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Life-cycle Modeling to Inform Conservation, Restoration, and Recovery Planning

A Concurrent Session at the 34th Annual Salmonid Restoration Conference held in Fortuna, CA from April 6-9, 2016.

Session Overview

- Session Coordinators:
  - Thomas Williams, NMFS Southwest Fisheries Science Center
  - Brian Cluer, NMFS West Coast Region

Life-cycle modeling can inform and provide context at landscape scales to address salmon and steelhead conservation and restoration decisions. Having an appropriately designed and spatially relevant life-cycle model provides a tool to evaluate impacts or options of various conservation, restoration, and recovery decisions including habitat loss or modification, discharge, water temperature, etc. This session will feature presentations that will illustrate how life-cycle models can provide context and understanding of impacts resulting from actions or modifications on ecological processes beyond site-specific or life-stage specific evaluations.

Presentations

(Slide 4) The Right Side Channel, at the Right Time: Using Life-cycle Analysis and Interdisciplinary Design to Build Resilient Side-channels on the Clackamas River
John Esler, Portland General Electric

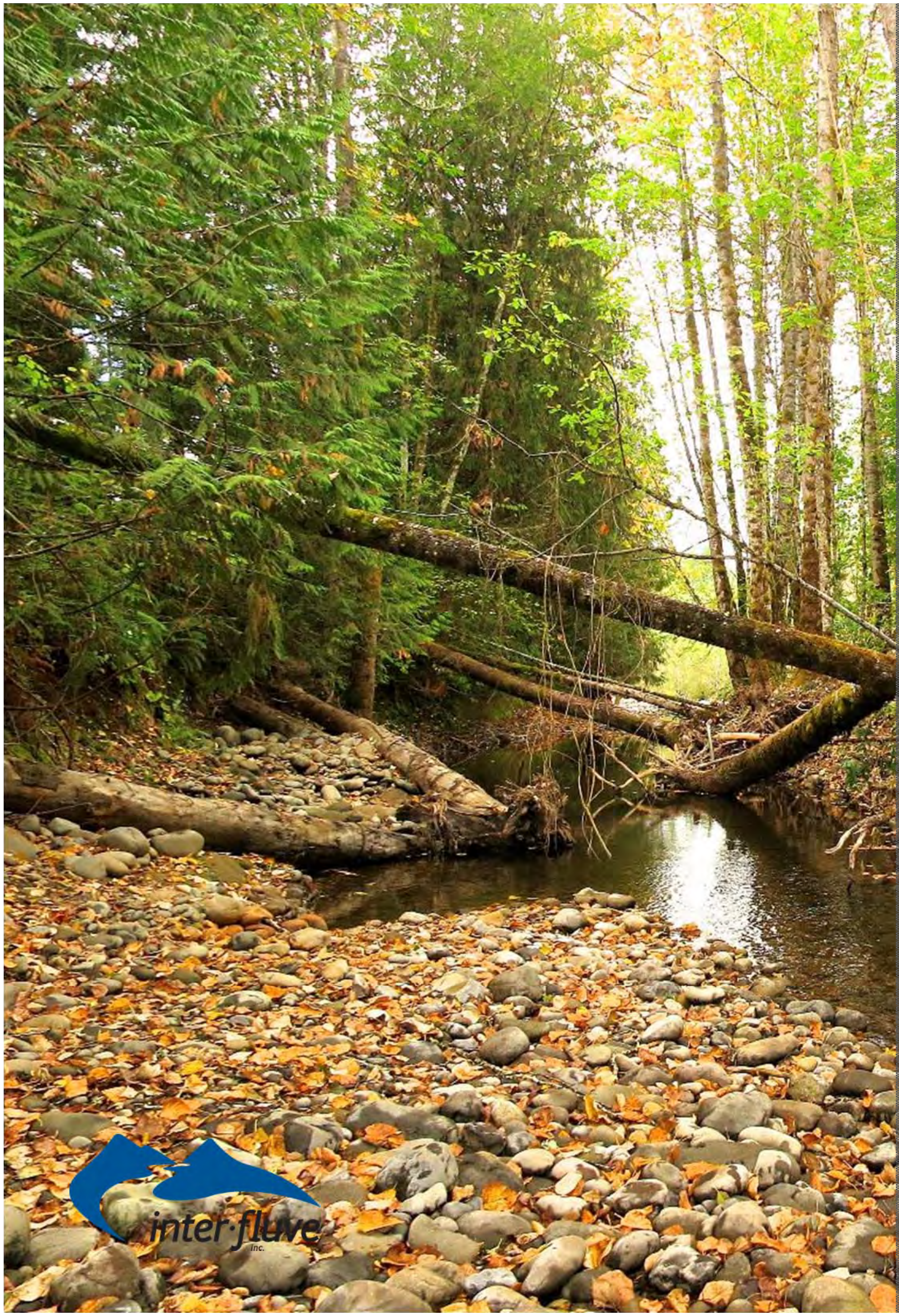
(Slide 53) Coho Life History Modeling in Coastal Northern California
Gabe Scheer, Humboldt State University

(Slide 80) Illuminating Population Consequences of Disparate Survival and Behavior between Hatchery- and Wild-origin Chinook salmon: the Role of Salmon Life-cycle Models
Michael Beakes, Ph.D., NMFS Southwest Fisheries Science Center

(Slide 122) Synergistic Benefits: Coupling Salmon Life-Cycle Monitoring and Population Models in Context
Joshua Strange, Stillwater Sciences

(Slide 171) The Black Box for Salmon Survival: Changing Perspectives on Marine Survival and Implications for Life-cycle Models
Cyril Michel, Ph.D., UCSC/NMFS-SWFSC

(Slide 225) Incorporating Life-history Diversity into Estimates of Skagit River Chinook Salmon Production
Corey Phillis, Ph.D., NOAA Fisheries contractor—Ocean Associates, Inc.



The Right Side Channel, at the Right Time: Using Life-Cycle Analysis & Interdisciplinary Design to Build Resilient Side Channels on the Clackamas River

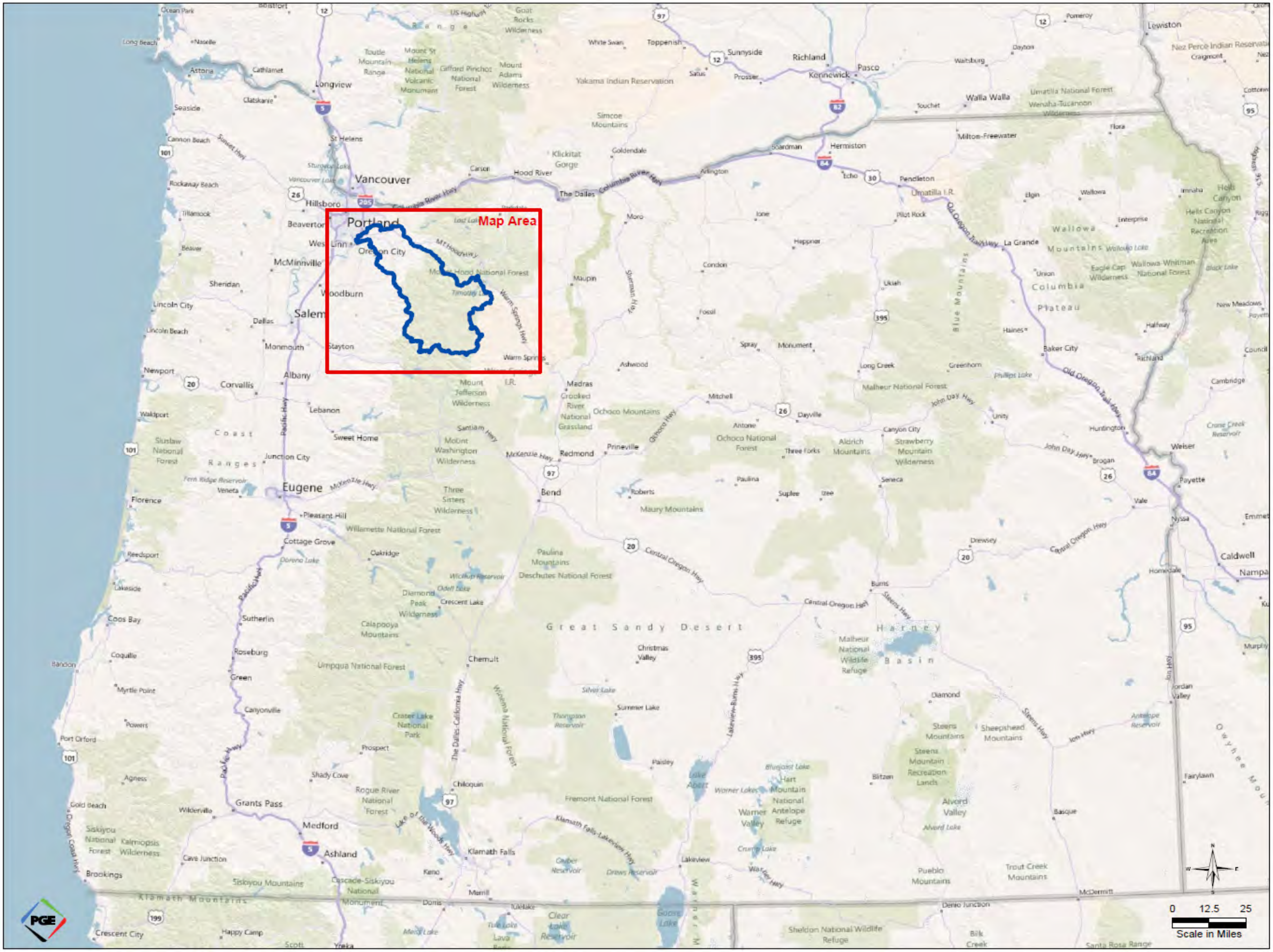
2016 Salmonid Restoration Foundation Conference - April 8, 2016

John Esler
Project Manager - Environmental Compliance & Licensing
Portland General Electric


This is a Caption

The Reluctant Side Channel Developer

- Relicensing PGE's Clackamas River project
- Need to mitigate for Temp
- Life cycle modeling
- Side channel site selection
- Milo McIver State Park side channel project


Map Area
Portland
Vancouver
Oregon City
Salem
Woodburn
Stayton
Hillsboro
Beaverton
McMinnville
Albany
Corvallis
Eugene
Lebanon
Sweet Home
Junction City
Cottage Grove
Roseburg
Grants Pass
Medford
Ashland
Klamath Falls
Chemult
Bend
Redmond
Prineville
Madras
Maupin
The Dallas
Hood River
Longview
Astoria
Seaside
Newport
Florence
Coos Bay
Brookings
Pendleton
Hermiston
Richland
Kennewick
Pasco
Walla Walla
La Grande
Baker City
Burns
Lakeview
Caldwell
Nampa
Lewiston
Great Sandy Desert
Mt Hood National Forest
Willamette National Forest
Umpqua National Forest
Deschutes National Forest
Fremont National Forest
Ochoco National Forest
Malheur National Forest
Crater Lake National Park
0 12.5 25
Scale in Miles

"I have been on all the rivers and tributaries of the Columbia from the Cascades to Priest’s Rapids, to which the Chinook salmon go . . . and I do not hesitate to say that the Clackamas River, with its clear, cold water, its rapids, and its long, shallow gravel beds, is the most natural and favorite region for salmon spawning.”

Commissioner Barin (U.S. Bureau of Fisheries- 1877)





AM AND FISH LADDER CAZADERO ORE.

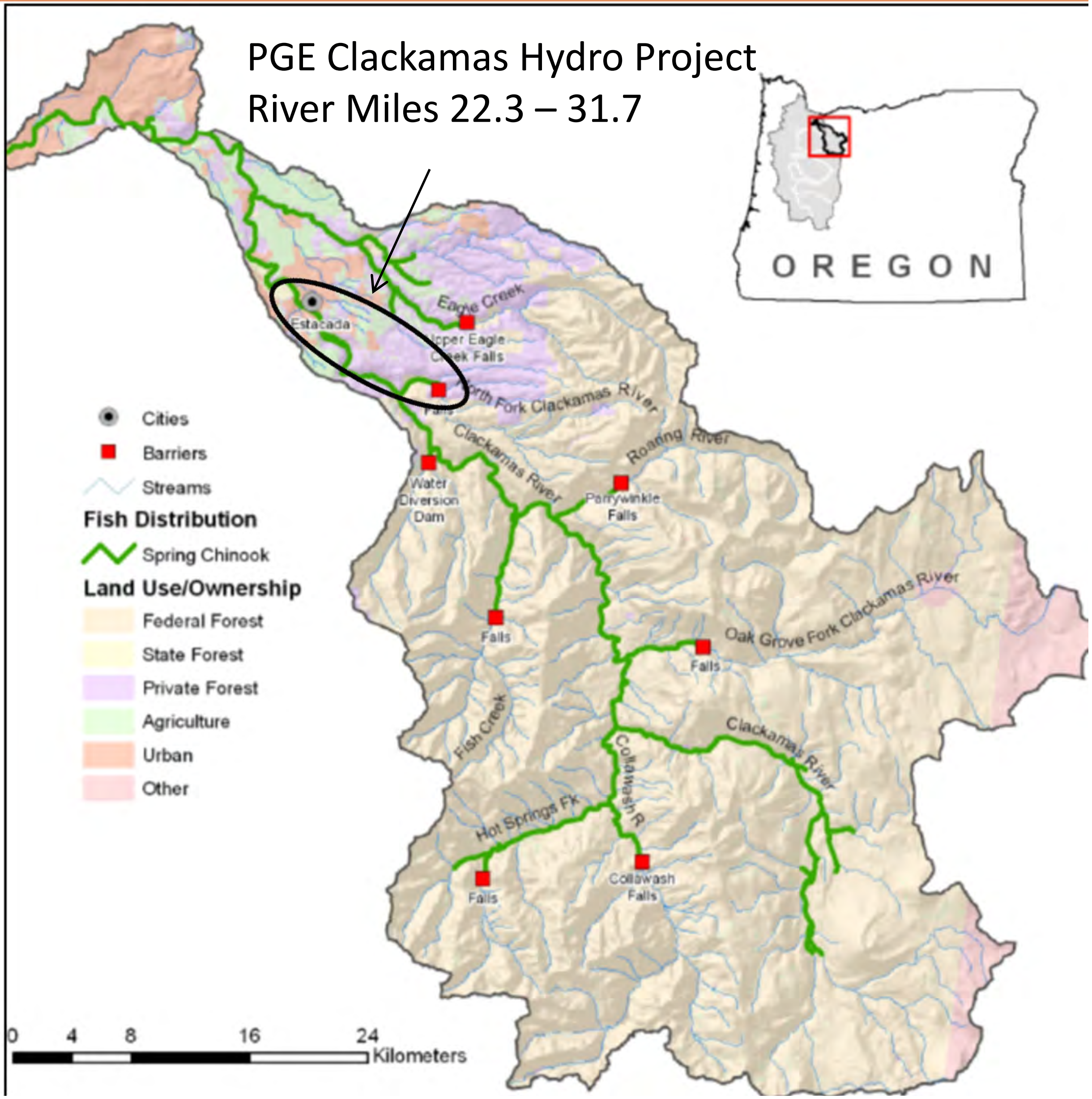
CLACKAMAS HYDROELECTRIC PROJECT (130 MW)

