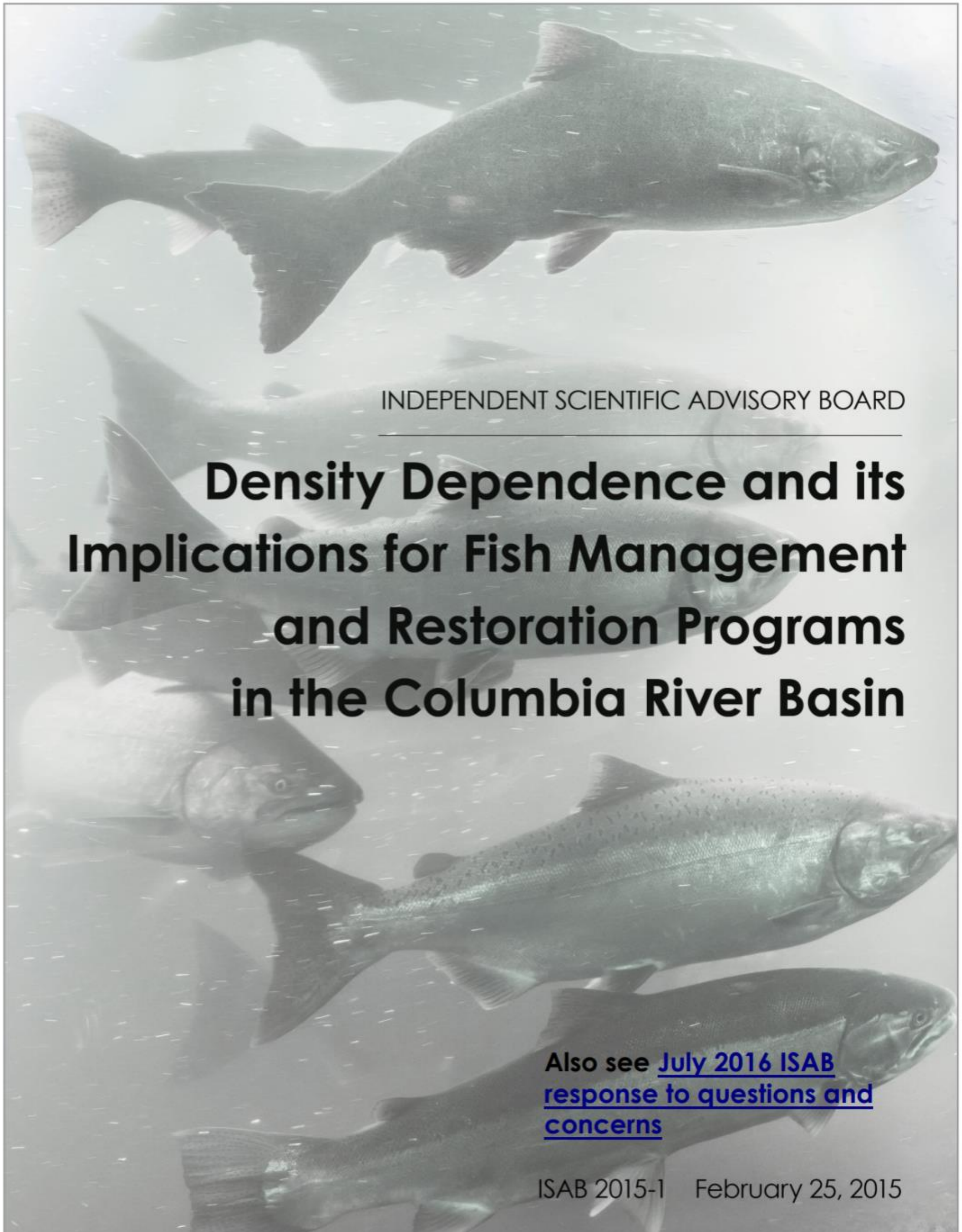
WATS 6900 – Ecohydraulics
WEEK 14: Life-cycle models (cont.)

UtahState University
DEPARTMENT OF WATERSHED SCIENCES

NICK BOUWES



INDEPENDENT SCIENTIFIC ADVISORY BOARD

Density Dependence and its Implications for Fish Management and Restoration Programs in the Columbia River Basin

Also see July 2016 ISAB response to questions and concerns

ISAB 2015-1   February 25, 2015

Density Dependence

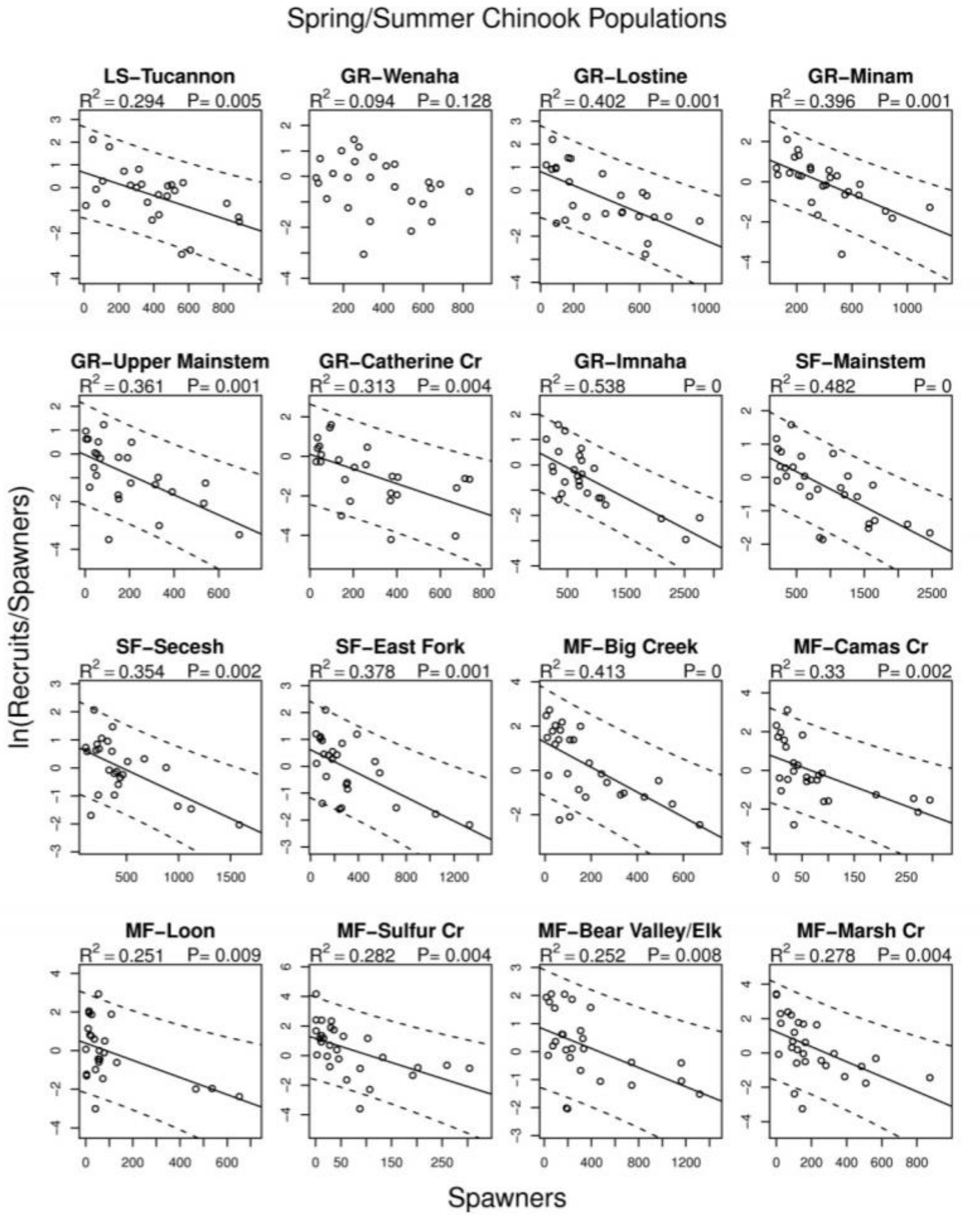
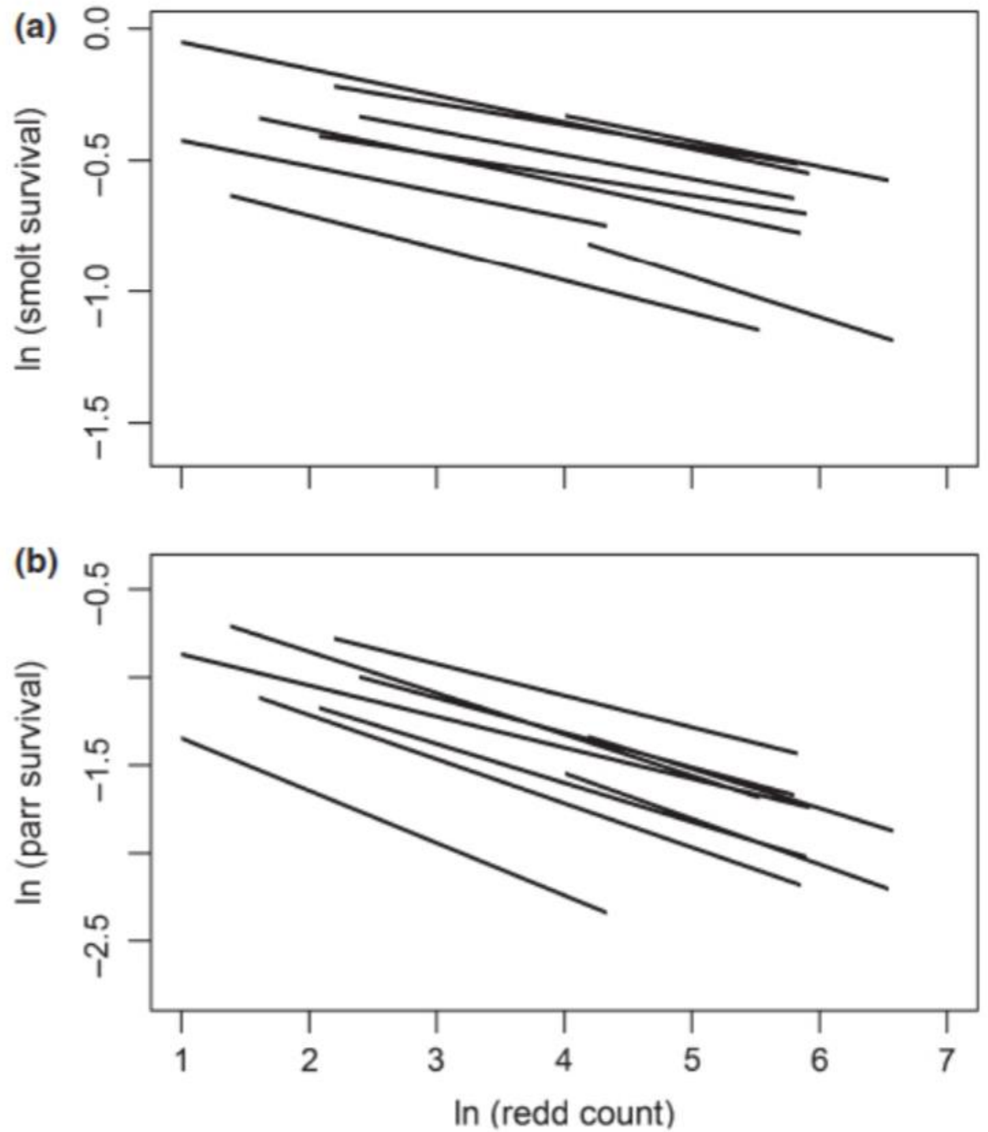


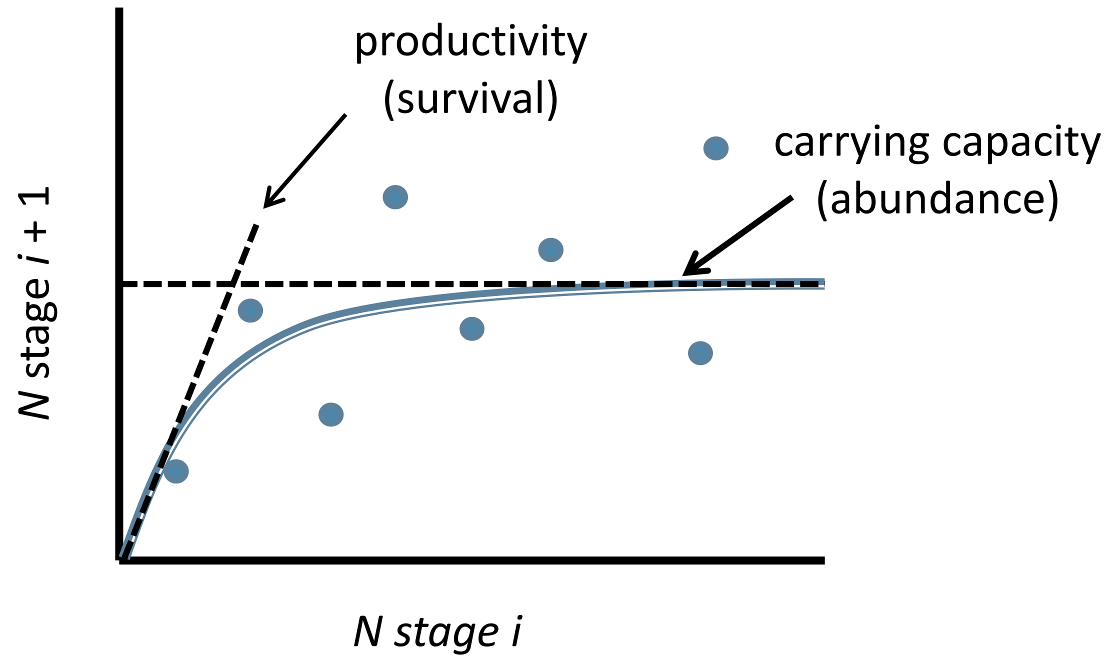
Figure V.1. Evidence for density dependence in 27 Interior Columbia River spring and summer Chinook populations, brood years 1980 to ~2005. Relationships based on the linearized form of the Ricker model. Recruitment includes ocean and in-river harvests. Dashed lines represent 95% prediction intervals for a specified number of spawners when regression was statistically significant ($P < 0.05$). Values less than log[R/S] < 0 indicate R/S is less than 1. LS = Lower Snake River, SF = South Fork Salmon River, MF = Middle Fork Salmon River, GR = Grande Ronde. Source: Zabel and Cooney (2013).

