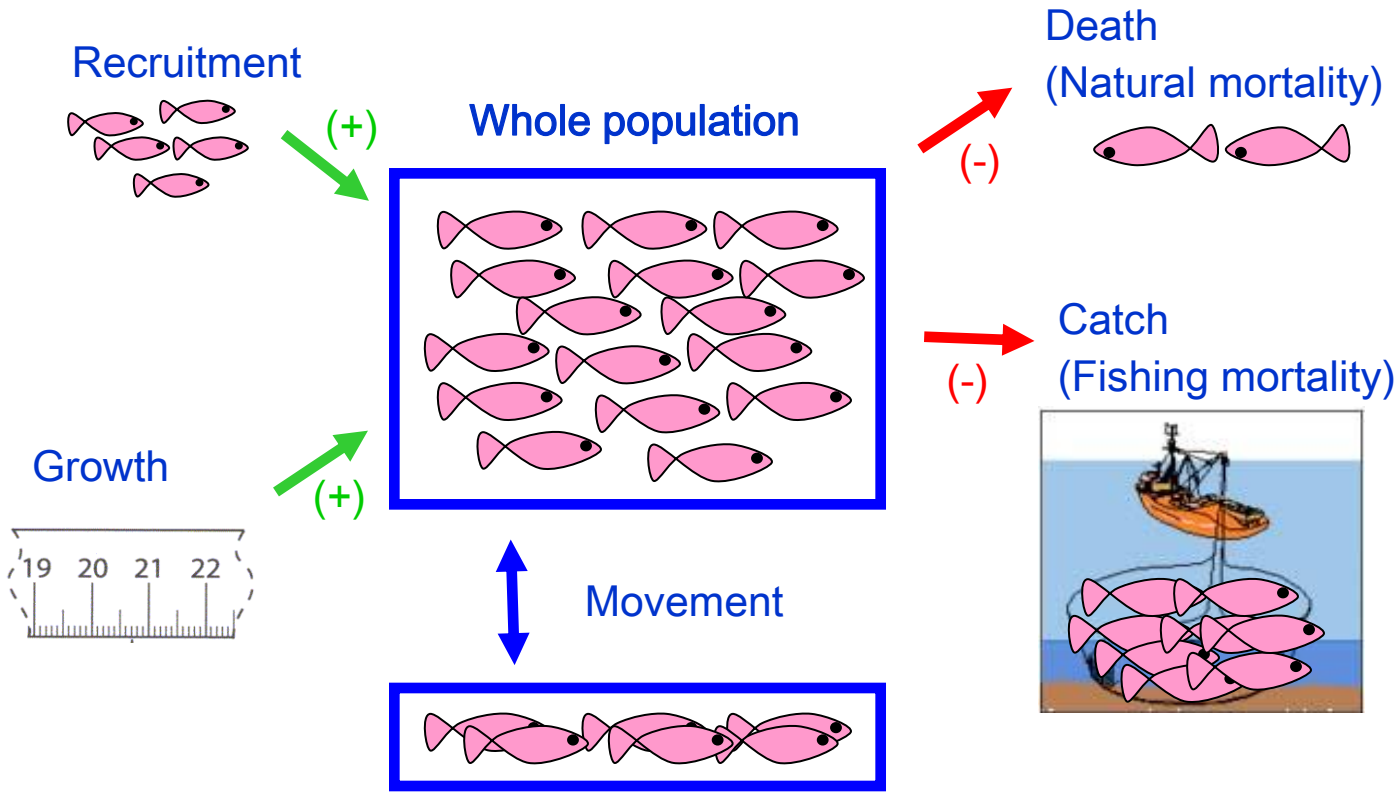


A generalised Marine fish life-cycle



Our conceptual model of a fish population

$$B_{t+1}=B_t+R+G-M-C$$

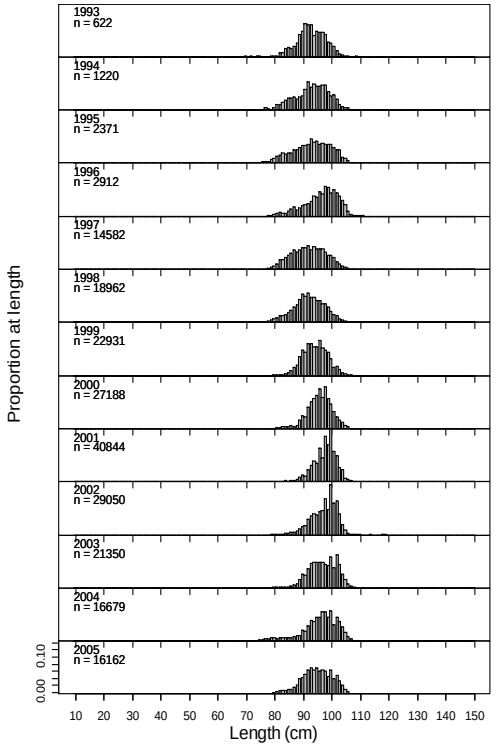


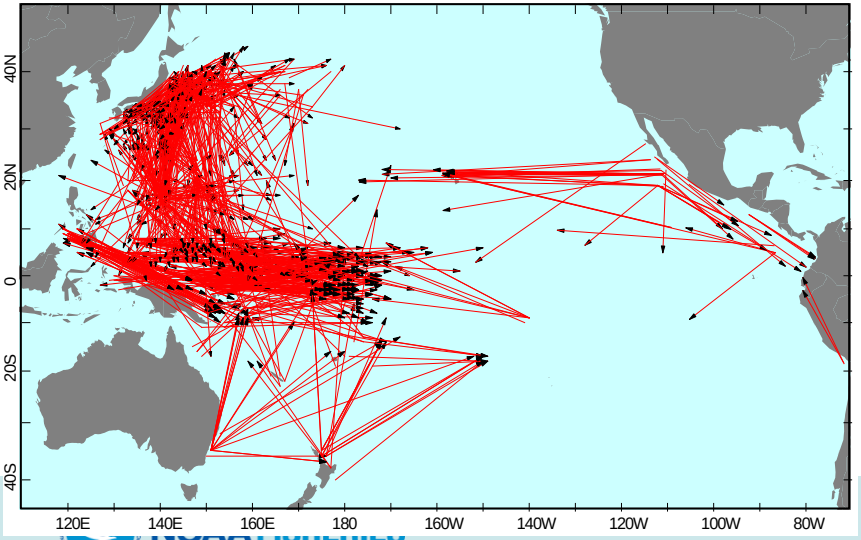
How is movement monitored?

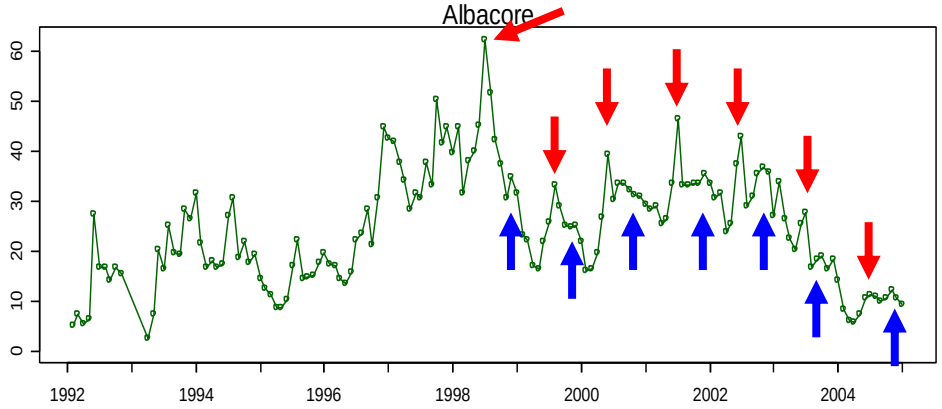
1. Size –frequency analyses

2. CPUE analyses

3. Tagging analyses







Comparisons

	Tropical Tunas/Marine Fish	Chinook Salmon
Reproductive mode	Broadcast spawning Area Sp? Dispersal?	Redds/Nests/Gravel
Fecundity	Millions of eggs AREA Specific (Var High)	1000's of eggs Area Specific (var low)
Growth rate	Fast/Area Specific	Relatively fast
Stage based Survival	Hypothesized (SCAL) Vary By area Non Est	Tags and detectors Estimable
Age to maturity	Depends by area 1-20+ yrs	3-5 years
Life span	4-12+ years	1-7 years
Movement	Multi-directional	Downstream, Northern, Southern, Upstream

What can we estimate regarding survival and movement in space?

Next steps

- Convert to Stan
- Add more populations
- Add complexity from Smolt to Adult (Lower River and Ocean)
- Add harvest, sealion predation and pre-spawning mortality.
- Project with restoration and climate change

Acknowledgements

- Casey Justice & Seth White, CRITFC
- Ted Seddell & Rich Carmichael, ODFW
- Damon Hauser, NOAA