Clackamas Hydro Features:

- 3 Dam Complex
- Low Head Dams (85-145')
- "Run of River" Projects

Anadromous Fish Species:

- Spring Chinook
- Coho
- Winter Steelhead
- Pacific Lamprey
- Fall Chinook
- Summer Steelhead



Clackamas License

- Fish protection and enhancement
  - Downstream passage 97%
  - Improved upstream passage
  - Improved diversion flows
- Terrestrial resource and vegetation management
  - Native plant re-vegetation
  - Invasive plant treatment
- Recreation Management
- WQ Management
  - Blue Green Algae
  - Total Dissolved Gas
  - **Temperature**

Clackamas Subbasin (Willamette Basin TMDL)

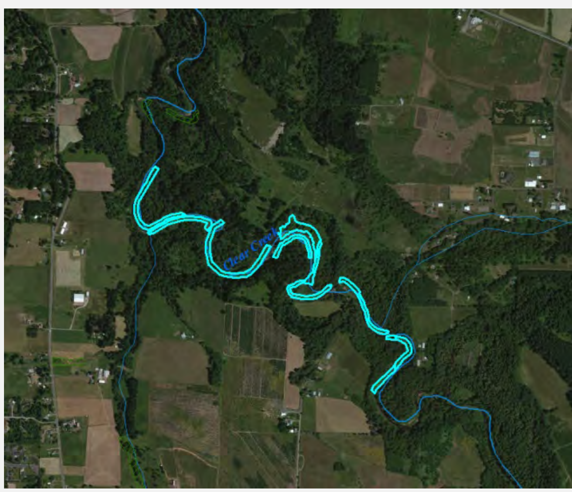
- TMDL defines the amount of a pollutant that can be present without causing water quality criteria to be exceeded.
- The most sensitive beneficial uses to temperature in the Clackamas Subbasin are:
  - Salmonid spawning and rearing
- Willamette Basin TMDL required a temperature management plan from PGE as part of the WQ certification for the Clackamas River Project.
- CE-Qual-W2 modeled impact from PGE operations <2 F

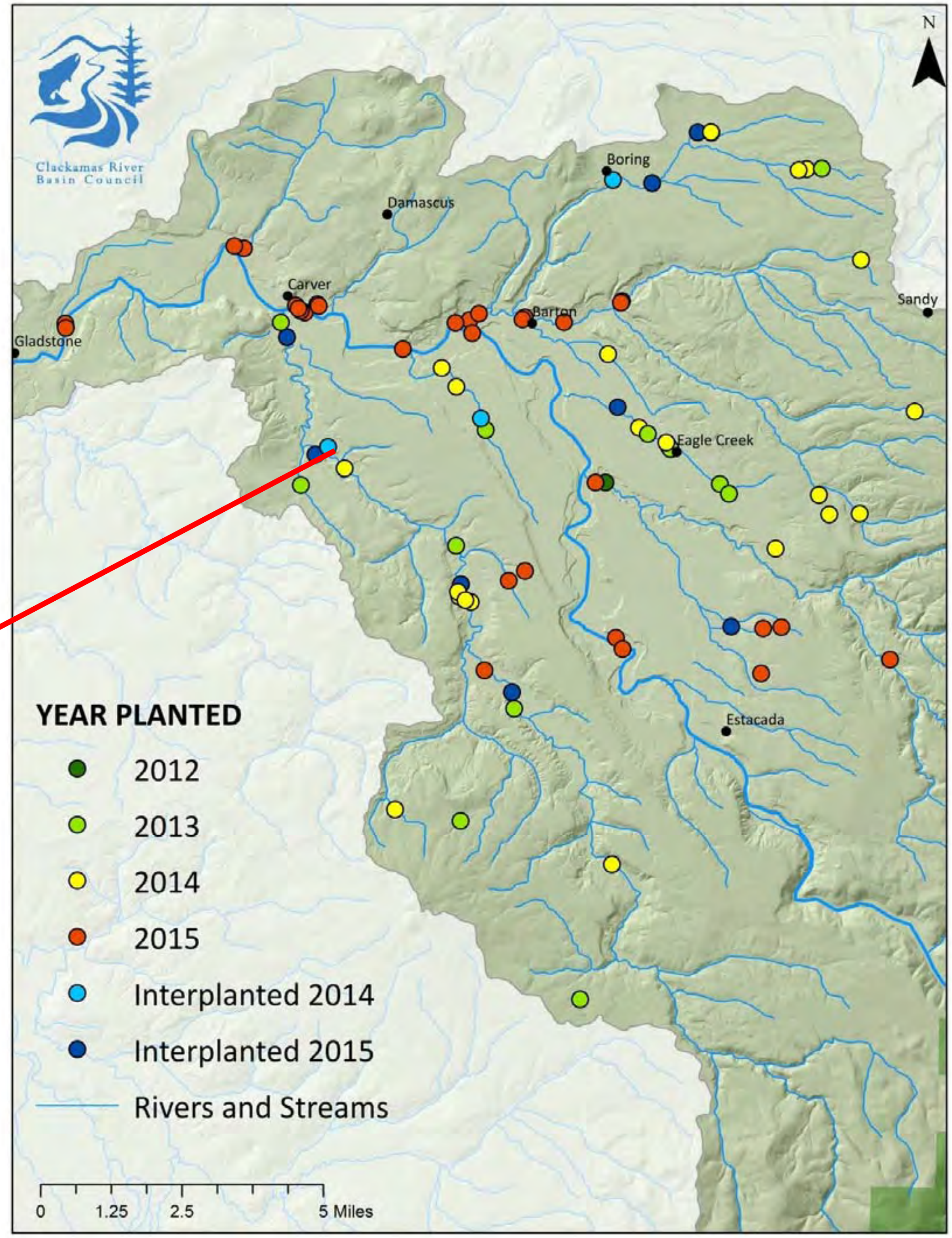
shade our streams
A CLACKAMAS RIVER BASIN COUNCIL PROJECT

- 30 miles of riparian revegetation to enhance stream shade and lower water temperatures
- Stream reaches with less than 70% riparian cover
- Landowner outreach, invasive species removal, native plantings and maintenance

Planting Shade Trees

- 250,335 plants
- 16.53 miles
- 92 tax lots





Channelize Faraday Lake

- Construct a 109-foot-wide channel through Faraday Lake.
- The channelization separates a cooler, faster moving channel of water from the slower moving portion of the lake
- Reduces the residence time and decreasing the amount of warming to the water as it passes through the lake.
- Lake drawdown of two feet implemented July 1 – September 30th to channel the flows entering the reservoir.

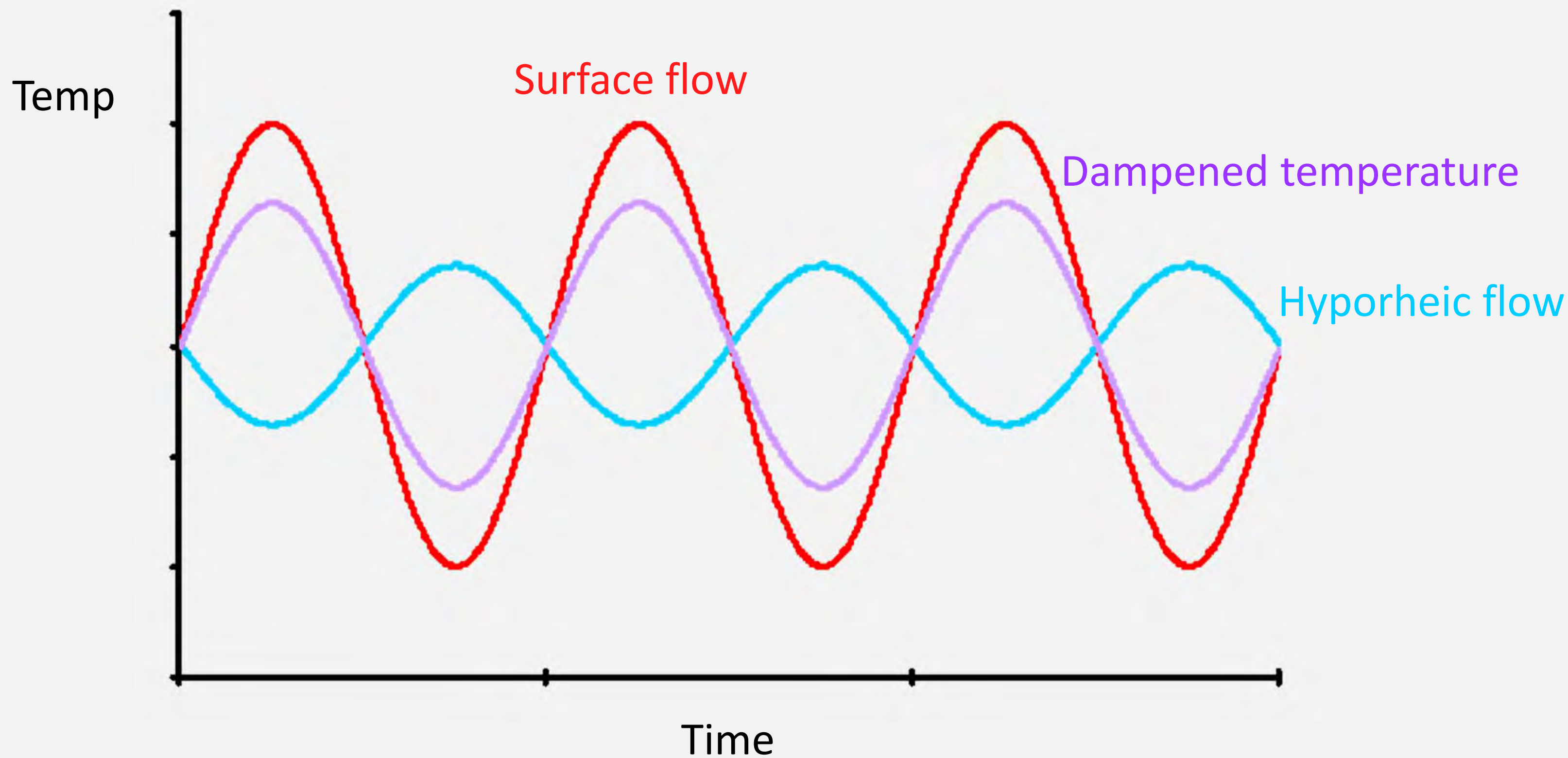
Channelize Faraday Lake

Gravel Augmentation

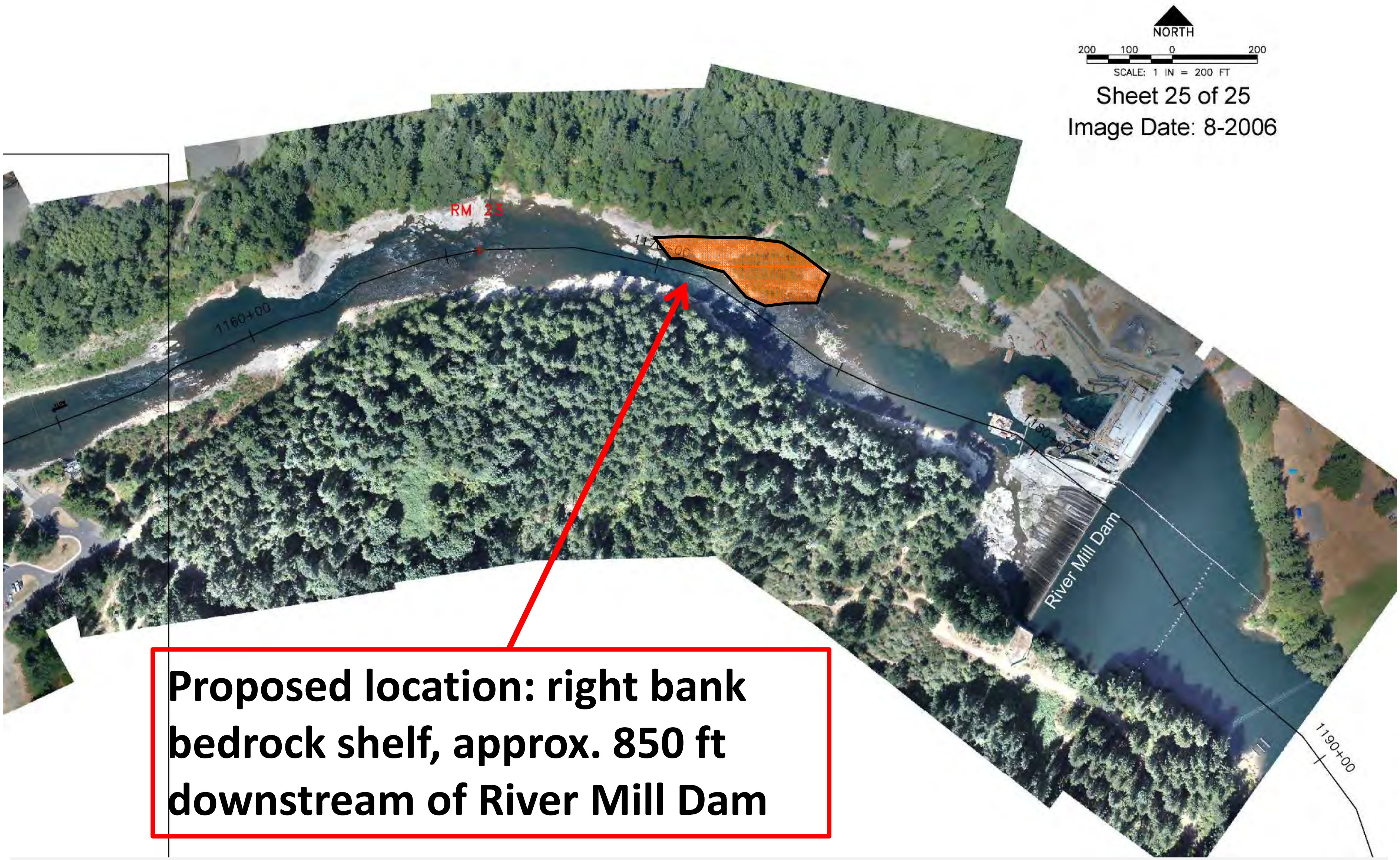
- Introduce coarse sediment to the river below our dam
- Up to 24,000 yd^3 annually subject to revision
- Material mobilizes from shore line in high-flow events
- Reverses channel changes caused by coarsening of bed load material
- But also could have value in reducing peak summer river temperatures