Density Dependence

Figure V.9. Population-specific predicted relationships between smolt survival (a) and parr survival (b) of spring/summer Chinook versus an index of parent spawners (redd counts). Survival is estimated from PIT tag data for the period from collection at the traps on the natal river to detection at the Lower Granite Dam (Snake River, Washington). A significant negative relationship ($P < 0.05$) is evident in all nine populations. The investigators suggest that the steeper slopes for parr reflect higher density dependent mortality during winter. More numerous spawners lead to reduced growth (Figure V.10) and lower survival. Source: Walters et al. (2013a).



Beverton-Holt Spawner-Recruit Model



$$N_{i+1} = \frac{N_i}{\frac{1}{prod.} + \frac{1}{capacity} N_i}$$

Relate this to freshwater habitat = smolts / spawner

Beverton-Holt as multistage life-cycle model

p_1 = survival from 0-1 yr

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Ecological Modelling 183 (2005) 231–250

ECOLOGICAL MODELLING

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ELSEVIER

A quantitative framework for the analysis of habitat and hatchery practices on Pacific salmon

Rishi Sharma[a,*], Andrew B. Cooper[b,1], Ray Hilborn[c]

$_{=1}p_i$

t-to-adult)

but still possible

$$C_n = \frac{P_n}{\sum_{i=1}^{n} {p_i}/{c_i}}$$

The Shiraz model: a tool for incorporating anthropogenic effects and fish–habitat relationships in conservation planning

Mark D. Scheuerell, Ray Hilborn, Mary H. Ruckelshaus, Krista K. Bartz, Kerry M. Lagueux, Andrew D. Haas, and Kit Rawson

Can. J. Fish Aquat. Sci. 63: 1596–1607 (2006) doi:10.1139/F06-056

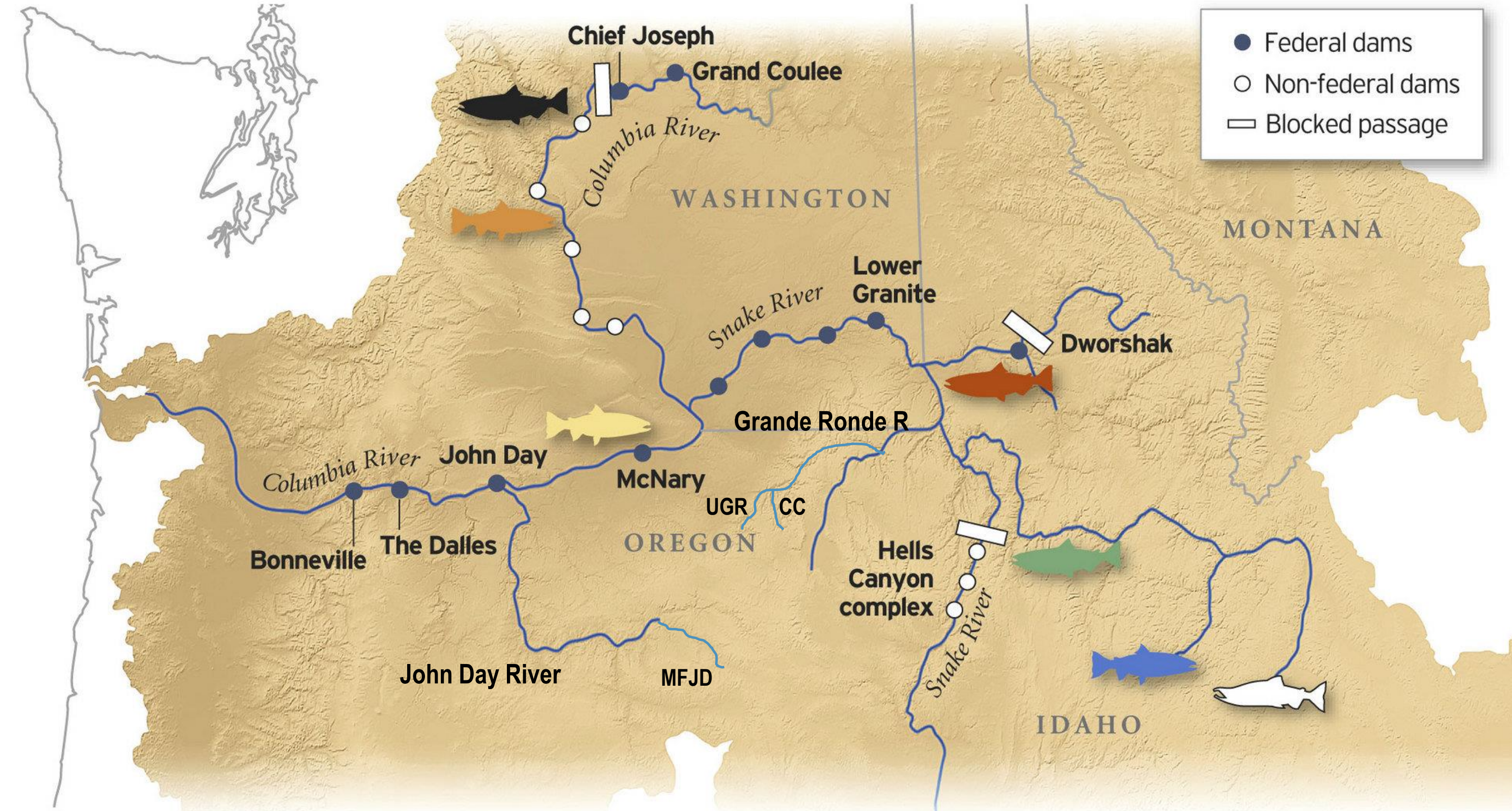
Optimal Stock Size and Harvest Rate in Multistage Life History Models

Elie Moussalli and Ray Hilborn[1]
Institute of Animal Resource Ecology, University of British Columbia, Vancouver, B.C. V6T 1W5

Moussalli, E., and R. Hilborn. 1986. Optimal stock size and harvest rate in multistage life history models. Can. J. Fish. Aquat. Sci. 43: 135–141.

Salmon status

The federal government's plan for dam operations on the Columbia and Snake rivers focuses on seven runs of wild fish listed under the Endangered Species Act that spawn above Bonneville Dam. Adult counts have risen since 2000, but averages of spawning fish reaching their home streams remain short of minimum goals for removing the runs from the endangered species list.