McBain & Trush

Gravel Augmentation



Gravel Augmentation



Proposed location: right bank bedrock shelf, approx. 850 ft downstream of River Mill Dam

Freshwater
Life Cycle Model

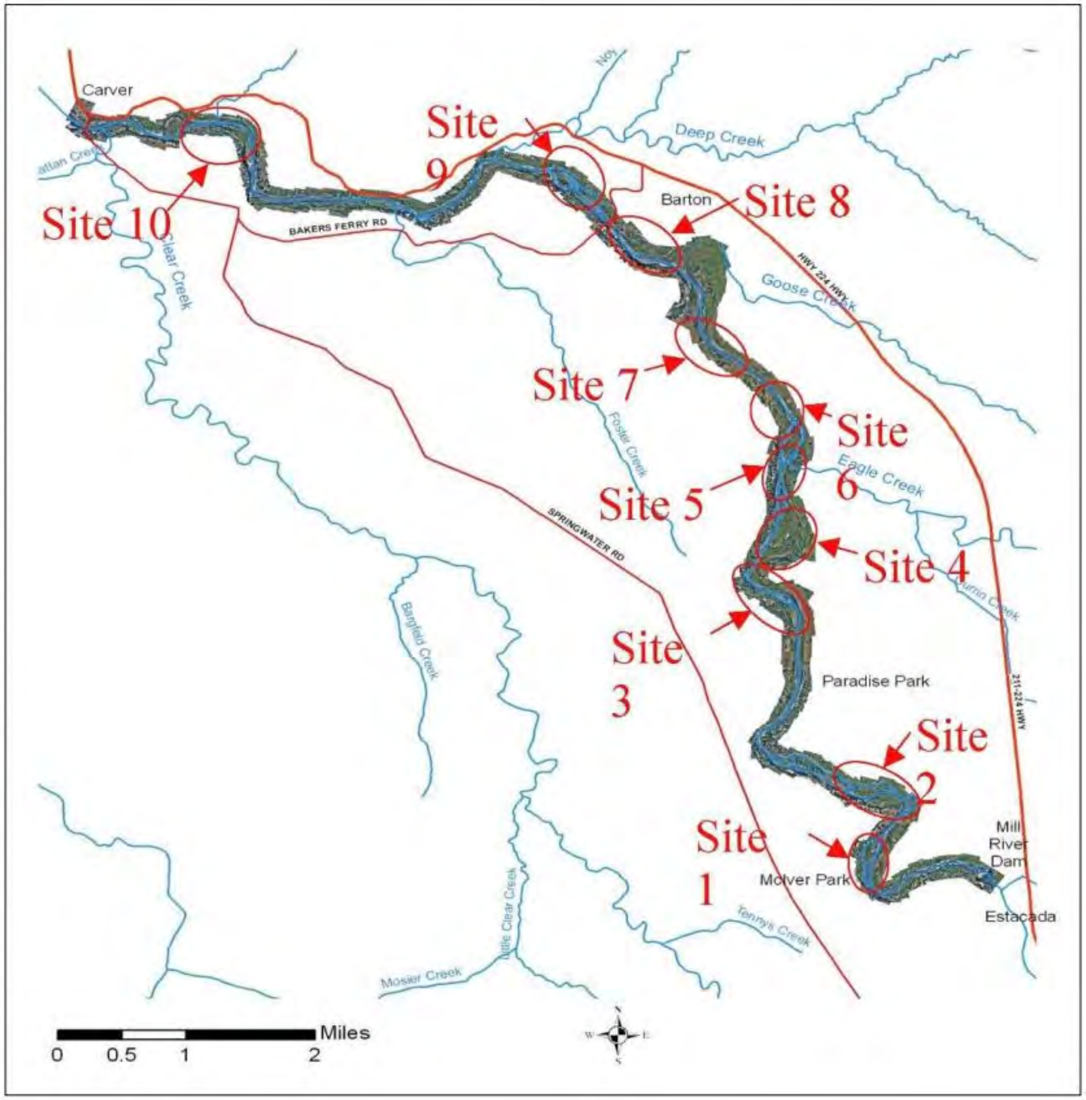
- Cramer Fish Sciences (CFS) developed a freshwater life-cycle model to predict the impacts of thermal effects of PGE facilities on salmonids in the lower Clackamas River.
- The model was used to determine differences in salmonid production in the lower Clackamas River under various temperature regimes.
- Temperature affects production via two mechanisms;
    - a reduction in habitat suitability (summer rearing)
    - and growth affecting winter survival.

Freshwater Life Cycle Model

- The model predicted a 13-15% reduction in juvenile production within the project area. (.1-.5% basin)
- Absolute losses in salmonid smolt production ranged from 3,100 to 4,200 annually.
- Model examined the mitigation value of increasing side channel habitat based on Phil Roni's work on the Klamath.
- Side channels have been found to be resistant to warming through a buffering effect that occurs from groundwater via intra-gravel seepage.

Why Side Channels?

- The density of juvenile salmonids in the summer in PGE's first constructed side channel averaged 0.220 fish/m^2.
- The relative density in a one mile segment of the mainstem Clackamas near the channel was 0.003 fish/m^2.
- Young salmon were found to be actively rearing in floodplain habitat, and achieving high growth rates due to the high levels of available prey.



Geomorphic Site Evaluation

- Gradient, Substrate
- Large Wood Cover Opportunity
- Access, Ownership
- Relative excavation volumes
- Priority for Chinook and Steelhead
- The Winner: McIver State Park

inter·fluve inc.

VORTEX I

- "A Biodegradable Festival of Life"
- Summer 1970 in Milo McIver Park
- 105,000 folks over the last weekend of August.

VORTEX I

- Held to prevent violent protests during an American Legion convention.
- Richard Nixon cancelled his Portland visit because of Vortex I

VORTEX I

- Governor McCall recounted: "**There was a lot of pot smoking and skinny dipping but nobody was killed.**"
- It remains the only state-sponsored rock festival in United States history

23

Please be careful: No trespassing.

We're working to enhance salmon habitat near Milo McIver Park.

Heavy equipment is in use – please keep out of the construction area.

For more information, please call us:

Portland General Electric
503-464-8563

Milo McIver State Park
503-630-7150

Milo McIver Project Goals

- Develop habitats for juvenile Steelhead & Chinook
- Year round flows
- Encourage hyporheic flows
- Large woody debris and boulder cover
- Minimize excavation volumes
- 20-year lifespan
- **(Built in a popular rafting river)**

24

Milo McIver Project Area

- Pre-1996 Flood
- Post-1996 Flood

- Hydraulic modeling was used as a tool to design proposed channel.
- Matched life cycle model limiting factors for target species (from Cramer - e.g. riffle/pool habitat)

Milo McIver Project Area

26

- Primary design concerns are high flow stability and low flow habitat conditions.
- Because of calibration, model could predict water surfaces for discharges where we didn't have surveyed observations (like 2015 super low flows)

Milo McIver Project Area

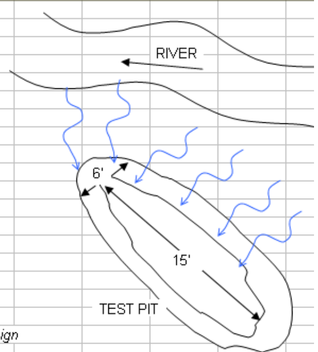
inter·fluve inc.

- For groundwater channel, gallery channel design was based on our estimate of deliverable water.
- These were derived from groundwater pump tests and available slope.
- Groundwater channel utilization, as expected, dominated by age 1+ Coho.

Milo McIver Project Area

28

	A–C	D	E	F	G
1	**Pump Test**				
2					
3	Initial Water Surface Elev. =	1638.2	ft		
4	Pump Test #1				
5	stable ws elev =	1637.7	ft		
6	drawdown =	0.5	ft		
7	volume =	32	gal		
8	ave fill time =	16.0	sec		
9	Pump Q1 =	2.0	gal/s		
10	=	120.0	gal/min		
11	=	0.27	cfs	*pit infiltration*	
12					
13	Pit Infiltration q =	0.27	cfs		
14	Pit Infiltration Length =	21	ft		
15	q/ft =	0.01	cfs/ft		
16	=	5.7	gpm/ft	*for perf pipe design*	
17					
18	Conceptual gallery =	200	ft		
19	Q =	2.5	cfs	*for conveyance design*	
20					
21					
22	**Gallery**				
23					
24	**Perf Pipe Design**				
25	min q/ft =	5.7	gpm/ft		
26					
27	From sediment characteristics: 4% of GSD < 1 mm				
28	assume D10 of aquifer sediment =	1	mm		
29	=	0.039	in		
30	slot size =	0.1	in		
31					
32	Slotted PVC well screen (Cetainteed)				
33	16" SDR26 with Certa-Lok, 0.100" slot width				
34	pipe dia =	16	in		
35					
36	**Design Q**				
37	slots open area =	133.1	sq-in/ft		
38	blockage factor =	50%			
39	flow rating =	20.6	gpm/ft	>	5.7 ok
40	gallery length =	200	ft		
41	q =	4126.1	gpm		
42	=	247566	gps		
43	=	9.2	cfs	per lateral	(check that pipe ca
44				<	2.79 ok
45	number of laterals =	1			
46	total Q =	9.2	cfs		
47					



	A	B	C	D	E	F	G	H
1	**Circular Pipe Flow**							
2	Diameter (ft..in)	1.33	16		OD =	[redacted]	in	
3	Slope	0.0015	ft/ft		thickness =	[redacted]	in	
4	Manning's N	0.012			ID =	[redacted]		
5	Depth	theta	A		T	Q	V	
6	0.07	0.90	0.03	0.60	0.58	**0.02**	**0.59**	
7	0.13	1.29	0.07	0.86	0.80	**0.07**	**0.92**	
8	0.20	1.59	0.13	1.06	0.95	**0.16**	**1.19**	
9	0.27	1.85	0.20	1.24	1.07	**0.28**	**1.42**	
10	0.33	2.09	0.27	1.40	1.15	**0.44**	**1.62**	
11	0.40	2.32	0.35	1.55	1.22	**0.63**	**1.79**	
12	0.47	2.53	0.44	1.69	1.27	**0.85**	**1.94**	
13	0.53	2.74	0.52	1.83	1.31	**1.08**	**2.08**	
14	0.60	2.94	0.61	1.96	1.33	**1.34**	**2.20**	
15	0.67	3.14	0.70	2.09	1.33	**1.61**	**2.31**	
16	0.73	3.34	0.79	2.23	1.33	**1.89**	**2.40**	
17	0.80	3.54	0.87	2.36	1.31	**2.16**	**2.47**	
18	0.87	3.75	0.96	2.50	1.27	**2.44**	**2.53**	
19	0.93	3.96	1.04	2.64	1.22	**2.70**	**2.58**	
20	1.00	4.19	1.12	2.79	1.15	**2.94**	**2.61**	
21	1.07	4.43	1.20	2.95	1.07	**3.15**	**2.63**	
22	1.13	4.69	1.26	3.13	0.95	**3.32**	**2.62**	
23	1.20	5.00	1.32	3.33	0.80	**3.43**	**2.59**	
24	1.27	5.38	1.37	3.59	0.58	**3.46**	**2.52**	
25	1.33	6.28	1.40	4.19	0.00	**3.22**	**2.31**	Full

Data Collection & Analyses

Table 1. LPIII Peak Discharge Estimates

Flow Event	Discharge (cfs)
Low flow	701
90% exc	825
1-year	7,405
2-year	27,619
5-year	41,309
10-year	50,232
25-year	61,213
50-year	69,144
100-year	76,849

	Discharge (cfs)	Water Surface Elev. at Inlet
Low Flow	701	269.70
90% Exc.	825	269.90