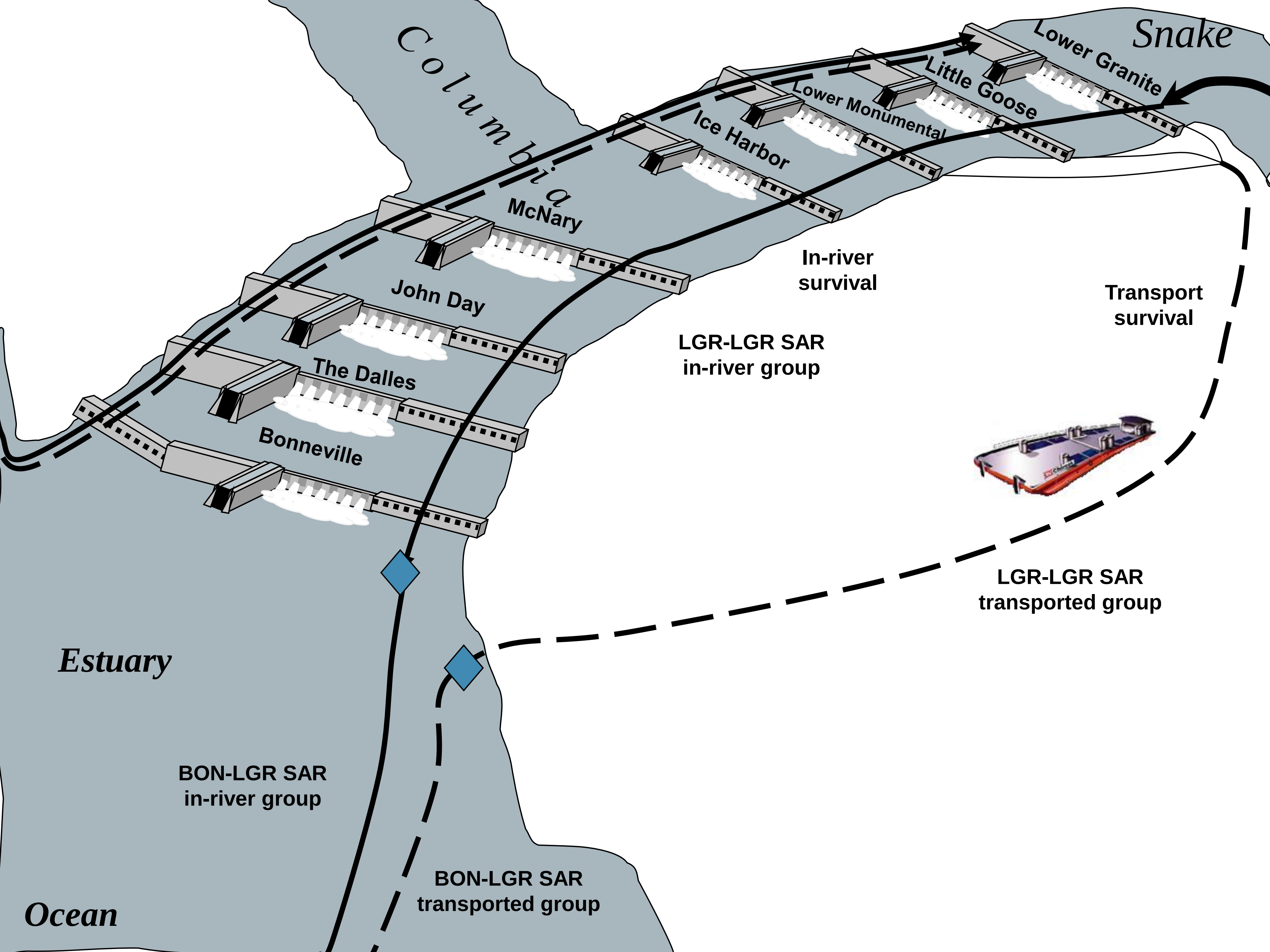


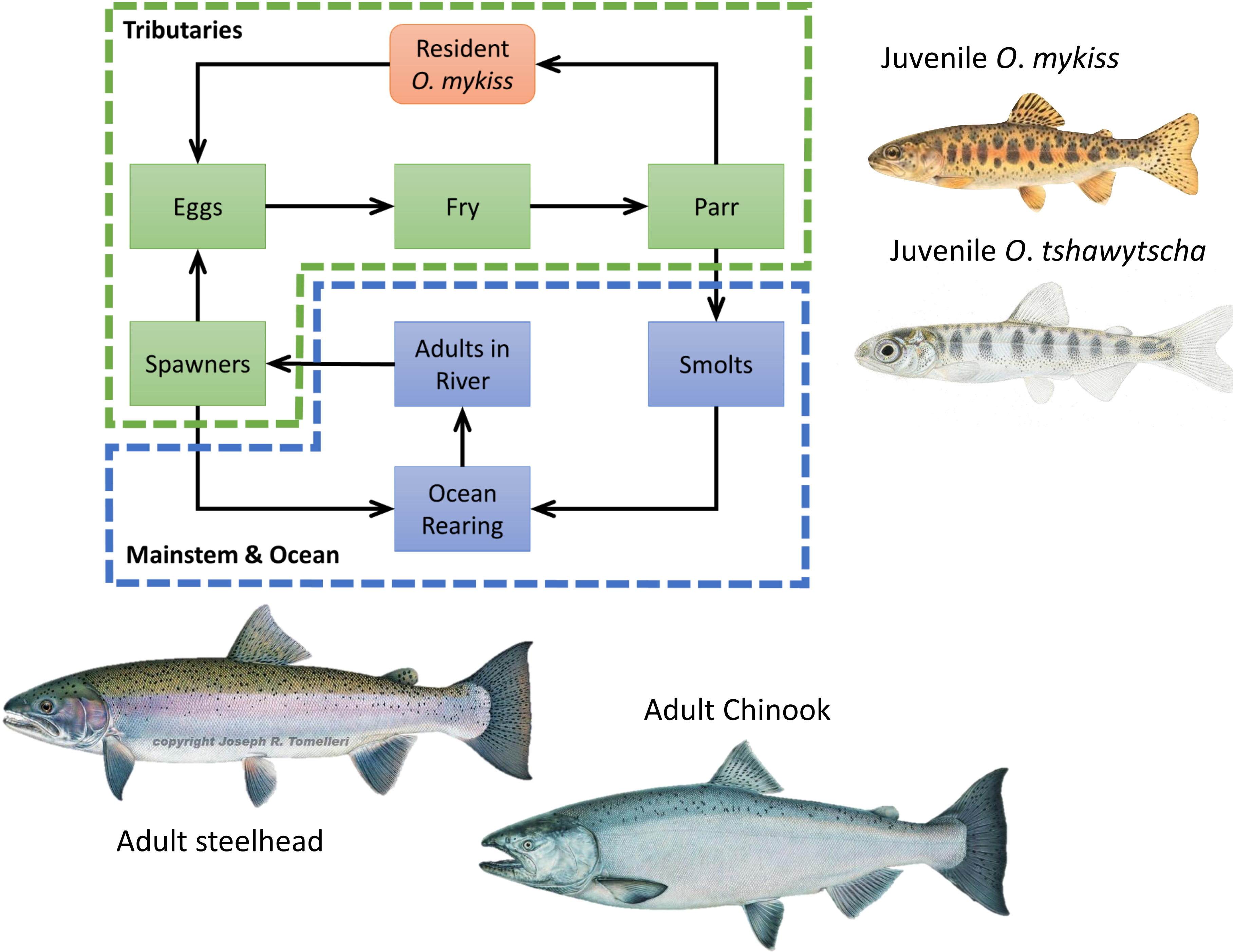
	Chinook salmon Snake River, fall	Chinook salmon Snake River, spring/summer	Chinook salmon Upper Columbia River, spring	Steelhead Upper Columbia River	Steelhead Snake River	Steelhead Mid-Columbia River	Sockeye salmon Snake River
10-year average, natural spawners	1,869	4,688	861	1,522	728	11,217	NA*
Percent of minimum recovery goal	62%	23%	19%	43%	36%	71%	NA*

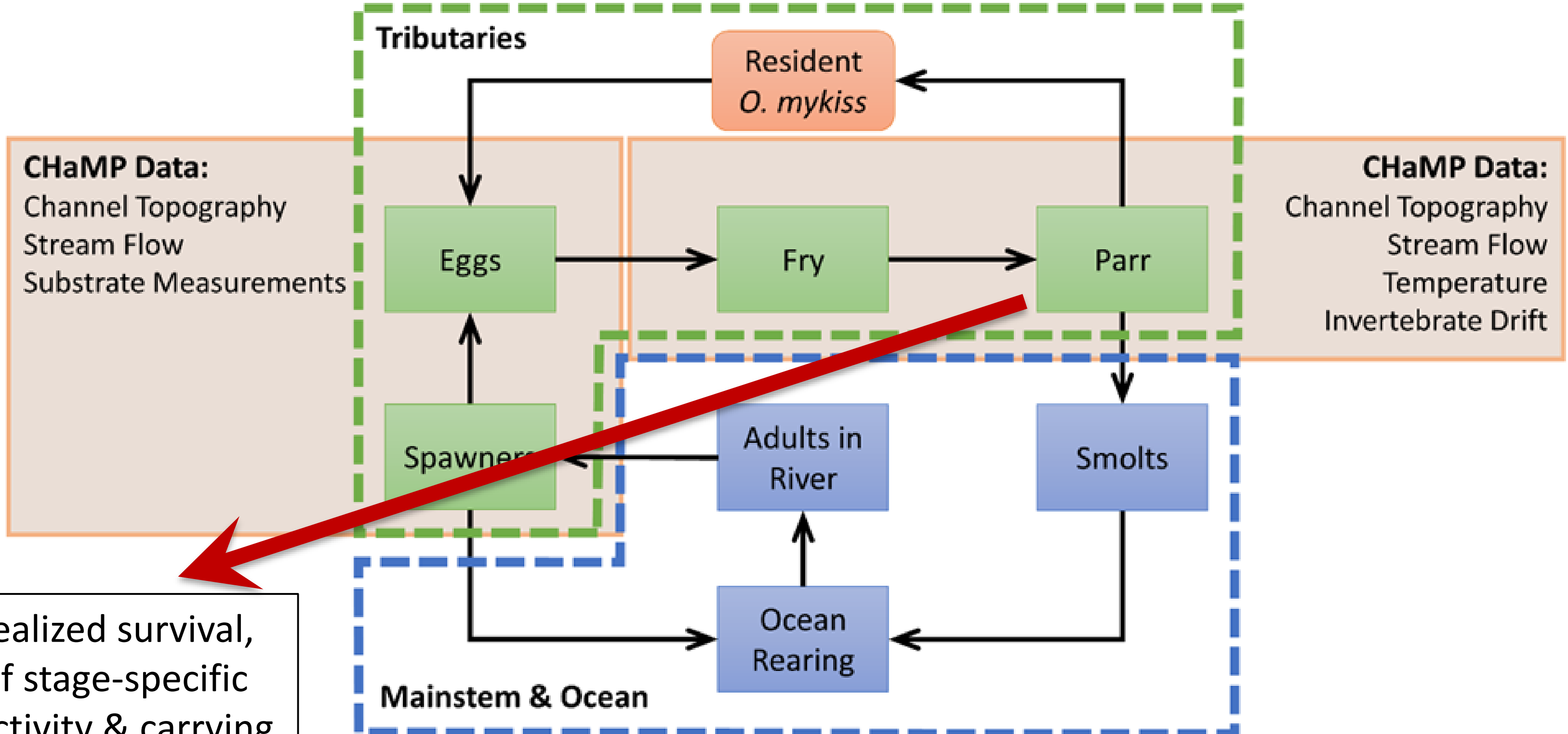
* Snake River sockeye are produced in a captive broodstock hatchery. Fishery managers say they have a high risk of going extinct.

DAVID BADDERS/THE OREGONIAN

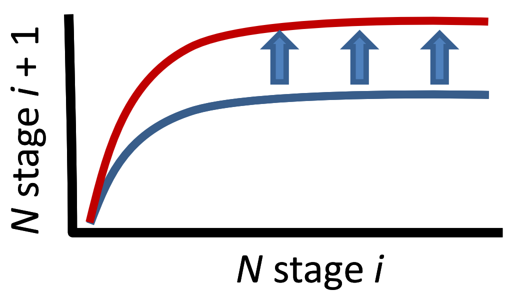
Source: National Oceanic and Atmospheric Administration.


Columbia
Snake
Lower Granite
Little Goose
Lower Monumental
Ice Harbor
McNary
John Day
The Dalles
Bonneville
In-river
survival
Transport
survival
LGR-LGR SAR
in-river group
LGR-LGR SAR
transported group
Estuary
BON-LGR SAR
in-river group
BON-LGR SAR
transported group
Ocean


Tributaries
Resident O. mykiss
Eggs
Fry
Parr
Spawners
Adults in River
Smolts
Ocean Rearing
Mainstem & Ocean
Juvenile O. mykiss
Juvenile O. tshawytscha
copyright Joseph R. Tomelleri
Adult steelhead
Adult Chinook



S_i = realized survival, fxn of stage-specific productivity & carrying capacity parameters (Beverton-Holt form)