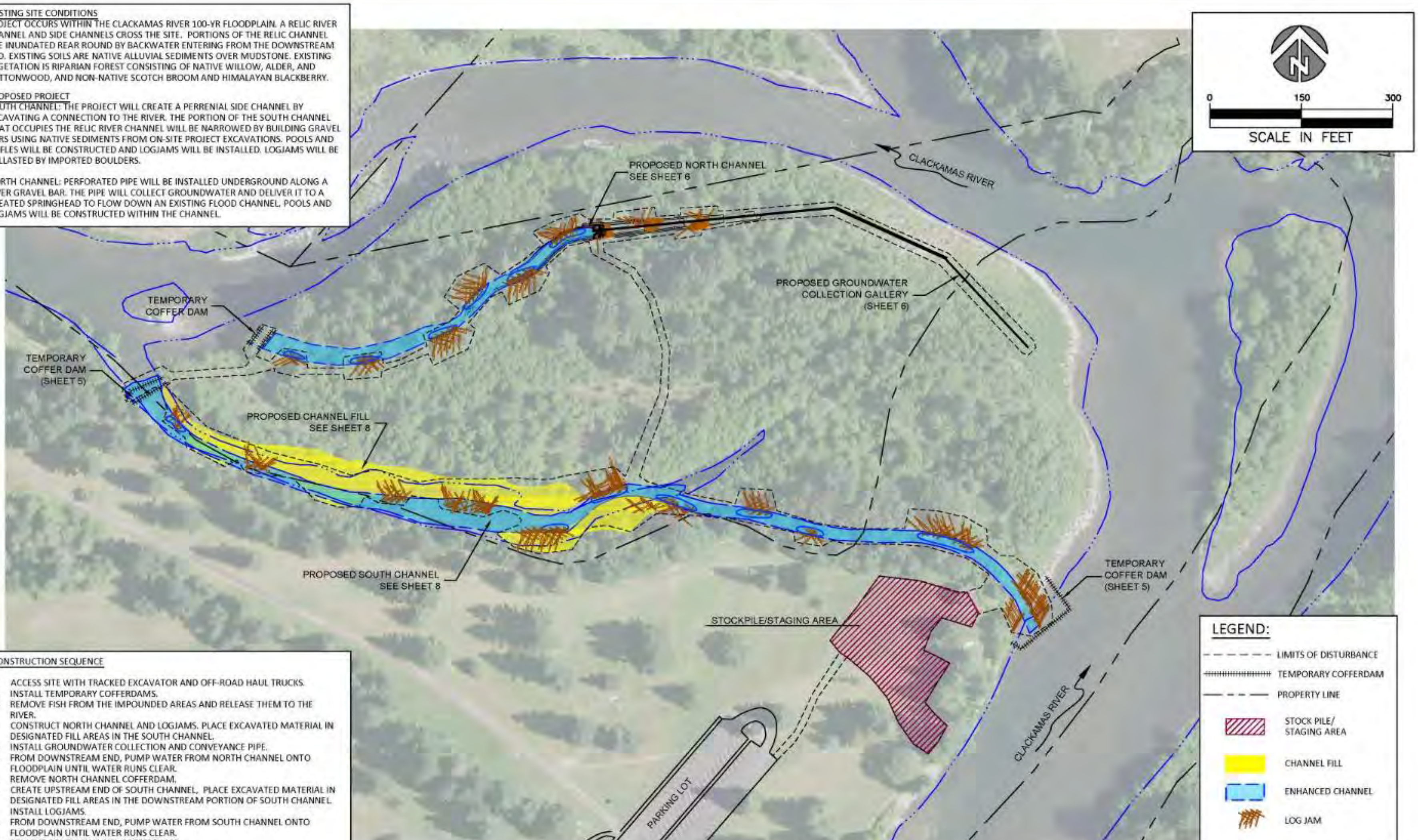
River Discharge (cfs)	South Side Channel Discharge (cfs)	Mobile sediment size (in)
701 (low)	3.3	0.3
825 (90% exc)	8.6	0.6
2,080 (50% exc)	94	1.9
7,400 (bankfull)	660	4.3

Data Collection & Analyses

EXISTING SITE CONDITIONS
PROJECT OCCURS WITHIN THE CLACKAMAS RIVER 100-YR FLOODPLAIN. A RELIC RIVER CHANNEL AND SIDE CHANNELS CROSS THE SITE. PORTIONS OF THE RELIC CHANNEL ARE INUNDATED REAR ROUND BY BACKWATER ENTERING FROM THE DOWNSTREAM END. EXISTING SOILS ARE NATIVE ALLUVIAL SEDIMENTS OVER MUDSTONE. EXISTING VEGETATION IS RIPARIAN FOREST CONSISTING OF NATIVE WILLOW, ALDER, AND COTTONWOOD, AND NON-NATIVE SCOTCH BROOM AND HIMALAYAN BLACKBERRY.

PROPOSED PROJECT
SOUTH CHANNEL: THE PROJECT WILL CREATE A PERRENIAL SIDE CHANNEL BY EXCAVATING A CONNECTION TO THE RIVER. THE PORTION OF THE SOUTH CHANNEL THAT OCCUPIES THE RELIC RIVER CHANNEL WILL BE NARROWED BY BUILDING GRAVEL BARS USING NATIVE SEDIMENTS FROM ON-SITE PROJECT EXCAVATIONS. POOLS AND RIFFLES WILL BE CONSTRUCTED AND LOGJAMS WILL BE INSTALLED. LOGJAMS WILL BE BALLASTED BY IMPORTED BOULDERS.

NORTH CHANNEL: PERFORATED PIPE WILL BE INSTALLED UNDERGROUND ALONG A RIVER GRAVEL BAR. THE PIPE WILL COLLECT GROUNDWATER AND DELIVER IT TO A CREATED SPRINGHEAD TO FLOW DOWN AN EXISTING FLOOD CHANNEL. POOLS AND LOGJAMS WILL BE CONSTRUCTED WITHIN THE CHANNEL.



CONSTRUCTION SEQUENCE

1. ACCESS SITE WITH TRACKED EXCAVATOR AND OFF-ROAD HAUL TRUCKS.
2. INSTALL TEMPORARY COFFERDAMS.
3. REMOVE FISH FROM THE IMPOUNDED AREAS AND RELEASE THEM TO THE RIVER.
4. CONSTRUCT NORTH CHANNEL AND LOGJAMS. PLACE EXCAVATED MATERIAL IN DESIGNATED FILL AREAS IN THE SOUTH CHANNEL.
5. INSTALL GROUNDWATER COLLECTION AND CONVEYANCE PIPE.
6. FROM DOWNSTREAM END, PUMP WATER FROM NORTH CHANNEL ONTO FLOODPLAIN UNTIL WATER RUNS CLEAR.
7. REMOVE NORTH CHANNEL COFFERDAM.
8. CREATE UPSTREAM END OF SOUTH CHANNEL, PLACE EXCAVATED MATERIAL IN DESIGNATED FILL AREAS IN THE DOWNSTREAM PORTION OF SOUTH CHANNEL. INSTALL LOGJAMS.
9. FROM DOWNSTREAM END, PUMP WATER FROM SOUTH CHANNEL ONTO FLOODPLAIN UNTIL WATER RUNS CLEAR.
10. REMOVE SOUTH CHANNEL COFFERDAMS.
11. EGRESS SITE. RESTORE STOCKPILE/STAGING AREA.

SITE PLAN - PROPOSED CONDITIONS

NO.	BY	DATE	REVISION DESCRIPTION	MM (DRAWN)	MM (DESIGNED)	MM, MB (CHECKED)
				MM, MB (APPROVED)	4/18/13 (DATE)	110225 (PROJECT)

MILO MCIVER STATE PARK
FISH HABITAT ENHANCEMENT PROJECT

inter·fluve
1020 Wasco Street, Suite I
Hood River, OR 97031
541.386.9003
www.interfluve.com

PROPOSED CONDITIONS
ACCESS, & STAGING

SHEET
3 OF 13


!BOATERS BEWARE!
Large woody material has been installed along the left bank of the river to enhance fish habitat. The project sites are located 1.3 to 1.8 miles downstream of this boat launch.
!BOATERS BEWARE!
After

Perennial Channel Upper

- Upper half was a flood channel exhibiting evidence of recent scouring flows
- Large inlet logjam constructed to preserve the grade of 1,900 ft channel
- Upper section re-graded with riffles and pools

33

Perennial Channel Lower

- Lower half deep pool habitat and scoured mudstone.
- Channel narrowed at top from 80 to 30 feet to reduce open water temperature effects.
- Large logs buried in channel margin

34

Groundwater Channel

- Historic high flow flood channel
- Constructed using slotted PVC pipes to capture hyporheic flow that is moving through gravel bars.

35

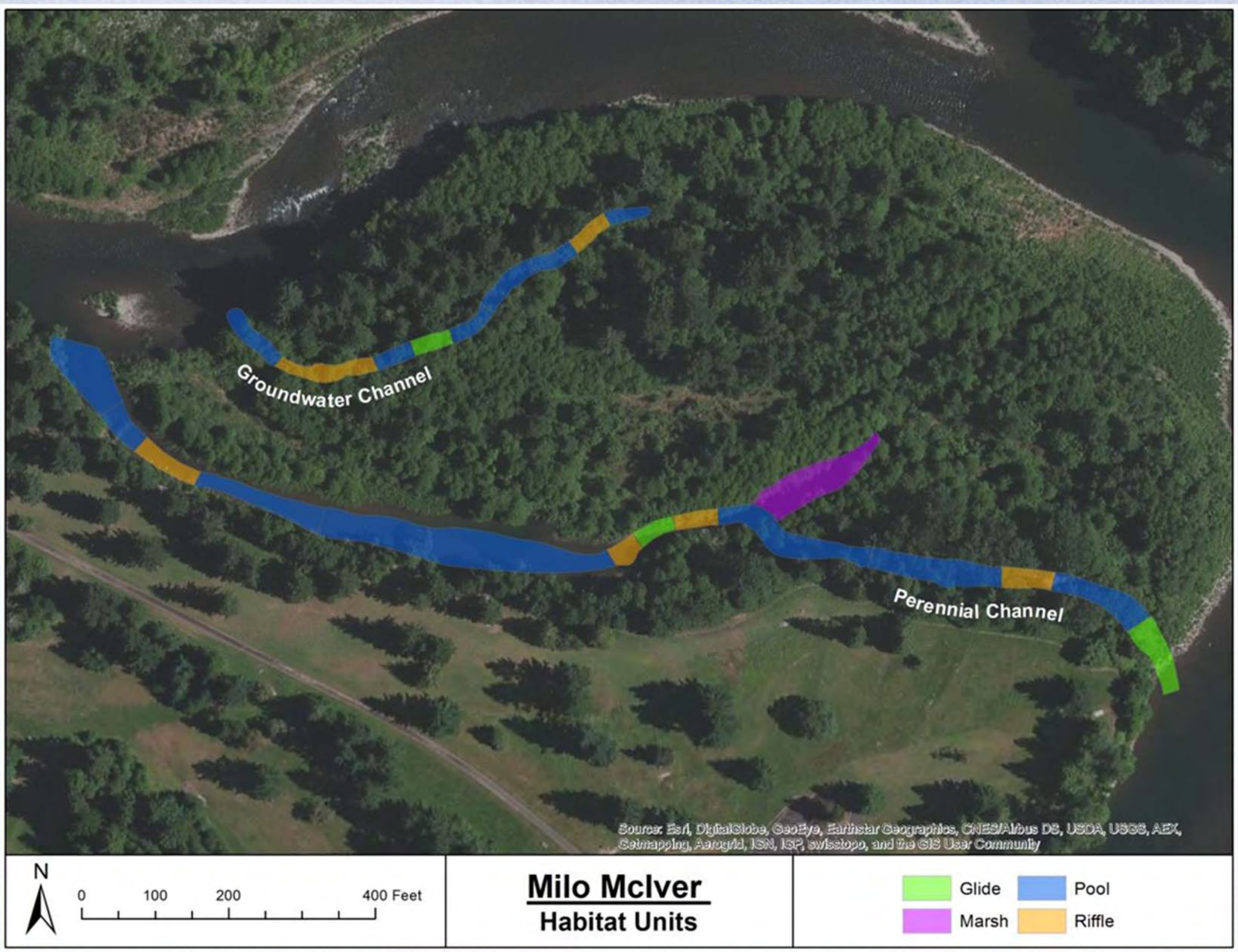
Groundwater Channel

- These pipes were buried at a depth and angle to convey flows into the open channel.
- The mature riparian habitat along 700 ft. open channel will provide a recruitment source and provide shade

Monitoring Goals for 2015

- Establish baseline conditions of the habitat at McIver Site
- Provide repeatable protocol for future monitoring efforts

McIver Side Channels



Groundwater Channel

- 700 feet (0.13 mi) long
- Pools = 63% riffles = 28.5%
  Glides = remaining 8.5%
- Six pools total
- Maximum pool depth was 3.3 feet

Habitat Unit Type	Groundwater Channel (m^2)
Pool	830.4
Riffle	375.5
Glide	112.1
Marsh	0.0
Total	**1318.0**

Groundwater Channel

- **Overstory:**

–33% large trees (DBH 21-31.9 in)

–67% small trees (DBH of 9 – 20.9 in)

- **Understory:**

–89% shrub/seedlings (DBH 1-4.9 in.

–11% grasses and forbs

- **LWD:**

–43 total number of pieces added

–Rate of 346/mile (large and med)

Groundwater Channel

- **Flows**
  - Lowest (8/12/2015) less than 3 cfs.
- **Gravel**
  - Upstream pebble count D50 = 53 mm (very coarse gravel)
  - Downstream D50 = 13 mm (medium-sized gravel)

Perennial Channel

- 1900 feet (0.36 mi) long
- Pools = 71%; Riffles = 11% , Glides = 7%, One marsh = 11%
- Eight pools total
- Maximum pool depth = 7 feet

Habitat Unit Type	Perennial Channel (m^2)
Pool	4107.6
Riffle	617.0
Glide	417.8
Marsh	640.9
Total	**5783.3**

Perennial Channel

- Overstory:
  - 73% small tree
  - 20% large tree
  - 7% sapling/pole size class
- Understory:
  - 53% shrub/seedling
  - 33% sapling/pole
  - 7% grasses (7% no vegetation)
- LWD:
  - 133 pieces added
  - Rate of 372/mile (large and medium)

Perennial Channel

- Upstream pebble count D50 = 126 mm (small cobble)
- Downstream D50 = 83 mm (small cobble)
- Flow in the perennial channel was approximately 15 cfs (08/12/2015)
- For comparison – December 2015 floods, approx. 4000 cfs in channel

PROJECT FLOOD EVENTS

Year	Date	Discharge (cfs)	Nearest Recurrence Interval
2014	Dec. 21, 2014	23,100*	<Q2 (Q2 = 27,670)
2015	Dec. 8, 2015	32,000*	>Q2 (Q2 = 27,670)

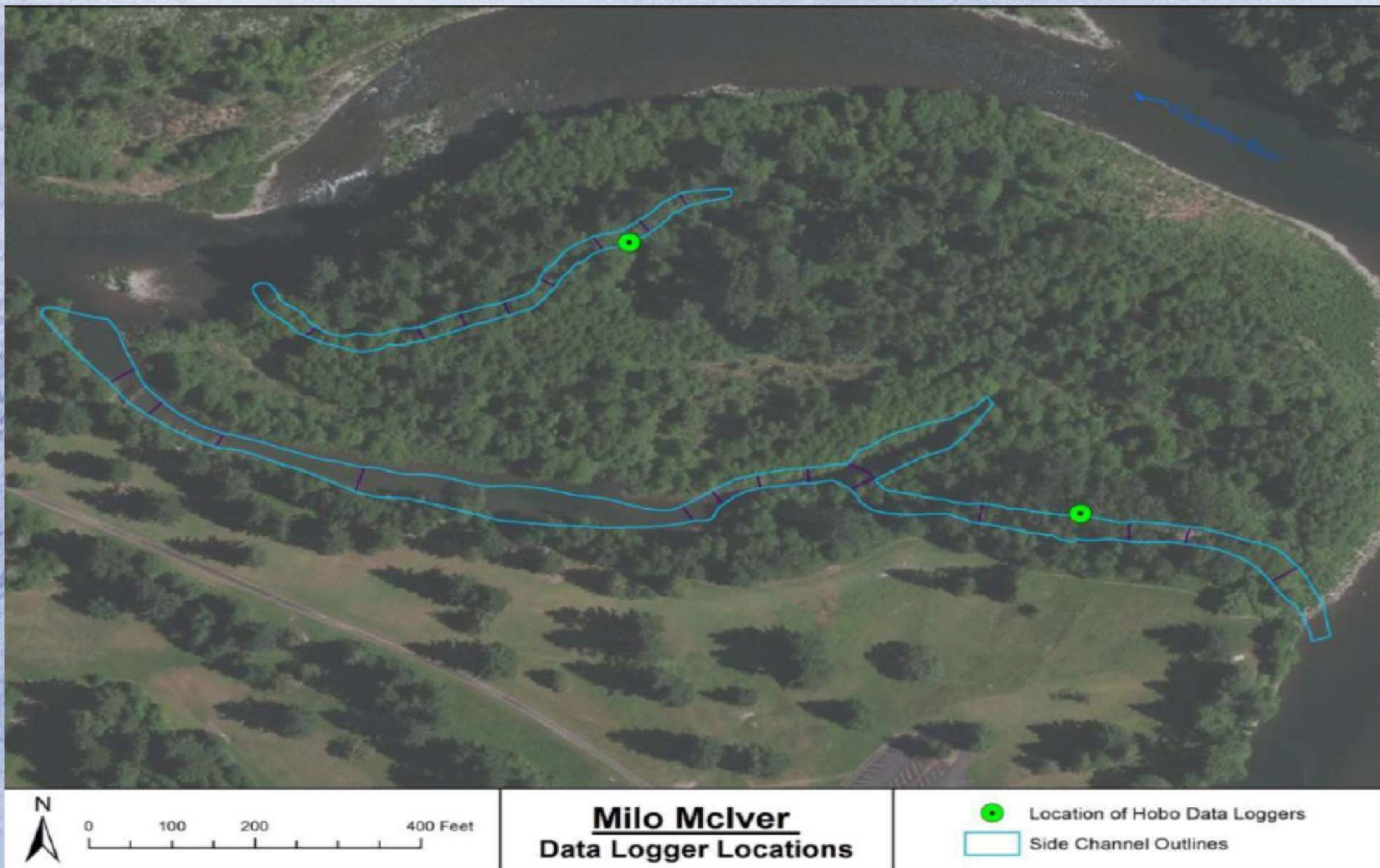
inter-fluve

Temperatures

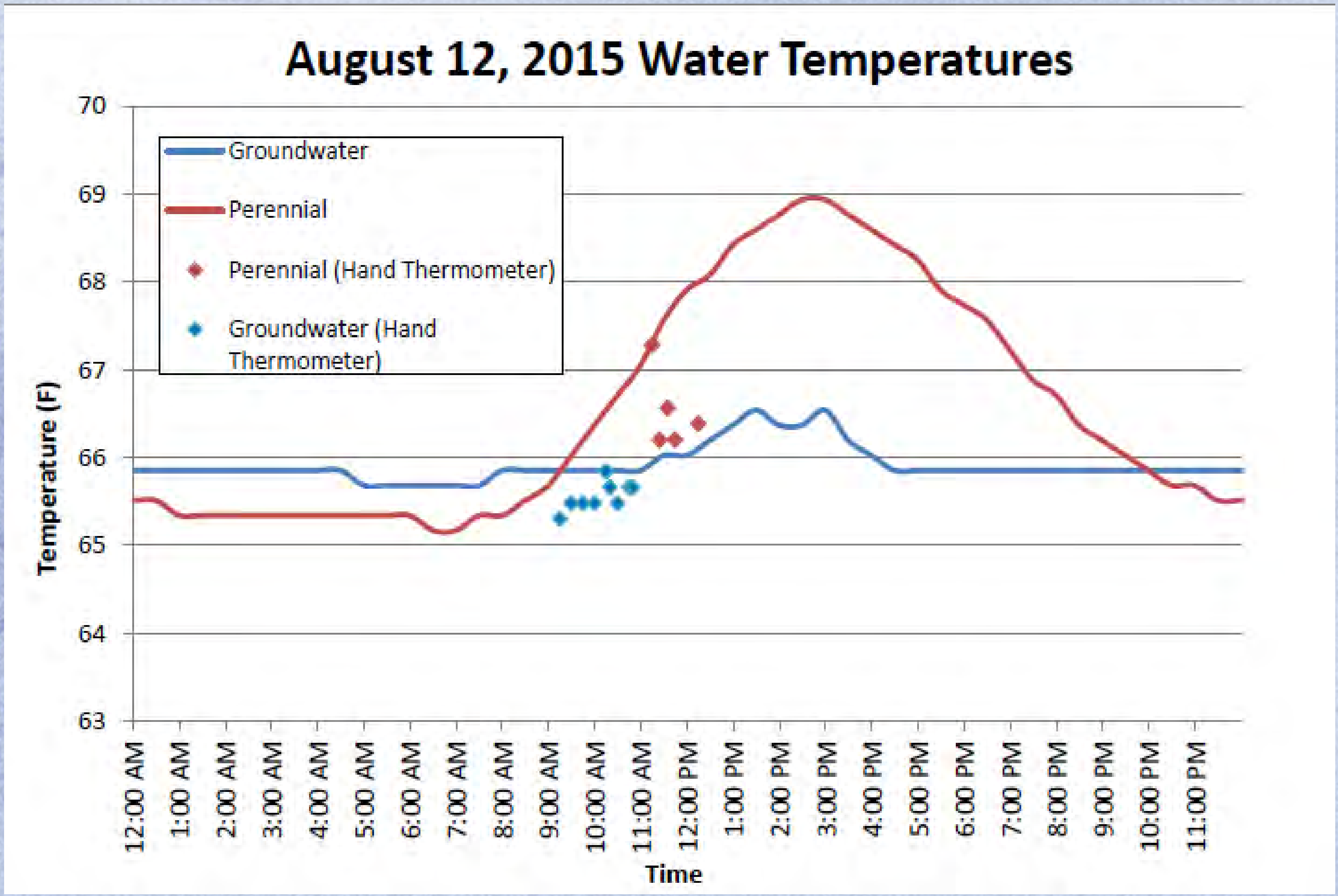
- Perennial Channel:
  - Summer and Fall: daily temperature fluctuations
  - lowest temperatures in early morning
  - As vegetation grows, likely see cooler channel temperatures

- Groundwater Channel:
  - less daily fluctuation
  - Summer: cooler than perennial channel during the daytime
  - Winter: channel generally warmer than perennial channel

Temperatures



Temperatures



Final Thoughts

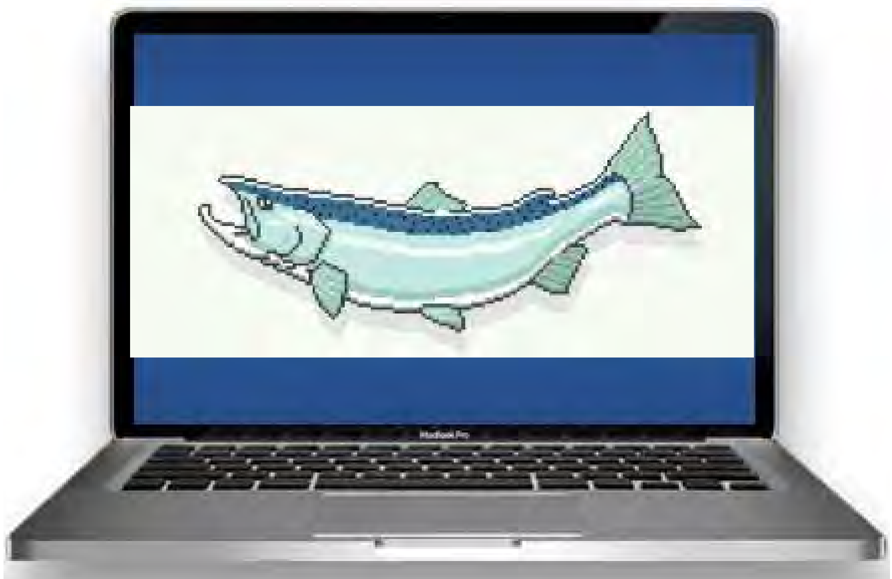
Juvenile salmonids observed in entire length of side channels

Periodic monitoring to determine how these channels perform over the long term

Money budgeted for maintenance and enhancements during 20 year commitment

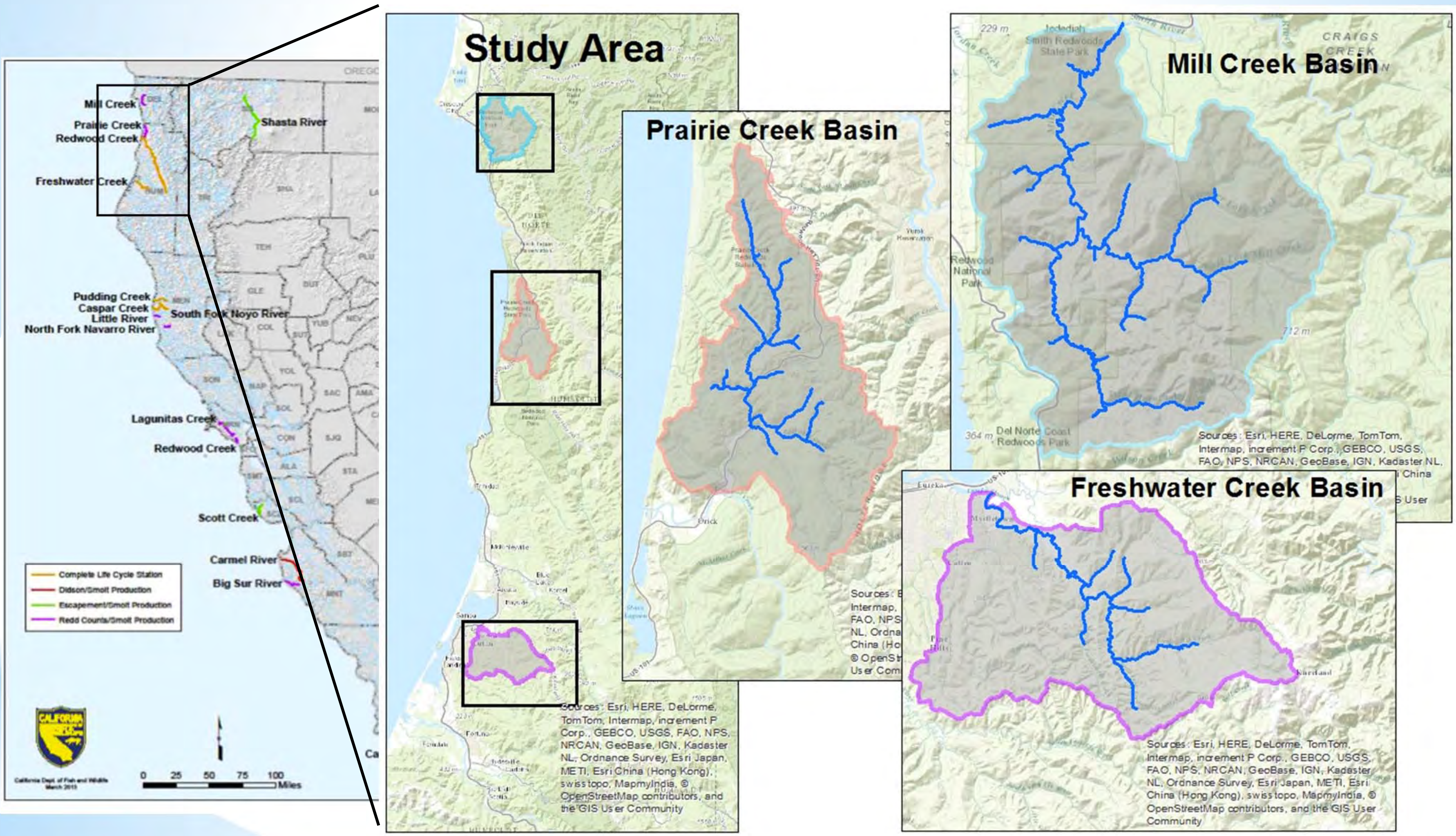
Experienced partners established trust with agency regulators and the public