$$N_{i+1} = \frac{N_i}{\frac{1}{prod.} + \frac{1}{capacity} N_i}$$

Grande Ronde Chinook

Weber et al. 2018

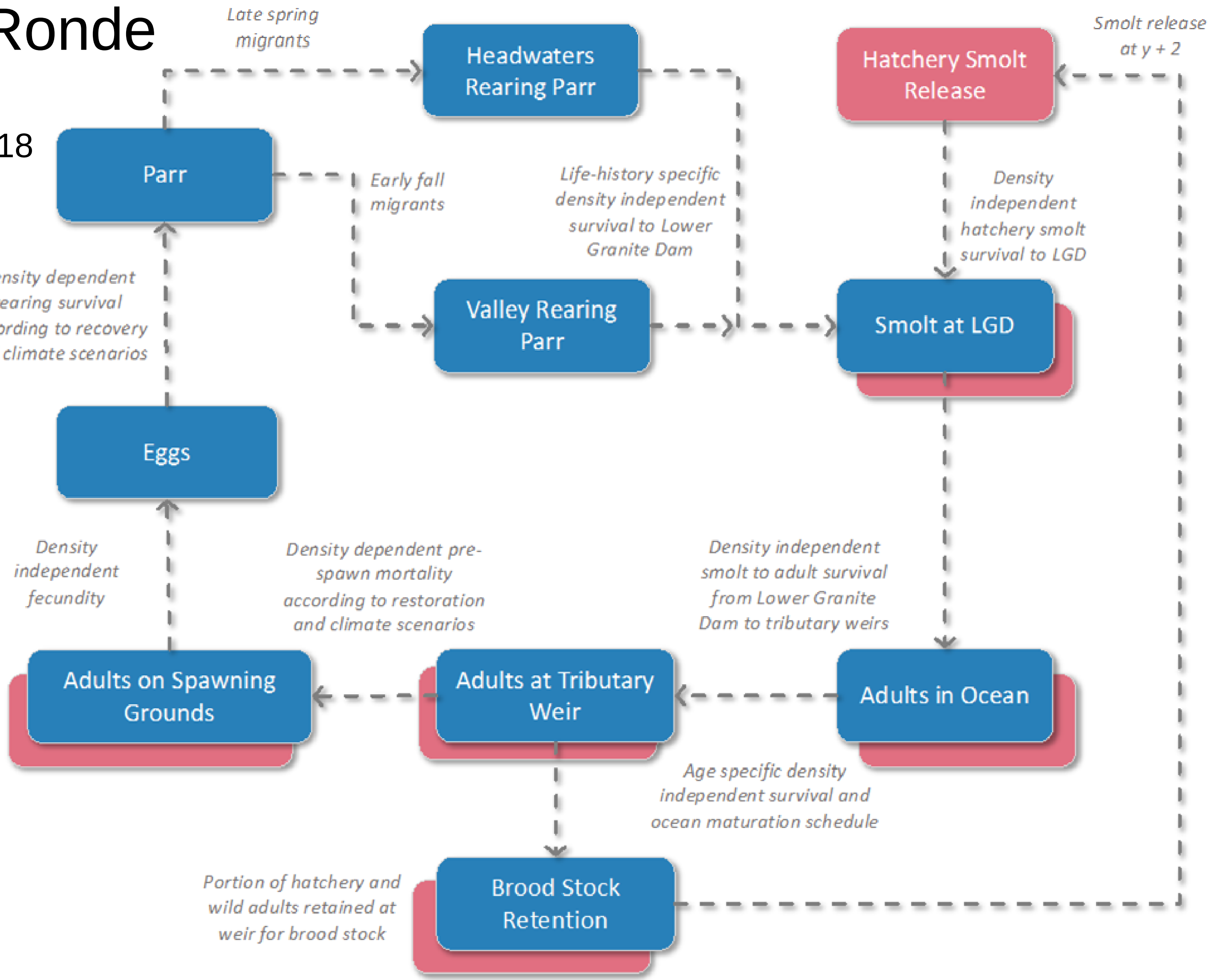
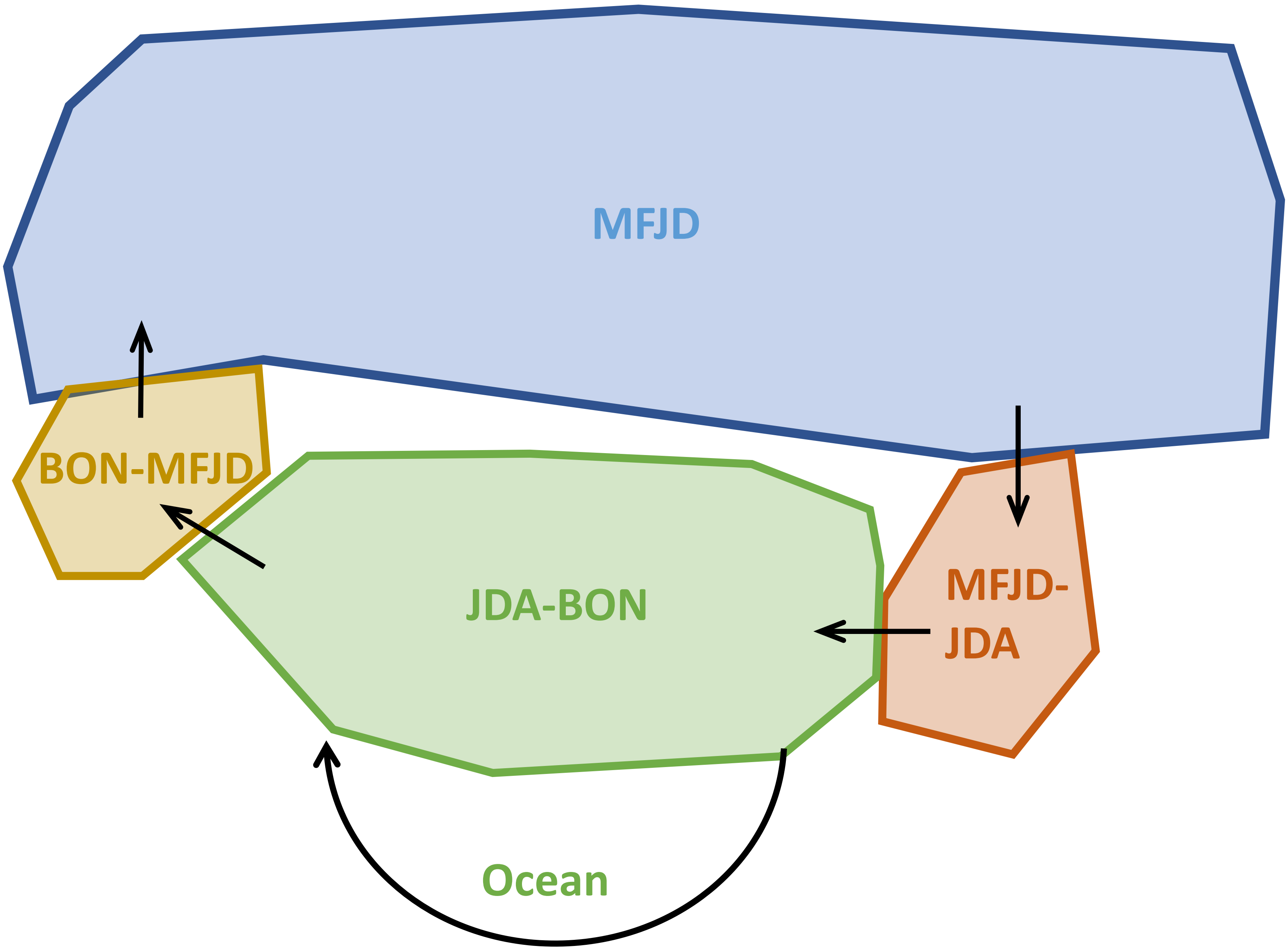
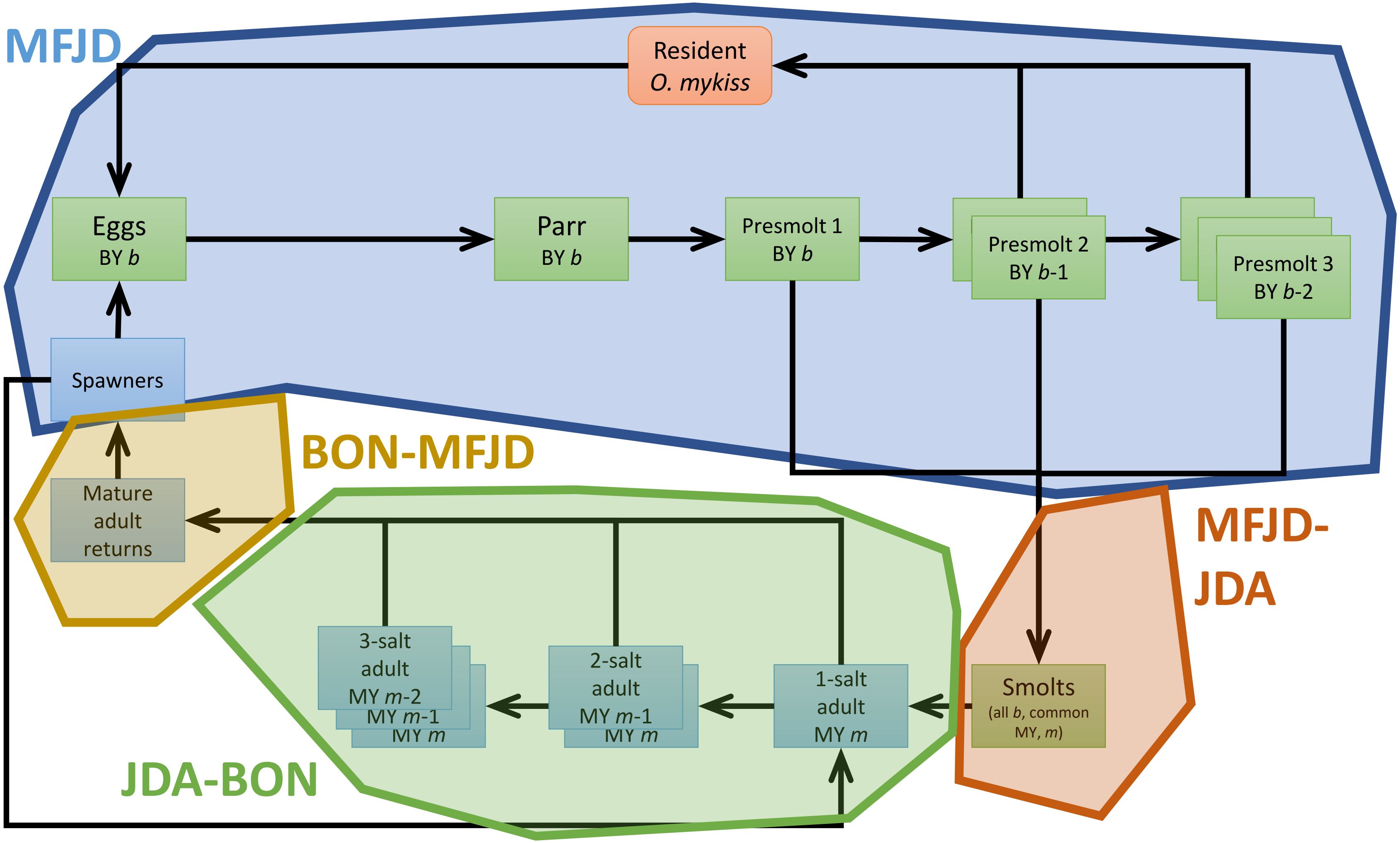


FIGURE 2. CONCEPTUAL DIAGRAM OF THE LIFE CYCLE MODEL (LCM) STRUCTURE. STACKED BOXES REPRESENT STAGES IN WHICH THE MODEL TRACKS NATURAL AND HATCHERY ORIGIN CHINOOK. ALL NATURALLY SPAWNED CHINOOK ARE CONSIDERED OF NATURAL ORIGIN.

JD *O. mykiss* life cycle and model structure



JD *O. mykiss* life cycle and model structure



Middle Fork John Day *O. mykiss* life cycle and model structure

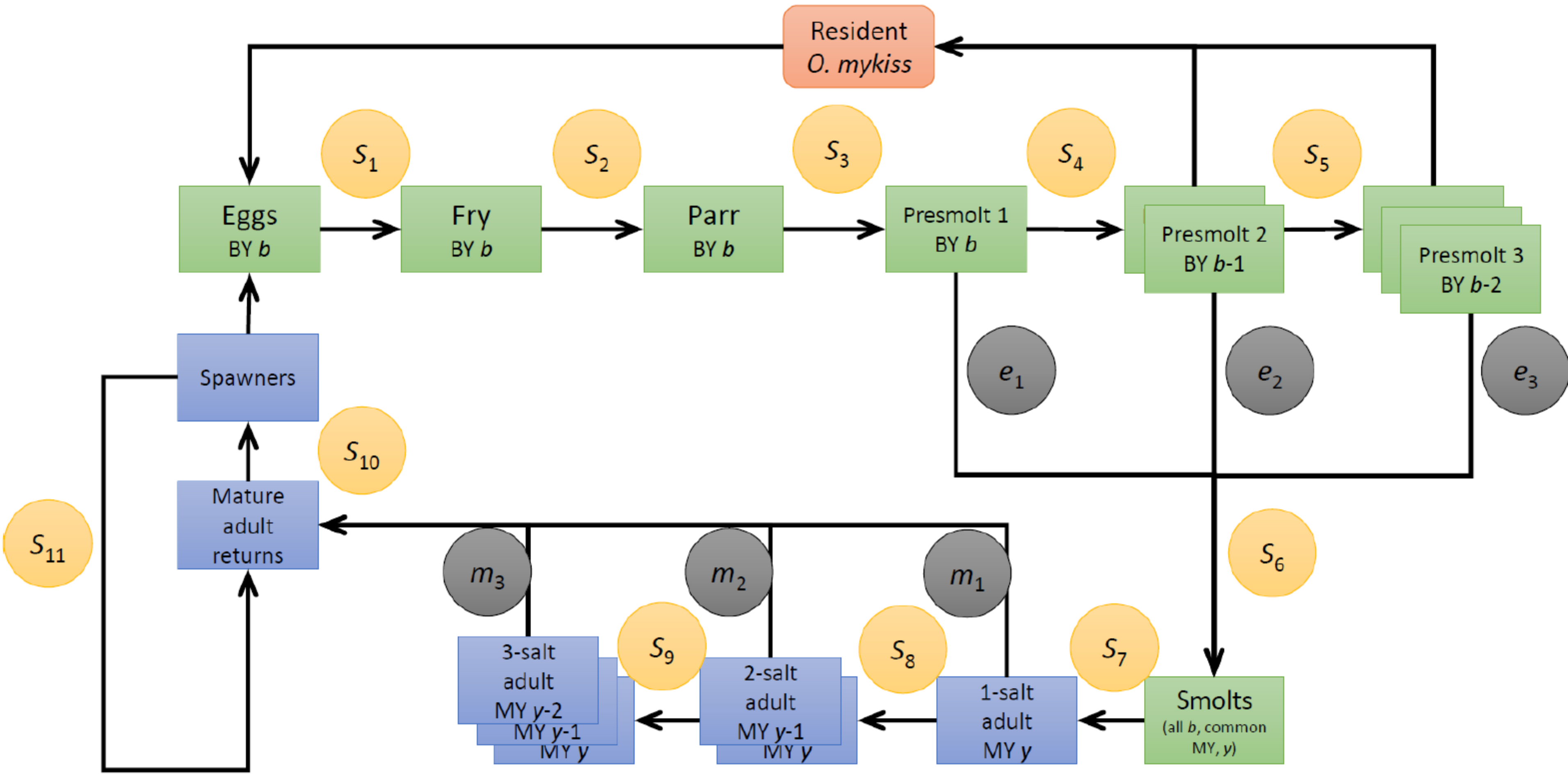


Figure A1. Diagrammatic representation of the Middle Fork John Day steelhead life cycle model. Parameter symbols correspond to definitions specified in Table A1.