Coho Salmon Life Cycle Modeling in Freshwater Creek

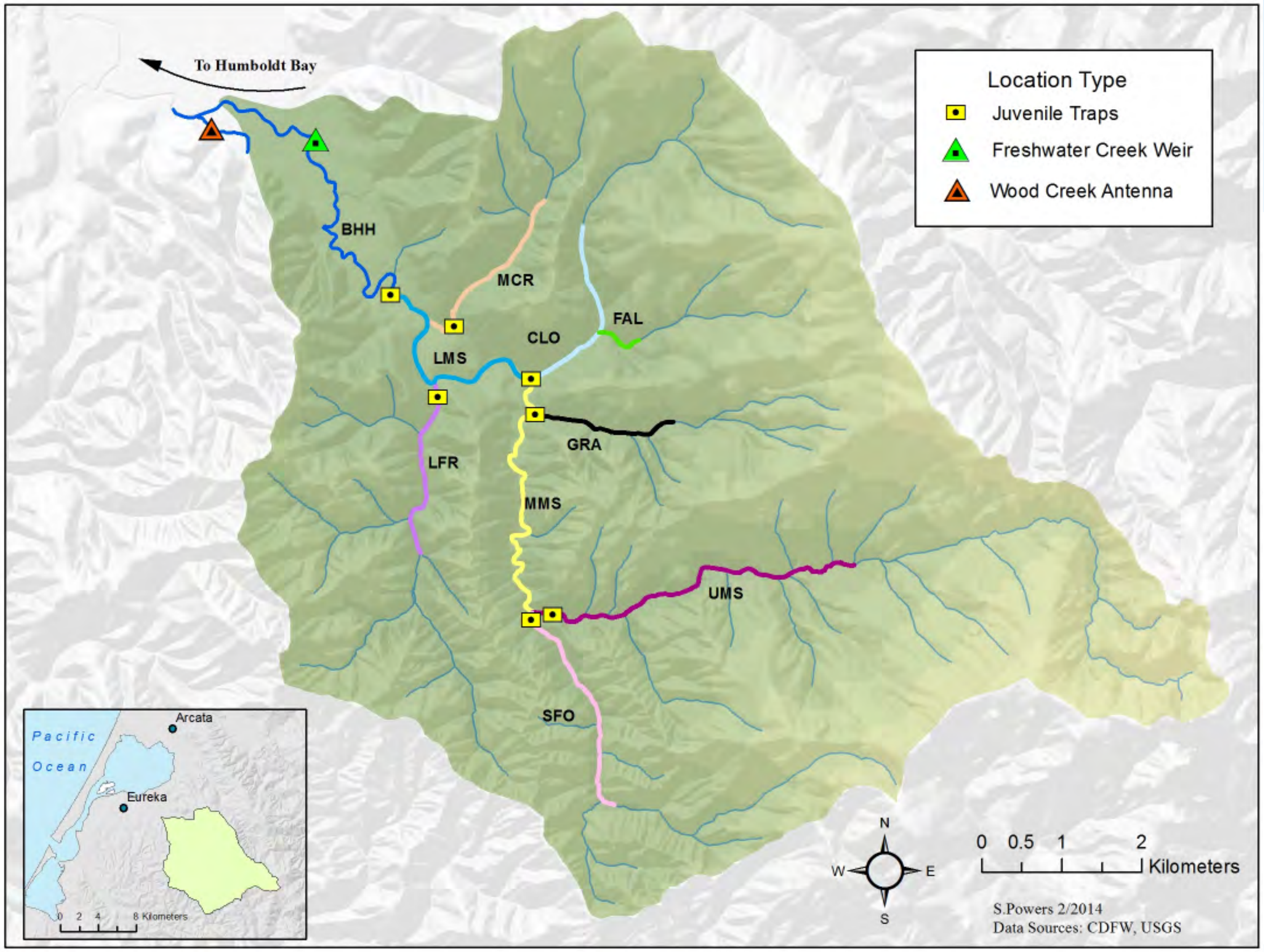


Gabe Scheer
Humboldt State University

Northern California Life Cycle Monitoring Stations

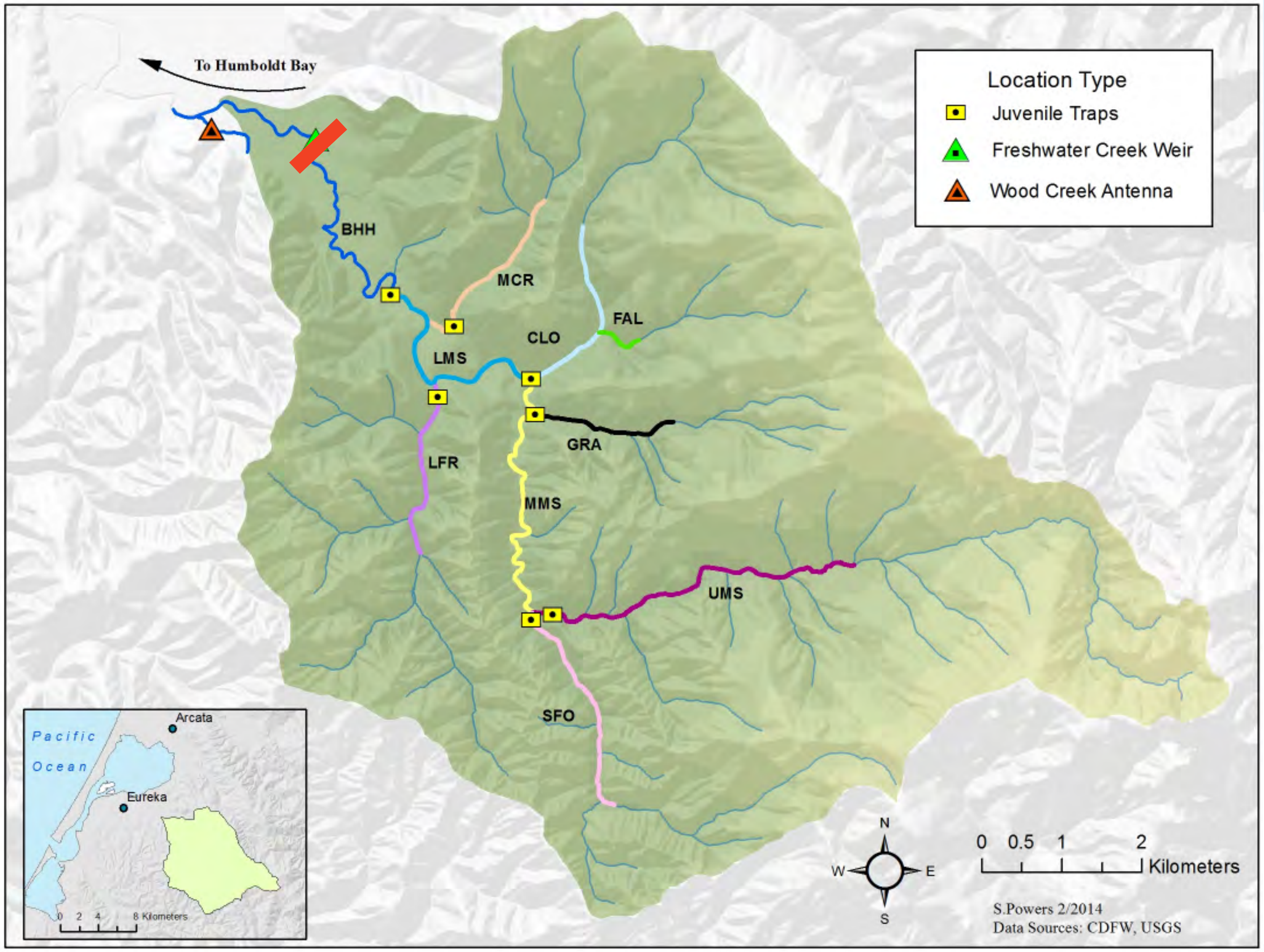


Freshwater Creek Life Cycle Monitoring Station



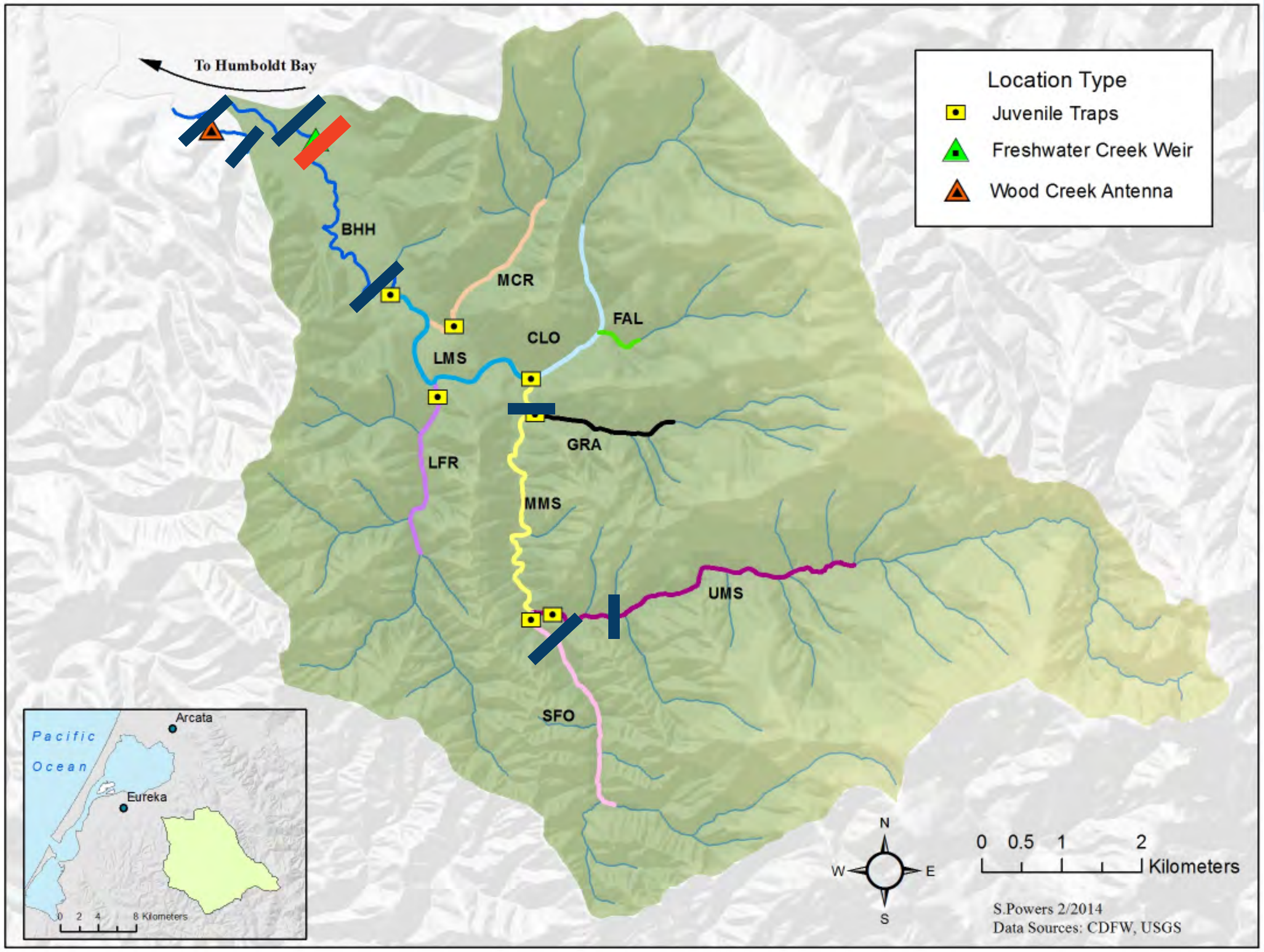
Area: 92 km^2 Anadromous habitat: 14.5 km