From: McHugh et al. 2017

Mousalli & Hilborn 1986, Sharma et al. 2005, Scheuerell et al. 2006

Life-cycle survival

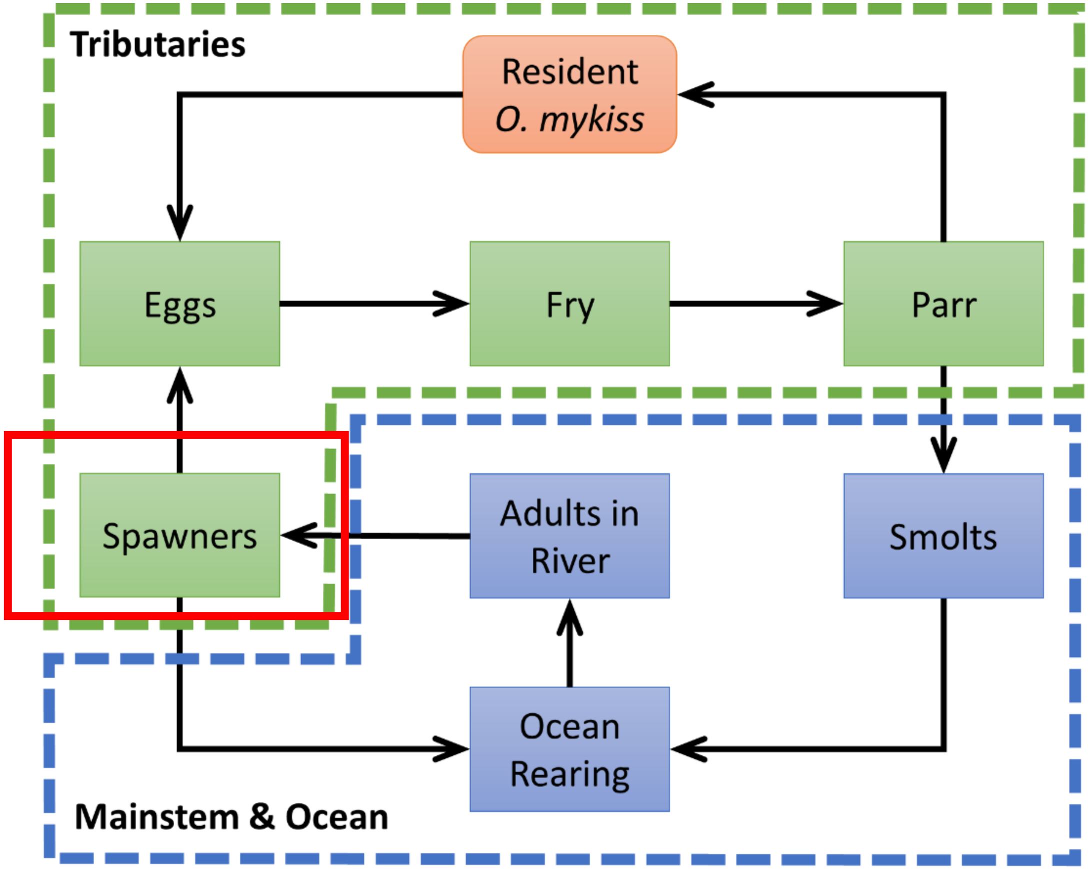
Spawner to Spawner (Recruits) = overall life-cycle survival (S_{lc})

- by cohort (brood year)
- arrival to basin (escapement)
- need to account for upstream mortality (harvest)

$$S_{lc} = SAR * S_{egg:smolt}$$

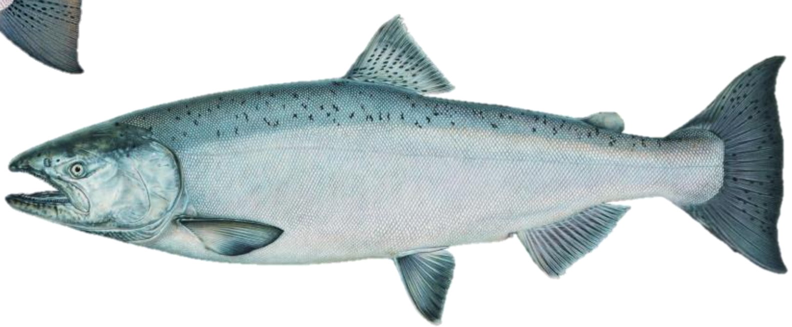
Mainstem, estuary, ocean *tributary*

Model parameterization: Where does the data come from?

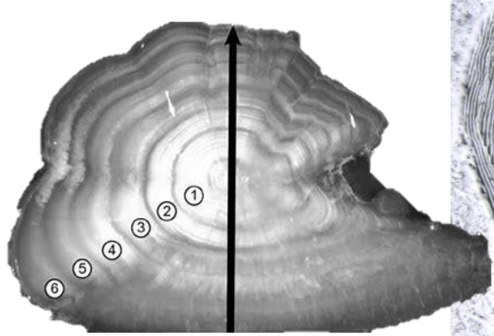


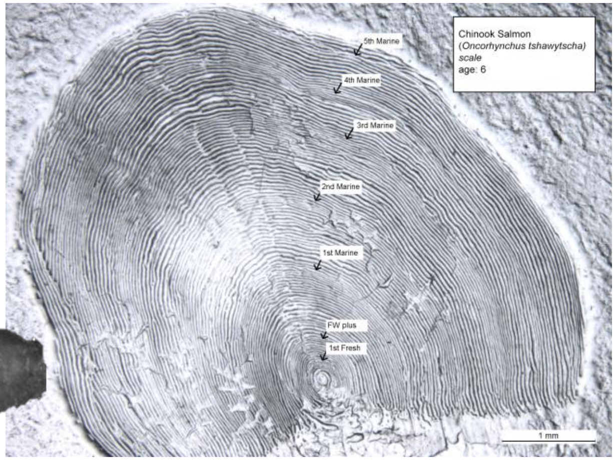
Adult steelhead

Adult Chinook



Redd Counts
Carcass Survey





Weir Counts

Adult expansion

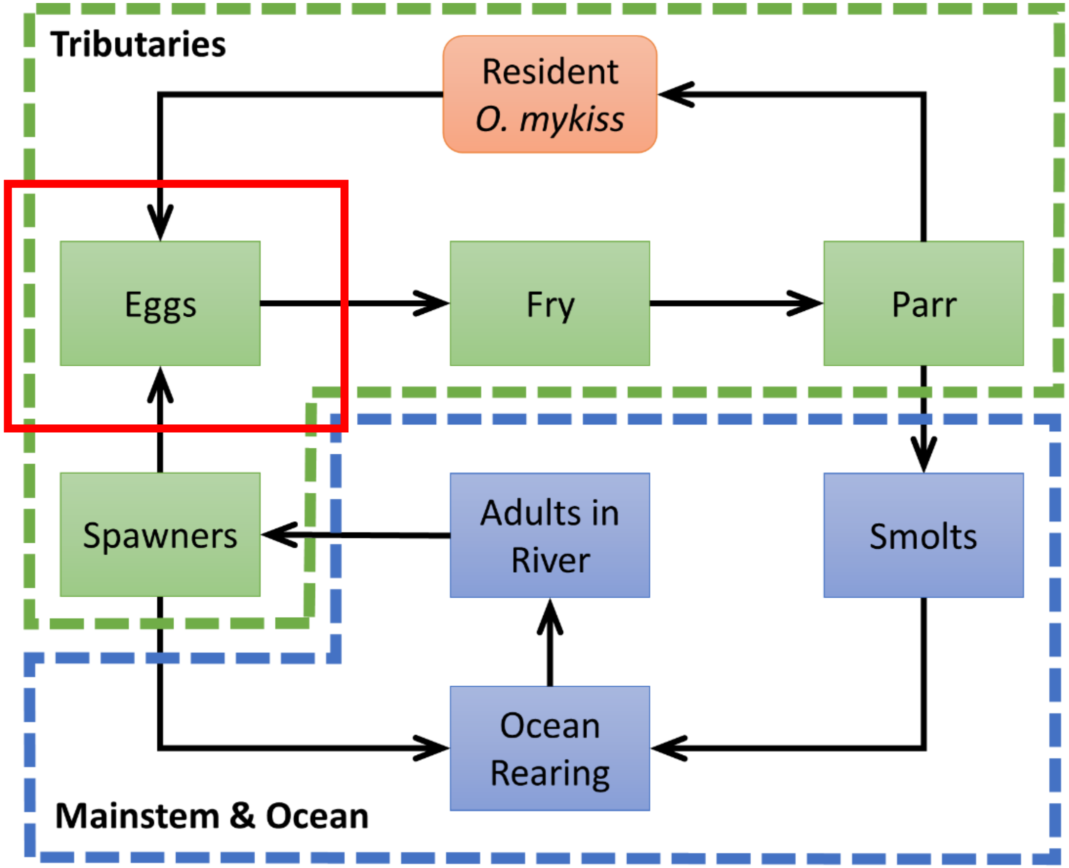
(tag @ LGR → detect at trib)

Grande Ronde Chinook spawners

Weber et al. 2018

TABLE 9. UNPUBLISHED ESTIMATES FROM ODFW OF ADULT CHINOOK ON THE SPAWNING GROUNDS AND NUMBER OF SPAWNERS IN LATE SUMMER USED TO DEVELOP BASE CASE PARAMETERS FOR THE LCM.

Catherine Creek				Upper Grande Ronde			
Brood year	Spawning grounds	Spawners	Survival	Brood year	Spawning grounds	Spawners	Survival
1987	699	684	0.98	1987	804	707	0.88
1988	727	691	0.95	1988	554	554	1.00
1997	82	72	0.88	1989	3	3	1.00
1998	101	91	0.90	1992	443	394	0.89
1999	88	81	0.92	1998	88	84	0.95
2000	61	54	0.89	2003	185	165	0.89
2001	556	513	0.92	2004	634	586	0.92
2002	462	432	0.94	2009	555	127	0.23
2003	487	424	0.87	2010	2339	2094	0.90
2004	216	216	1.00	2011	1559	1359	0.87
2005	152	146	0.96	2012	718	392	0.55
2006	283	253	0.89	2013	1084	395	0.36
2007	174	174	1.00	2014	1918	1388	0.72
2008	219	219	1.00	2015	1841	1144	0.62
2009	293	281	0.96	2016	239	151	0.63
2010	999	973	0.97	2017	155	99	0.64
2011	1725	1657	0.96				
2012	716	667	0.93				
2013	514	489	0.95				
2014	1101	1059	0.96				
2015	522	514	0.98				
2016	420	364	0.87				
2017	139	139	1.00				

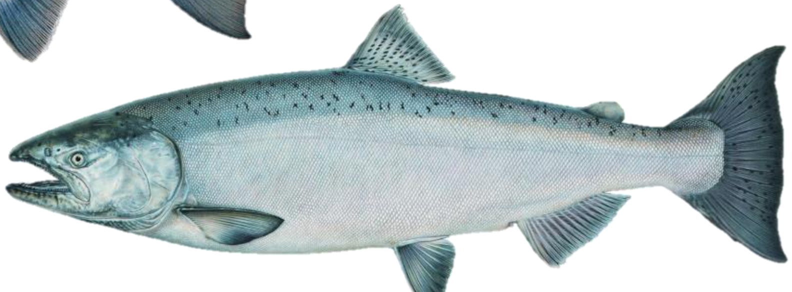


Model parameterization: Where does the data come from?

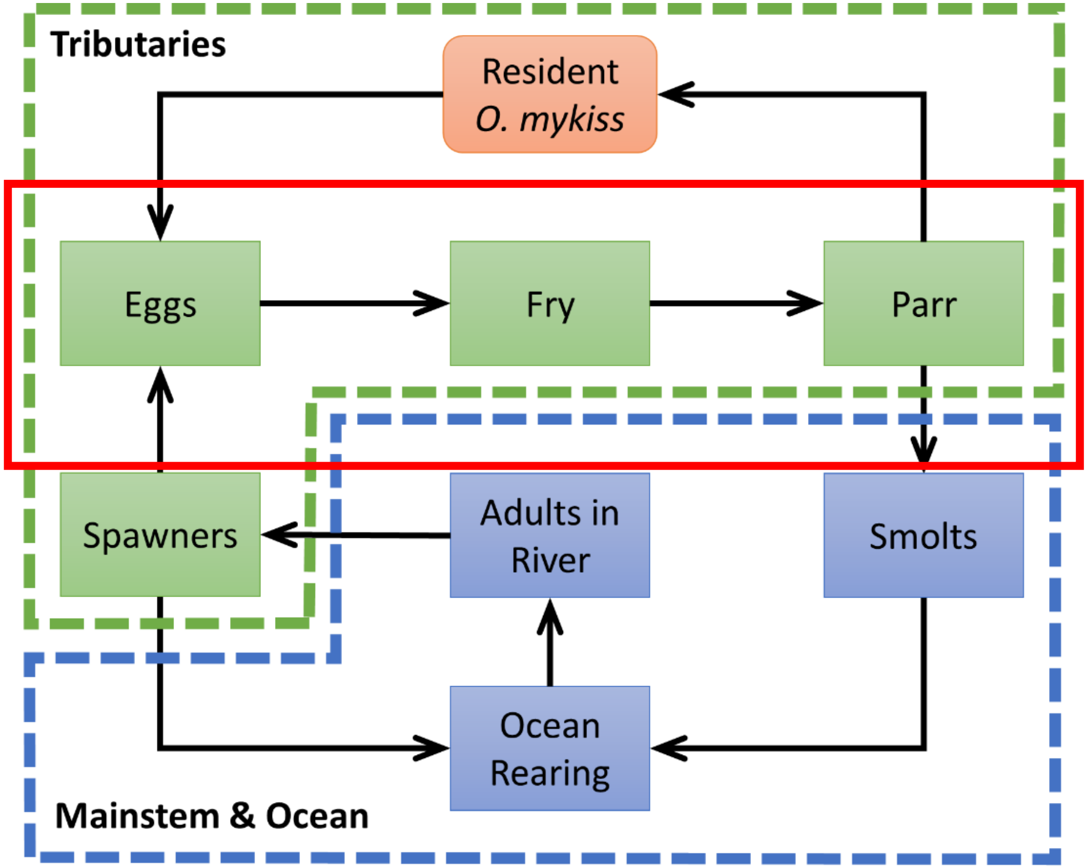
Year	Fecundity (eggs per. female)
1997	3782
1998	4066
1999	3742
2000	3872
2001	3801
2002	3754
2003	3868
2004	3742
2005	3852

Adult steelhead

Adult Chinook



Model parameterization: Where does the data come from?