Freshwater Creek Life Cycle Monitoring Station

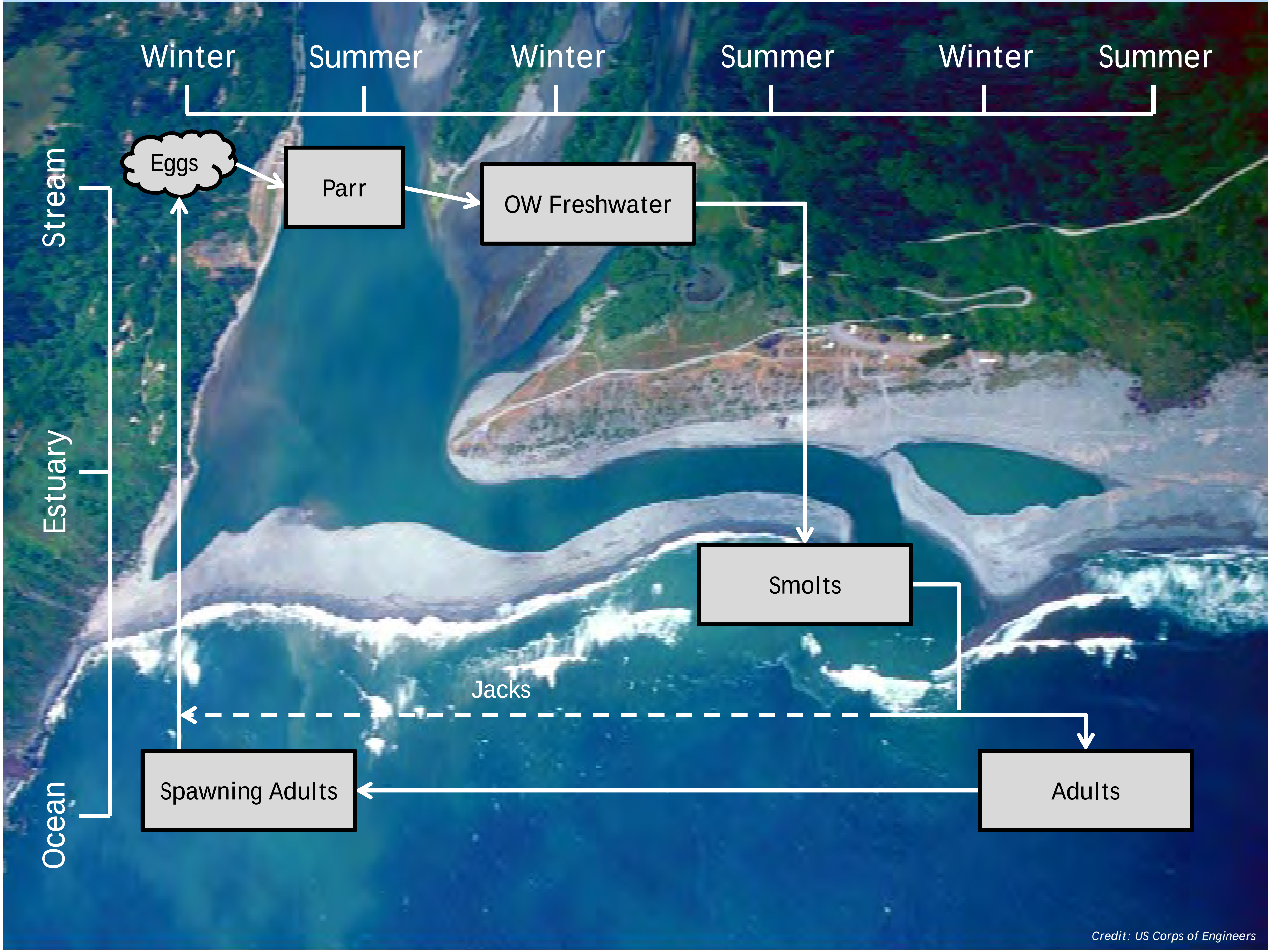


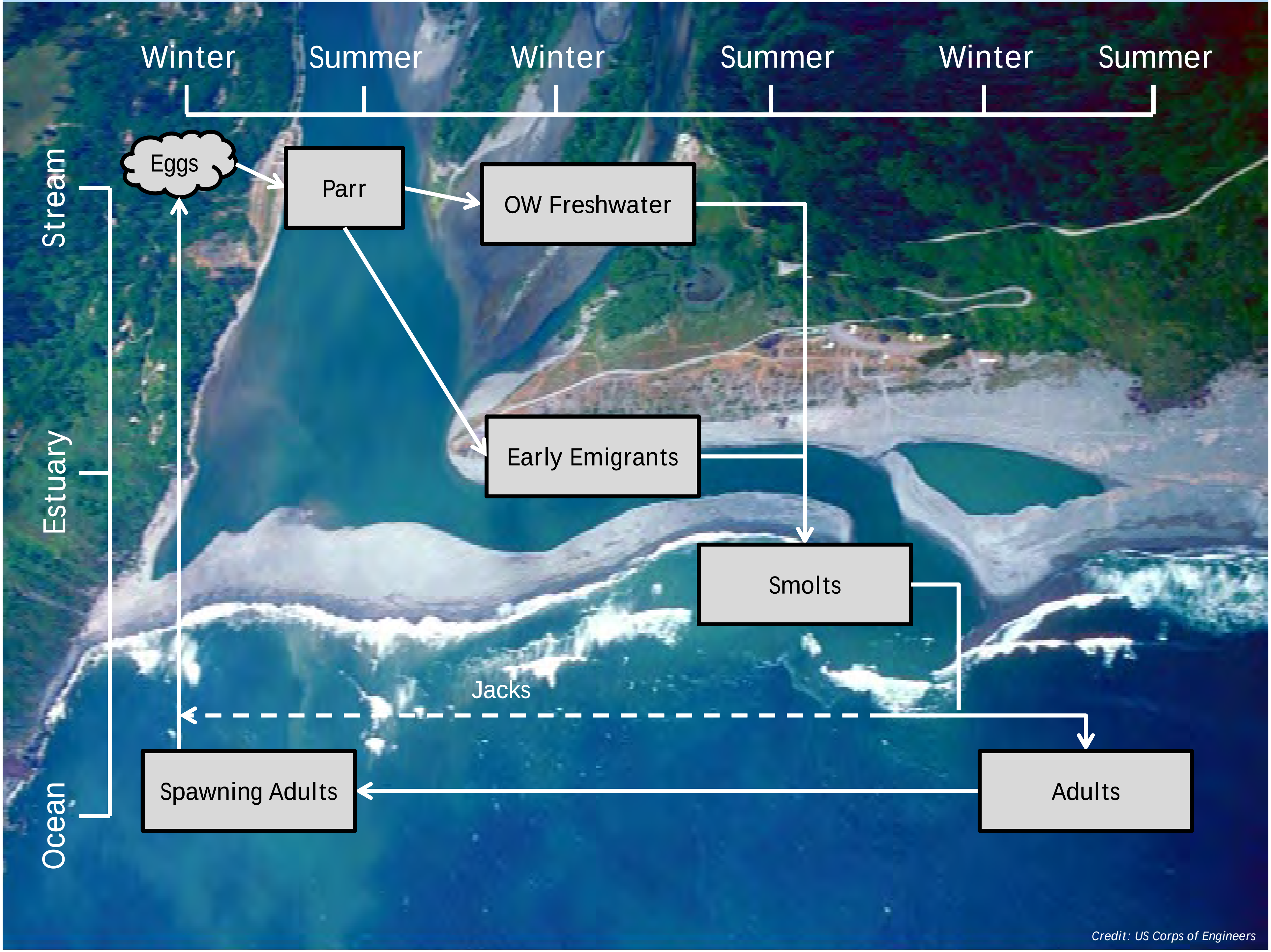
Permanent weir located near upper extent of tidally influenced habitat

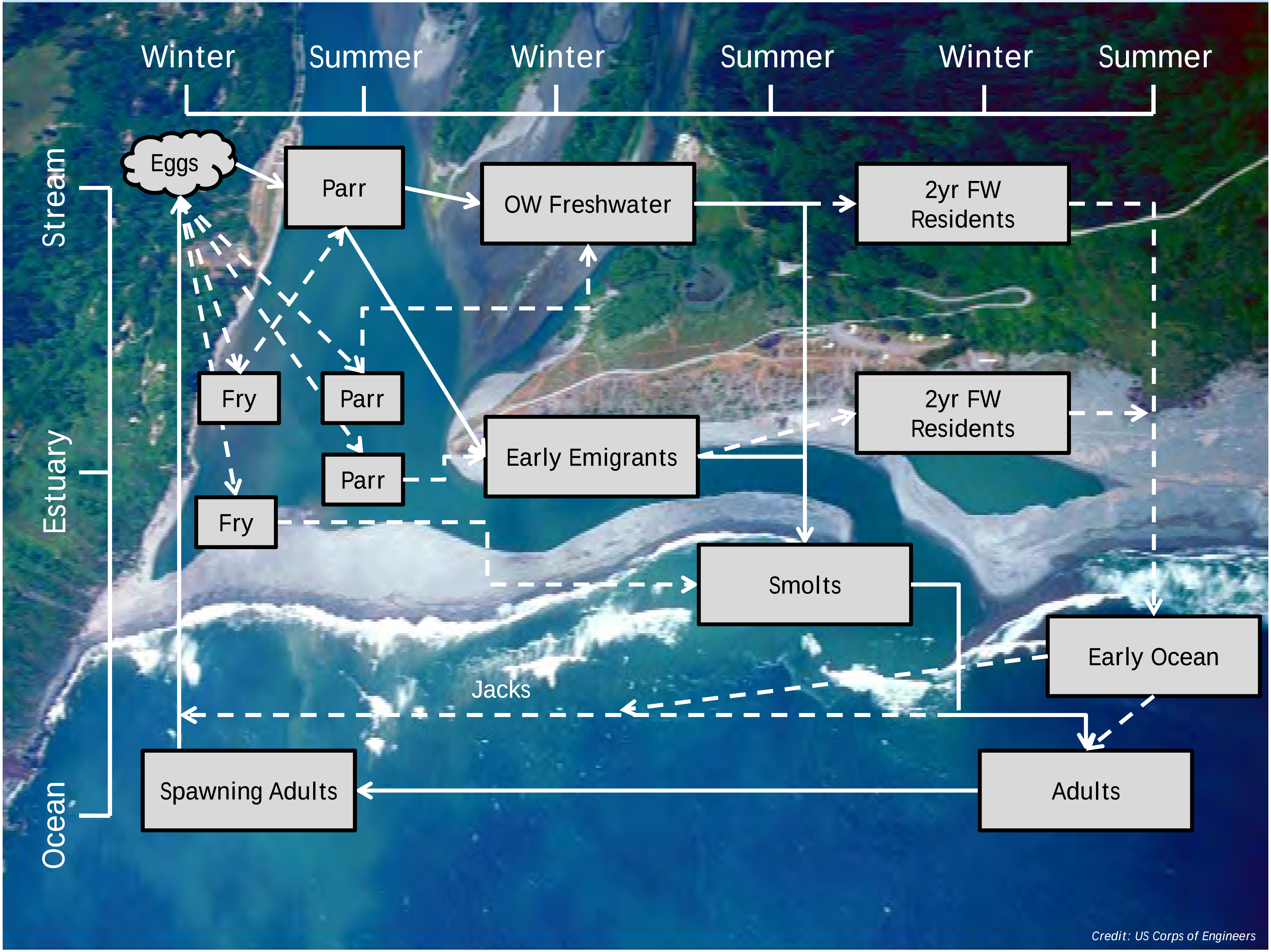
Freshwater Creek Life Cycle Monitoring Station