Abundance

Lincoln-Peterson

$$\frac{M}{N} = \frac{R}{C}$$

$$N = \frac{MC}{R}$$

where

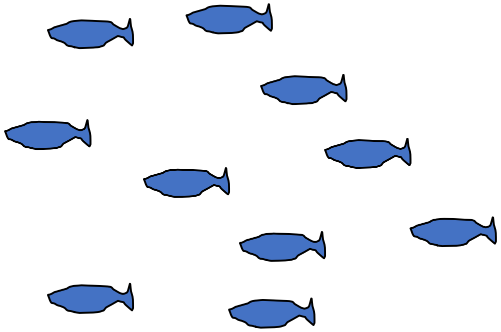
- N = Estimate of total population size
- M = Total number of animals captured and marked on the first visit
- C = Total number of animals captured on the second visit
- R = Number of animals captured on the first visit that were then recaptured on the second visit

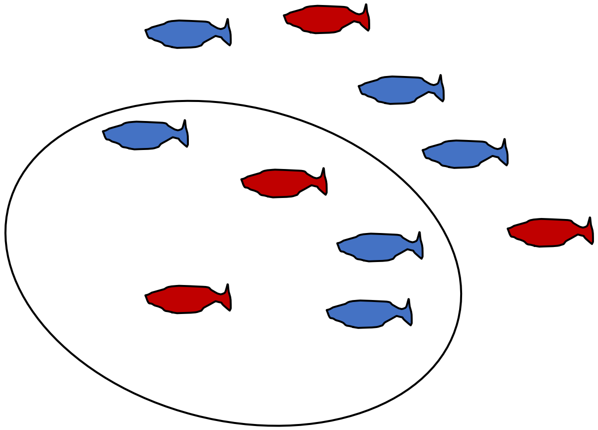
Lincoln-Peterson

$$\frac{4}{N} = \frac{2}{5}$$

$$N = \frac{4 * 5}{2}$$

N=10





Cormack-Jolly-Seber

- ϕ= apparent survival probability (includes emigration and immigration)
- *p* = capture probability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DOI: 10.1080/00028487.2014.963254

ARTICLE

Comparison of Tributary Survival Estimates of Steelhead using Cormack–Jolly–Seber and Barker Models: Implications for Sampling Efforts and Designs

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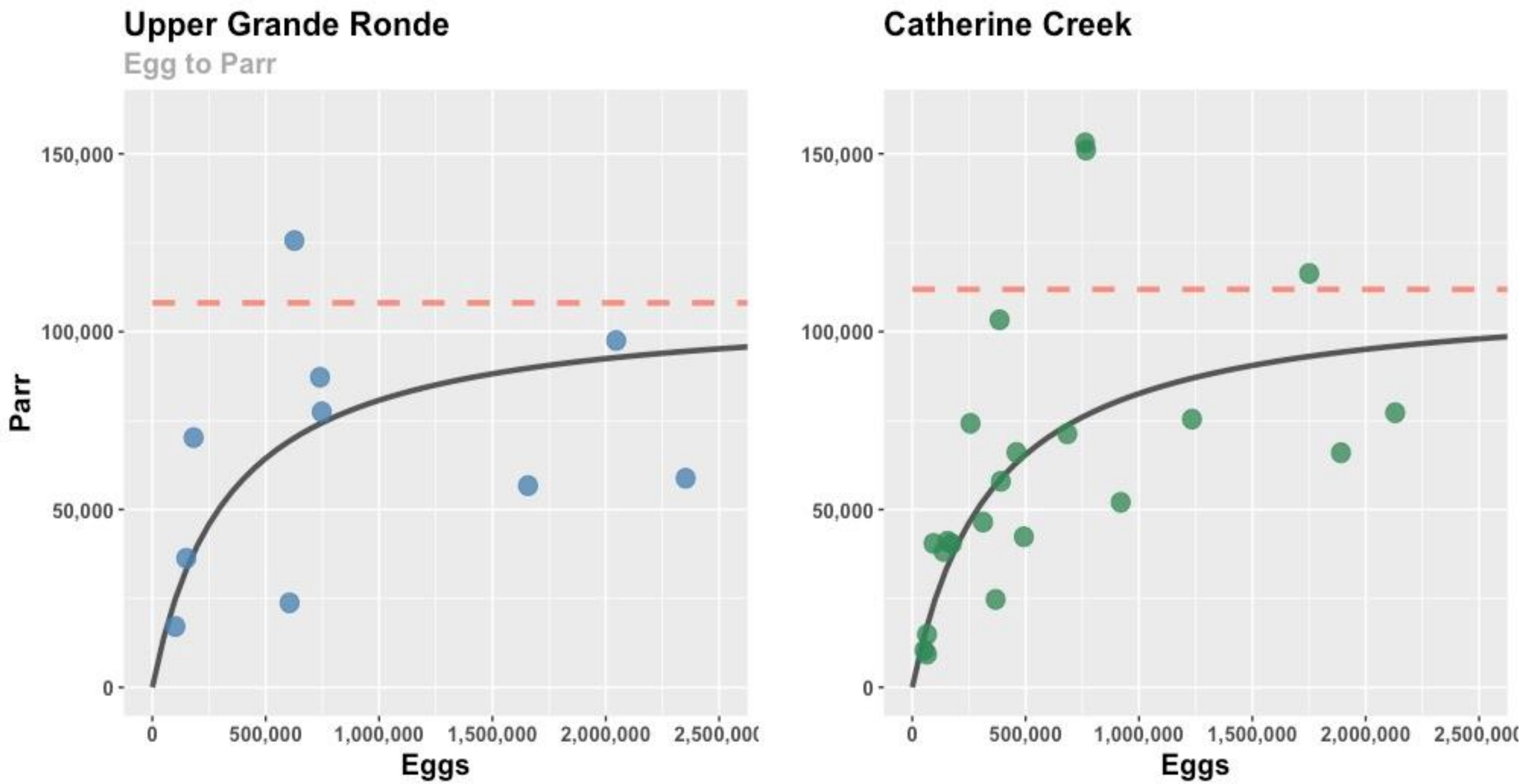
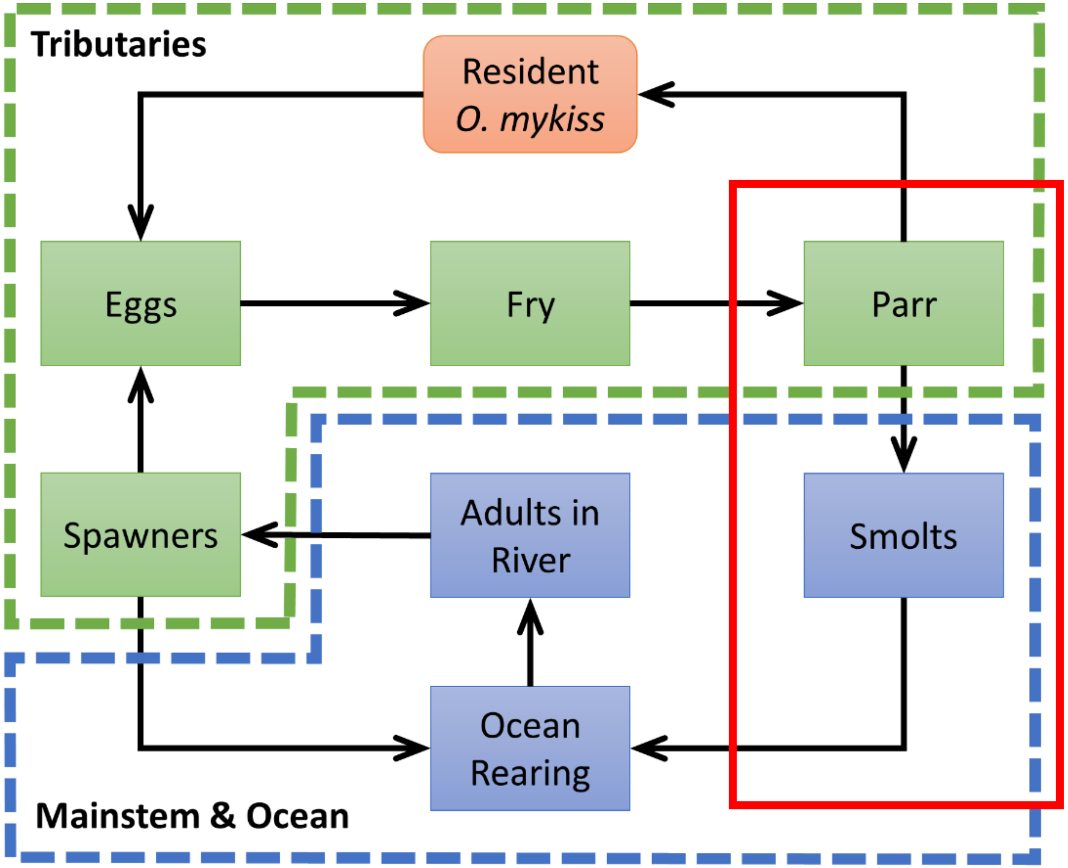
Barker Model

- ***S*** = survival probability
- *p* = capture probability
- *r* = the probability found dead and the tag reported (assume 0)
- *R* = the probability of being resighted (alive) between capture events
- *R*′ = the probability that the fish dies, is not found dead but was resighted alive between capture events before it died.
- F_i = site fidelity
- F'_i = immigration rate

Beverton-Holt for egg-to-parr



Model parameterization: Where does the data come from?



PIT tag

Mark-recapture

Life-cycle survival

Spawner to Spawner (Recruits) = overall life-cycle survival (S_{lc})

- by cohort (brood year)
- arrival to basin (escapement)
- need to account for upstream mortality (harvest)

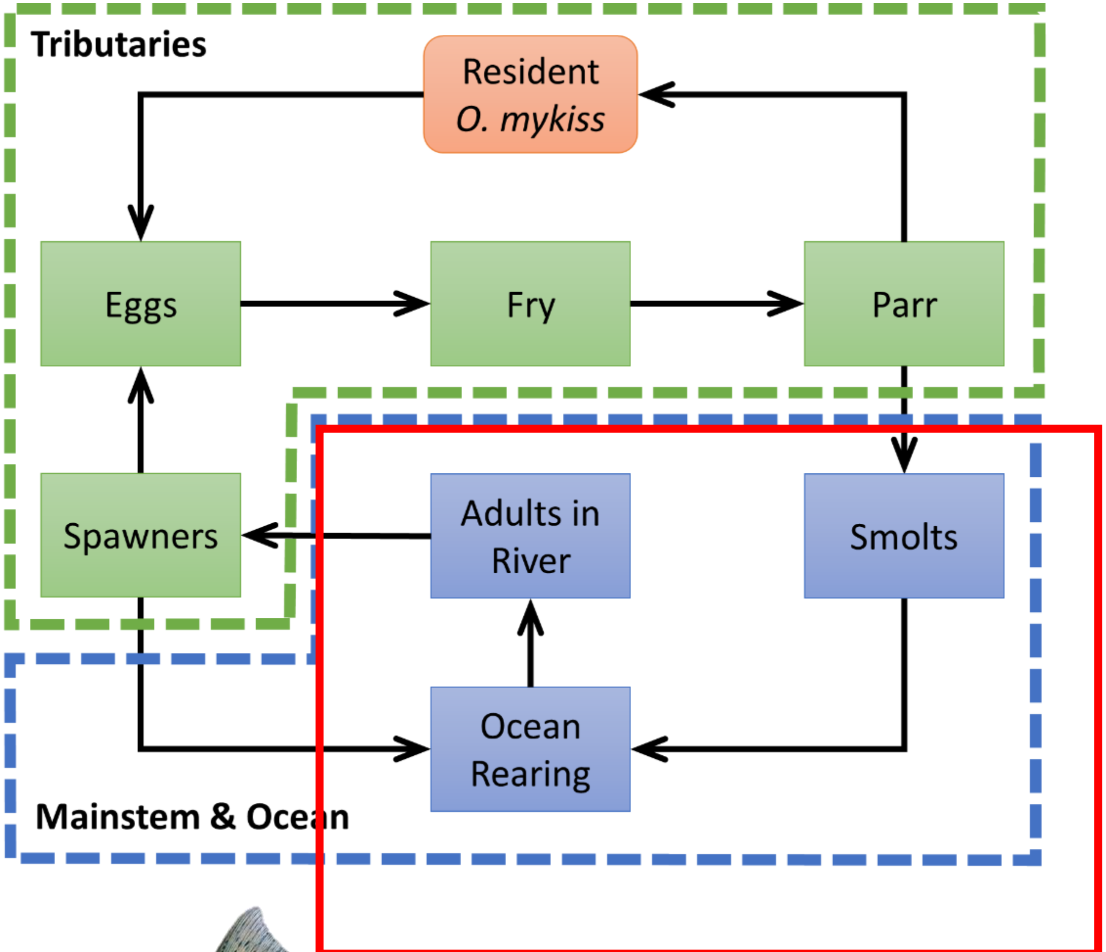
$$S_{lc} \quad = \quad SAR \quad * \quad S_{egg:smolt}$$

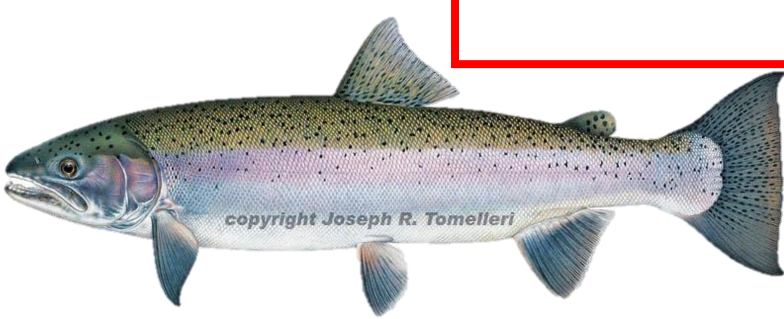
Mainstem, estuary, ocean *tributary*

eggs=Spawners*Fecundity to smolt

fish-in to fish-out

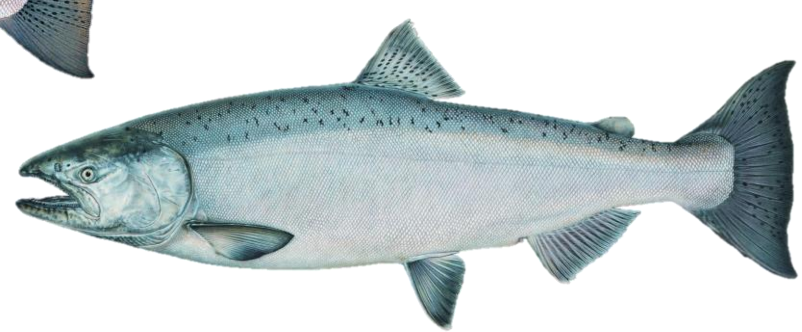
Model parameterization: Where does the data come from?

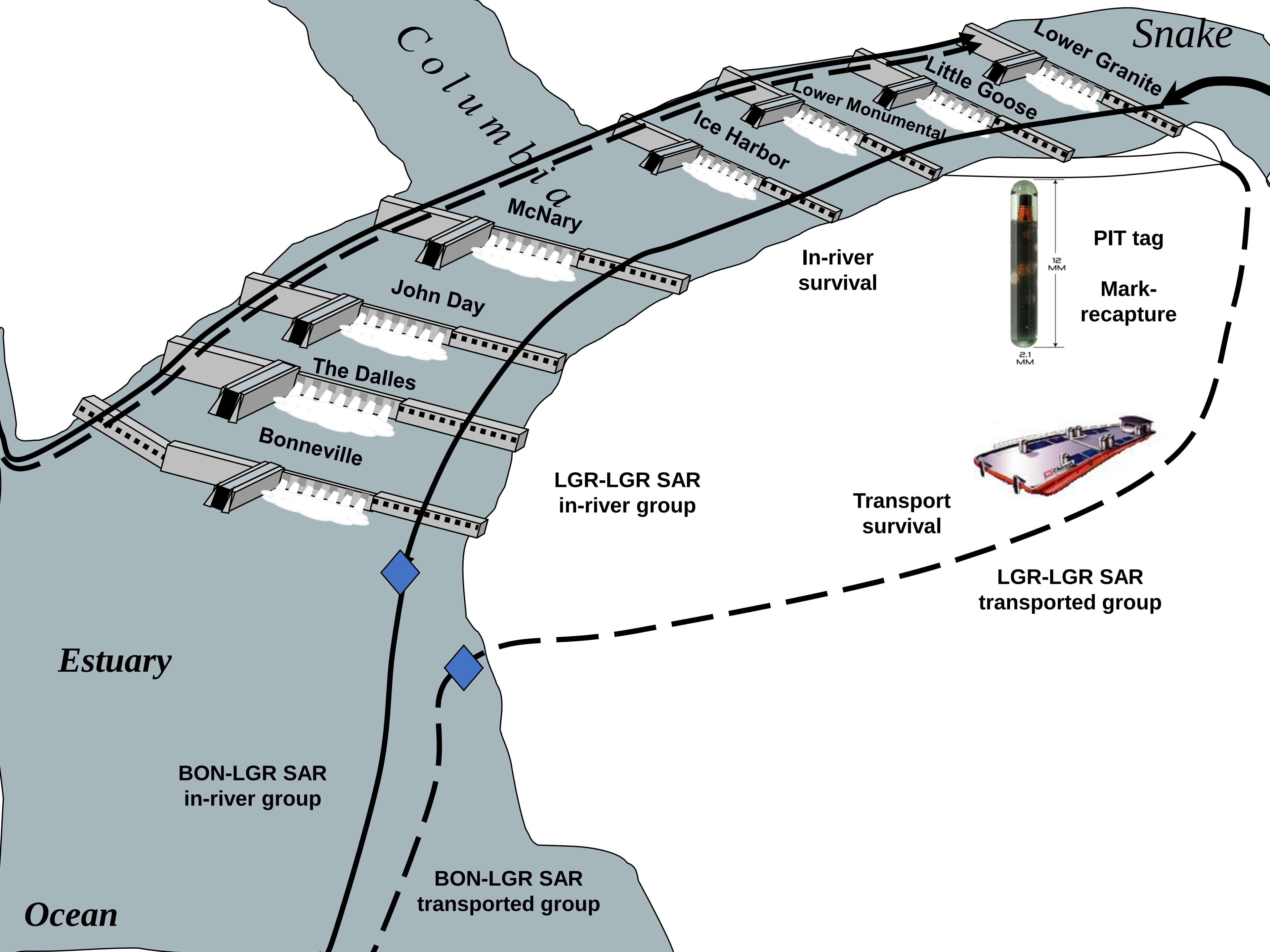




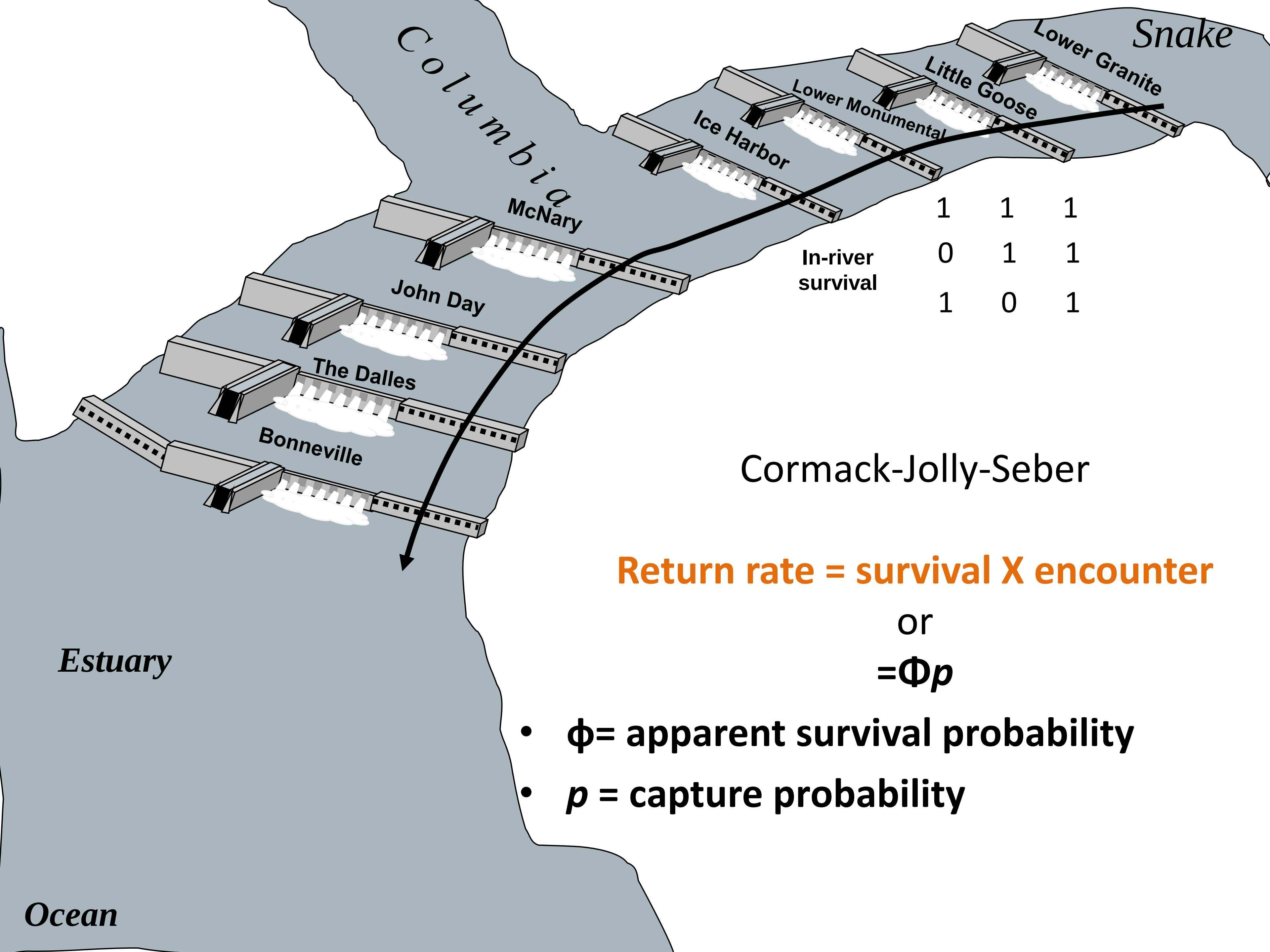
Adult steelhead

Adult Chinook





Columbia
Snake
Lower Granite
Little Goose
Lower Monumental
Ice Harbor
McNary
John Day
The Dalles
Bonneville
PIT tag
12 MM
2.1 MM
Mark-recapture
In-river survival
Transport survival
LGR-LGR SAR in-river group
LGR-LGR SAR transported group
Estuary
Ocean
BON-LGR SAR in-river group
BON-LGR SAR transported group



Cormack-Jolly-Seber

Return rate = survival X encounter

or

=Φ*p*

- **ϕ= apparent survival probability**
- ***p* = capture probability**

Grande Ronde Chinook SARs

Weber et al. 2018

TABLE 6. NATURAL ORIGIN SARS BASED ON ESTIMATES OF SMOLT AT LGD AND ADULT RETURNS TO THE SPAWNING GROUNDS ON EACH SYSTEM. ANNUAL RETURNING AGE STRUCTURE WAS OBTAINED VIA NOAAS SALMON POPULATION SUMMARY (SPS) DATABASE SYSTEM.

	Catherine Creek						Upper Grande Ronde					
				Return age structure						Return age structure		
Brood year	SAR	Smolt at LGD	Adults at weir	Age-3	Age-4	Age-5	SAR	Smolt at LGD	Adults at weir	Age-3	Age-4	Age-5
1992							0.008	11155	92	0%	91%	9%
1993	0.025	6519	163	7%	7%	85%	0.006	21732	127	0%	7%	93%
1994	0.007	2891	21	0%	39%	61%						
1995	0.058	1641	96	11%	90%	0%						
1996	0.027	3139	85	3%	95%	2%	0.018	3162	56	3%	95%	2%
1997	0.072	6131	441	6%	82%	12%	0.014	7337	100	4%	83%	13%
1998	0.070	6099	428	0%	21%	79%	0.039	7436	292	0%	27%	73%
1999	0.023	3763	87	0%	98%	2%						
2000	0.009	5768	53	12%	77%	12%	0.012	4247	53	4%	96%	0%
2001	0.008	5427	46	6%	86%	8%	0.012	1666	20	0%	97%	3%
2002	0.013	11163	144	4%	73%	23%	0.033	1919	64	0%	73%	28%
2003	0.008	8714	68	1%	26%	74%	0.018	2082	37	1%	4%	95%
2004	0.033	3372	112	5%	78%	16%	0.005	13156	71	12%	89%	0%
2005	0.035	3204	113	8%	75%	18%	0.017	5680	98	5%	76%	19%
2006	0.116	5375	625	9%	90%	1%	0.033	4518	150	11%	82%	7%
2007	0.079	7071	557	10%	55%	35%						
2008	0.043	11168	475	7%	84%	9%	0.031	10498	329	22%	65%	13%
2009	0.082	3238	267	28%	56%	16%	0.036	9314	335	11%	69%	19%
2010	0.052	13916	726	5%	93%	2%	0.032	26758	849	6%	88%	6%
2011	0.076	3938	300	17%	67%	16%	0.066	5979	396	22%	72%	5%

Model Output

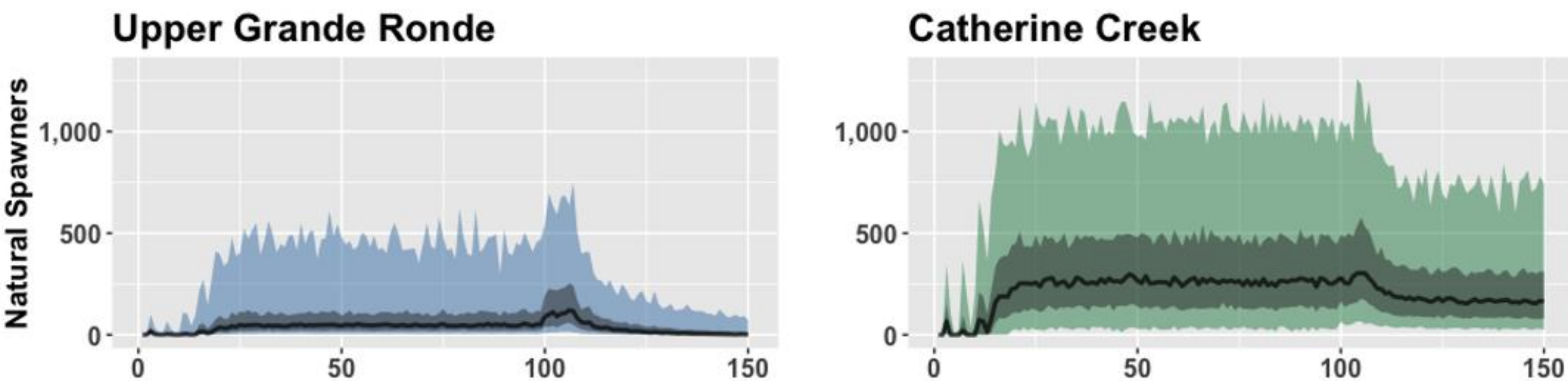


FIGURE 6. VISUAL DEPICTION OF MODEL SIMULATION BEHAVIOR SHOWING MAJOR LIFE-STAGE ABUNDANCE FOR 500 ITERATIONS OF A 150 YEAR MODEL. COLORED REGIONS REPRESENT THE 5TH AND 95TH, GREY REGIONS REPRESENT 25TH AND 75TH, AND BLACK LINES REPRESENT THE MEDIAN POPULATION ABUNDANCE. VISUALIZATIONS ALSO DEMONSTRATES THE IMPACT THAT CEASING HATCHERY SUPPLEMENTATION IN YEAR 100 HAS ON THE TRAJECTORY OF EACH POPULATION.

Model Validation

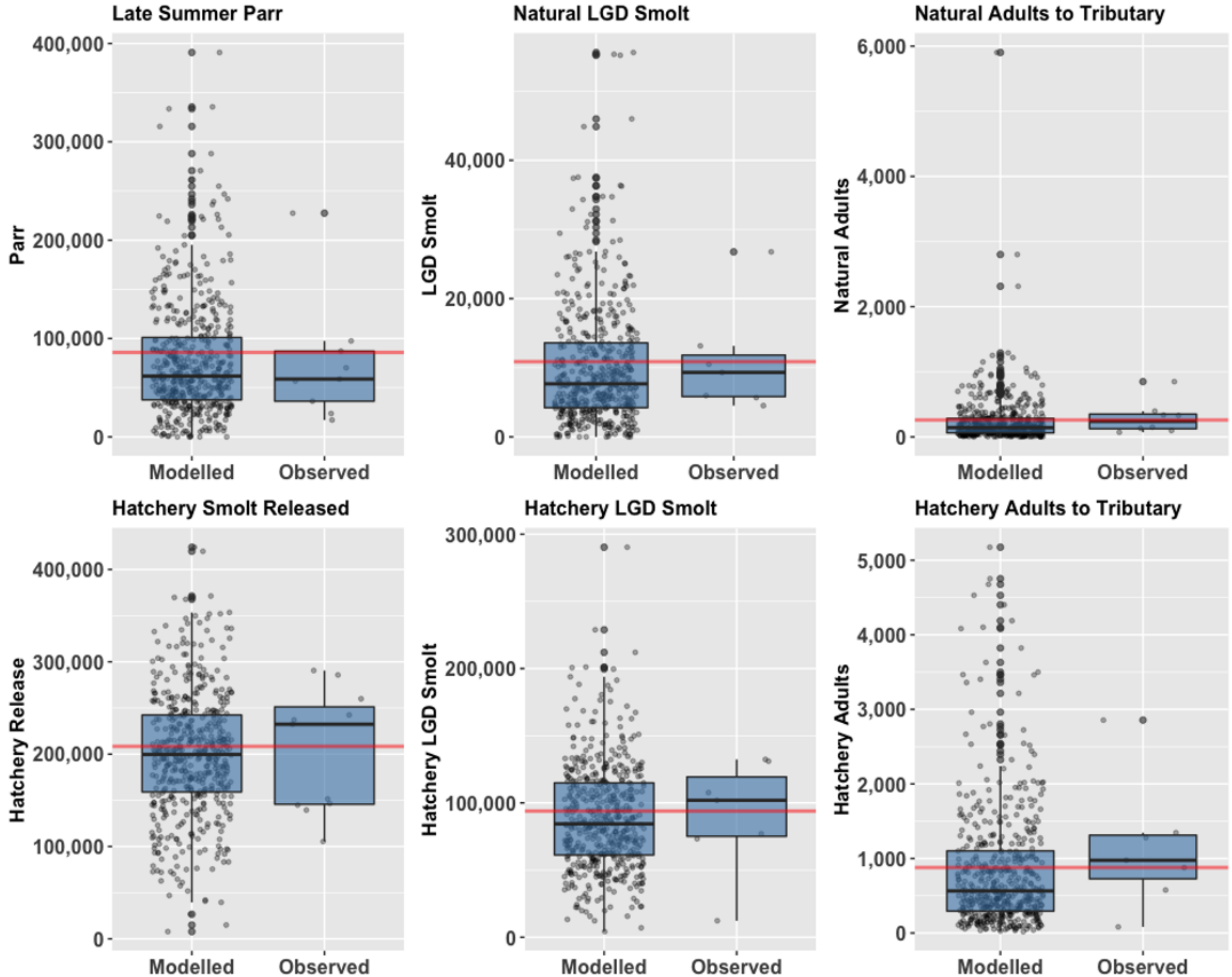


FIGURE 7. VISUAL VALIDATION OF MODEL PERFORMANCE FOR THE UPPER GRANDE RONDE. FIGURES CONTRAST THE DISTRIBUTION OF POPULATION ABUNDANCES FOR LIFE-STAGES AS MODEL PREDICTIONS AND OBSERVED ESTIMATES. THE MODELLED DATA IS BASED ON THE POPULATION ABUNDANCE AT YEAR 50 FROM 500 ITERATIONS OF A BASE MODEL SCENARIO. THE RED LINE SHOWS THE MODEL PREDICTED POPULATION ABUNDANCE AT EACH LIFE-STAGE WHEN MODEL STOCHASTICITY HAS BEEN TURNED OFF (I.E. DETERMINISTIC MODEL PREDICTION).

Model Validation

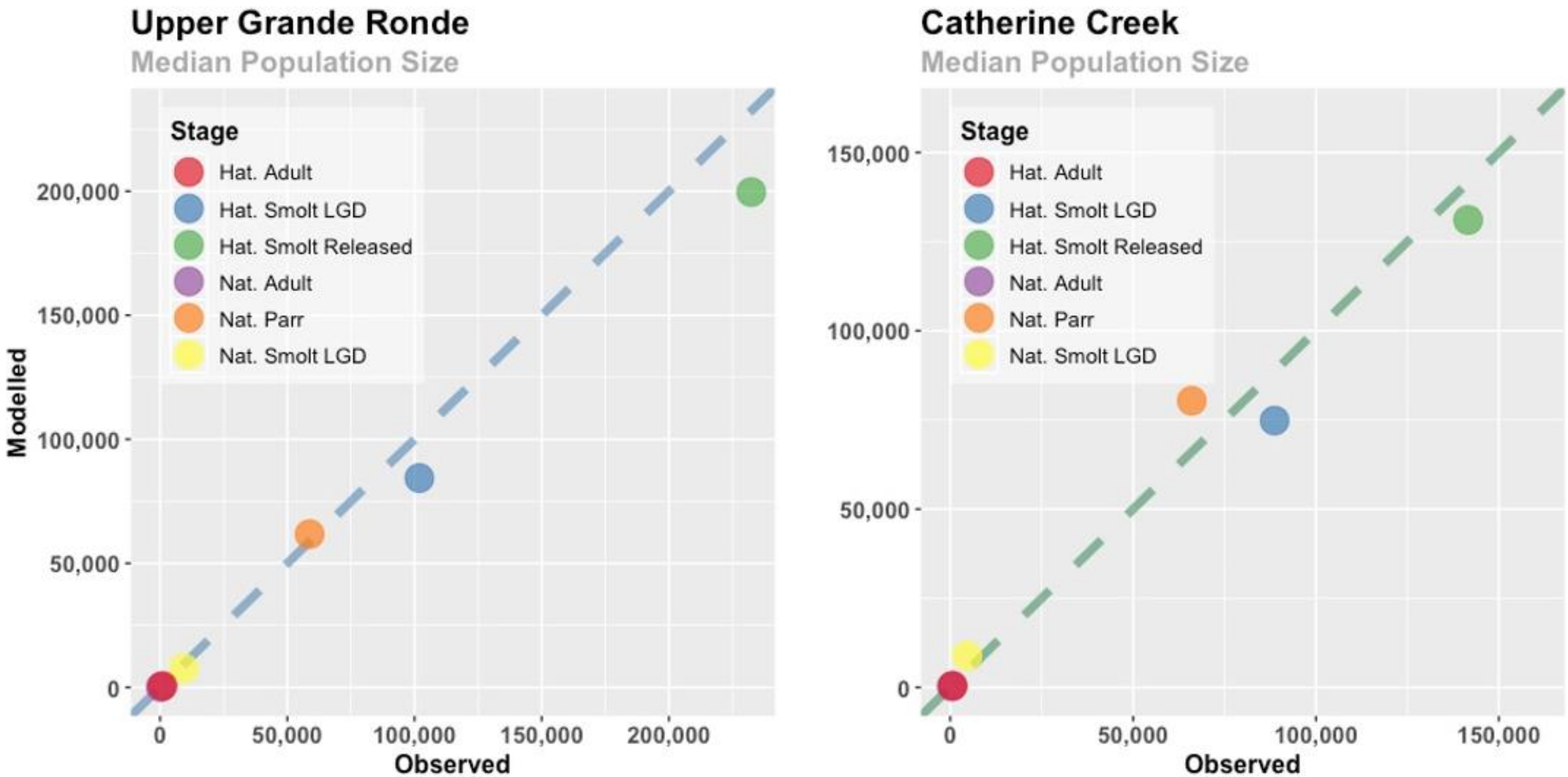


FIGURE 9. VISUAL VALIDATION OF MODEL ACCURACY BETWEEN OBSERVED AND MODEL PREDICTED POPULATION ABUNDANCES FOR NATURALLY (NAT.) AND HATCHERY (HAT.) REARED COMPONENTS OF THE POPULATION.

Parameter Sensitivity

Parameter Group	Parameter	Average Sens.
Capacity	Adult/Egg Cap.	0.014
	Age-0 Parr Cap.	0.336
	Age-1+ Presmolt Cap.	0.668
Productivity/Survival	Egg-to-parr S	1.202
	Age-0 Parr S	1.480
	Age-1 Presmolt S	1.739
	Age-2+ Presmolt S	0.244
	Smolt migration S	2.120
	Ocean age-1 S	2.123
	Ocean age-2 S	0.950
	Ocean age-3 S	0.012
	Adult Mainstem/Prespawn S	0.986
	Steelhead post-spawn S	0.117
	Rainbow post-spawn S	0.005
Other Life Hist. Parms	Smolt prob. 1	0.189
	Smolt prob. 2+	1.222
	Mat. prob. OA1	0.432
	Mat prob. OA2+	0.130
	Steelhead Fecundity	1.189
	Resident Fecundity	0.001

- One-at-a-time proportional perturbations, -50 to +50%
- Sensitivity index:

$$Sens = \frac{(R_{scen} - R_{base})/R_{base}}{(P_{scen} - P_{base})/P_{base}}$$

- R = mean N_{spawn}
- Noteworthy parameters:

-- juvenile capacity (and breakout)
-- high-mort., common stages
-- repeat spawning = negligible
-- residency, inconsequential

- But abundance is only part of the story…