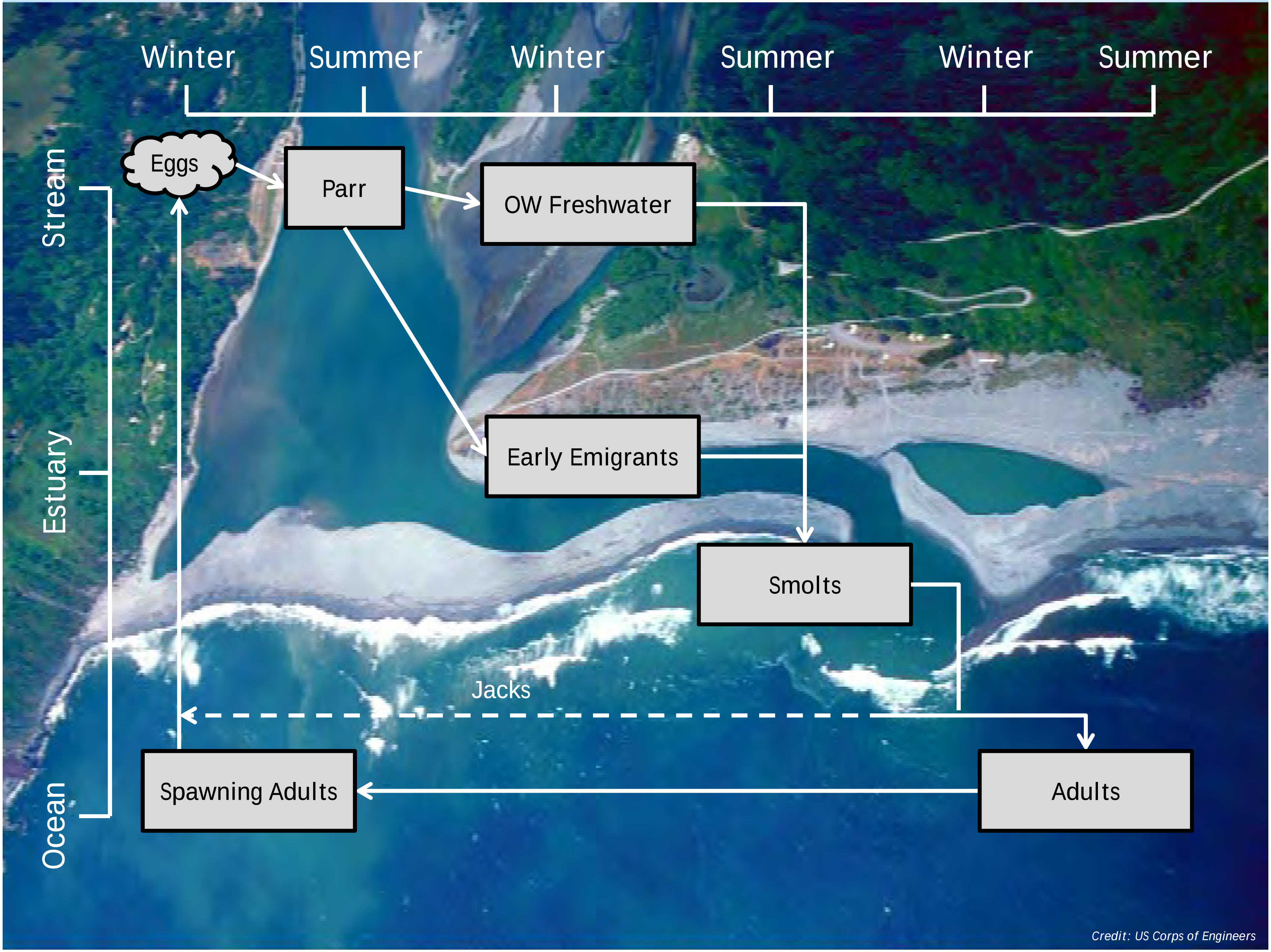


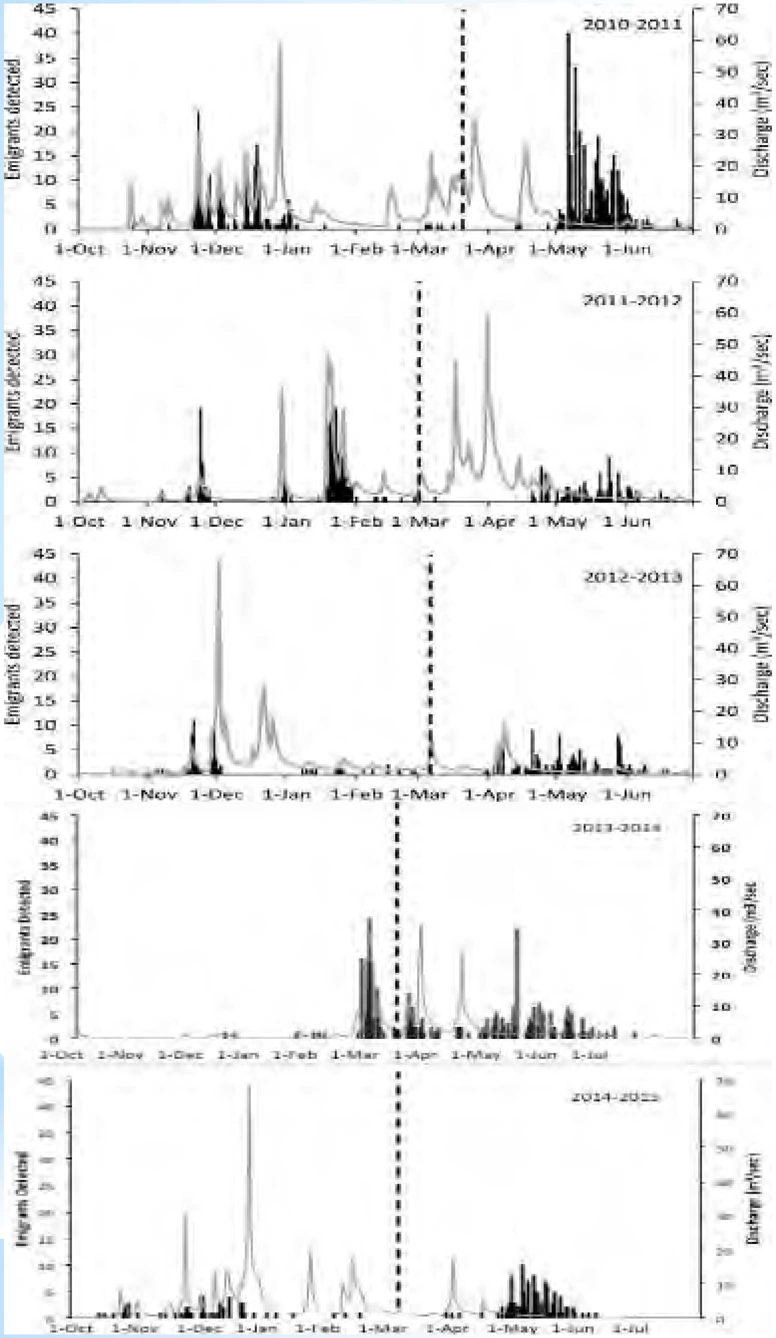
Antennas located throughout the basin and in wood creek marsh in the stream estuary ecotone


Winter
Summer
Winter
Summer
Winter
Summer
Stream
Estuary
Ocean
Eggs
Parr
OW Freshwater
Smolts
Jacks
Spawning Adults
Adults
Credit: US Corps of Engineers


Winter
Summer
Winter
Summer
Winter
Summer
Stream
Estuary
Ocean
Eggs
Parr
OW Freshwater
Early Emigrants
Smolts
Jacks
Spawning Adults
Adults
Credit: US Corps of Engineers

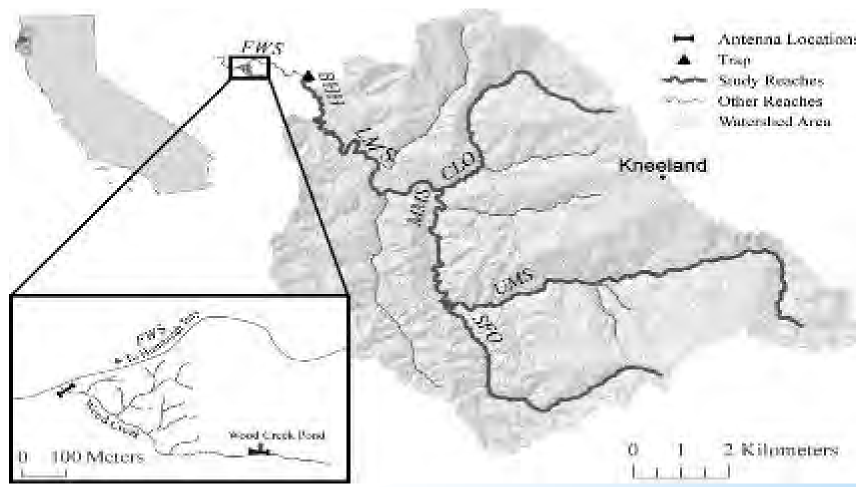

Winter
Summer
Winter
Summer
Winter
Summer
Stream
Estuary
Ocean
Eggs
Parr
OW Freshwater
2yr FW Residents
Fry
Parr
Parr
Early Emigrants
2yr FW Residents
Fry
Smolts
Early Ocean
Jacks
Spawning Adults
Adults
Credit: US Corps of Engineers

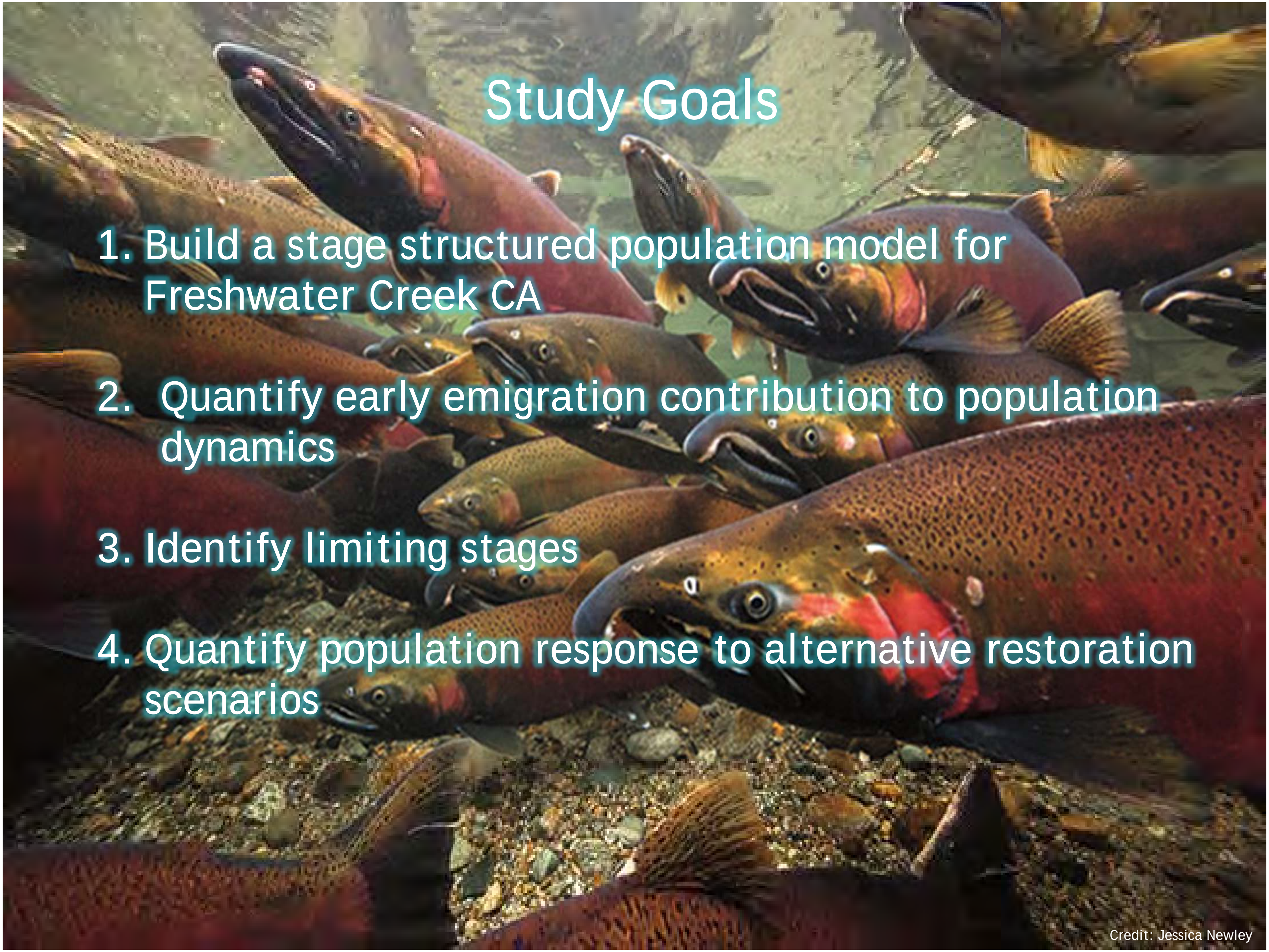

Winter
Summer
Winter
Summer
Winter
Summer
Stream
Estuary
Ocean
Eggs
Parr
OW Freshwater
Early Emigrants
Smolts
Jacks
Spawning Adults
Adults
Credit: US Corps of Engineers



Early Emigrants

- Missed by spring migrant trapping
- Early emigrants account for 2-29% of fall tagged fish (2010-2015)
- Many rear in the estuary and associated tidally influenced habitat





Study Goals

1. Build a stage structured population model for Freshwater Creek CA

2. Quantify early emigration contribution to population dynamics

3. Identify limiting stages

4. Quantify population response to alternative restoration scenarios

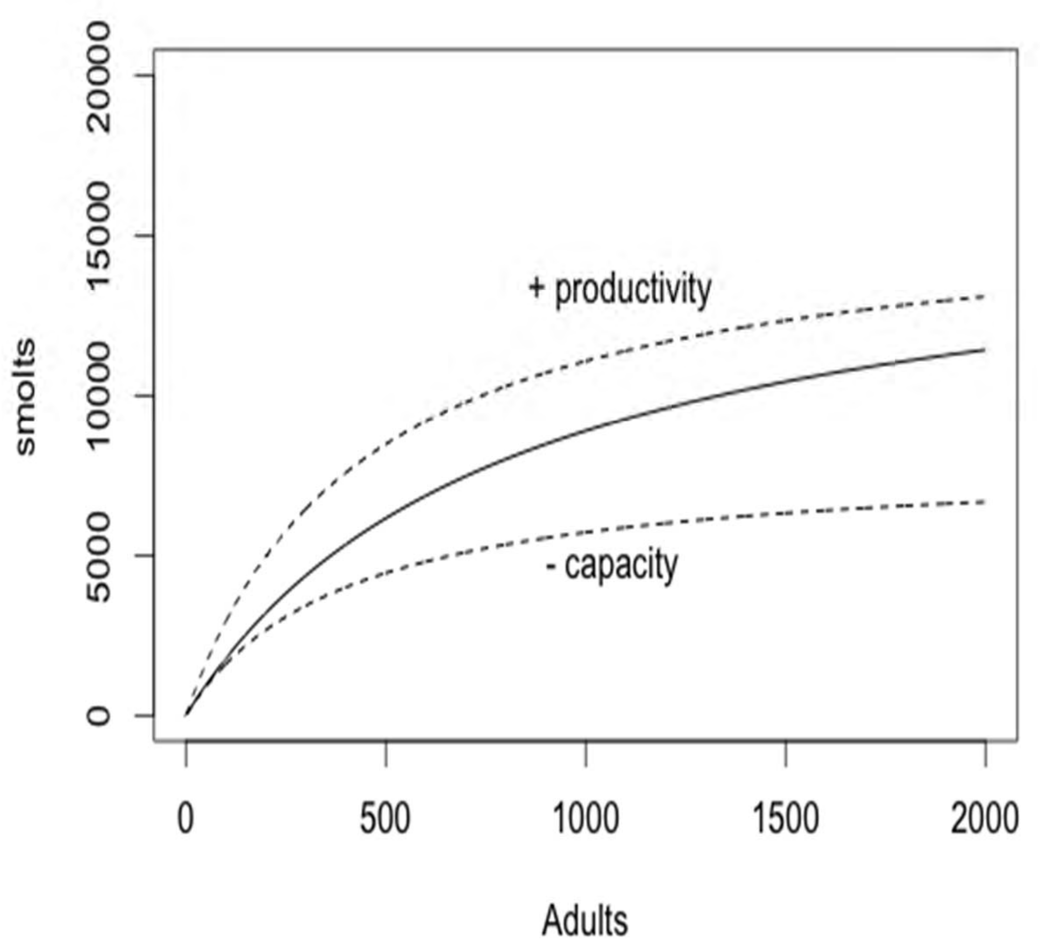
Basic Model Framework

- Modified Leslie matrix design
- Parameterized to reach-scale resolution
- 6 reaches and estuary included
- Beverton-holt functions
  - Used to model parameters associated with:
    - Habitat capacity
    - Productivity (survival)

(1) $$N_{s+1} = \frac{N_s}{\frac{1}{p_{s\rightarrow s+1}} + \frac{1}{c_{s+1}} N_s}$$

(2) $$p_{s\rightarrow s+1} = \prod_r p_{s\rightarrow s+1,r}$$

(3) $$c_{s\rightarrow s+1} = \prod_r c_{s\rightarrow s+1,r}$$



Parameterizing The Model

- Cormack-Jolly-Sebert modeling using Program Mark and standard statistical methods

- Parameterized with CDFW data:
  - Overwinter survival
  - Early emigration parameters
  - Marine survival
  - Carrying capacity
  - Spring/Summer survival
  - Fecundity +(Shapilov and Taft 1954)

- Literature values used for stages with incomplete/missing data:
  - Egg survival (Moring and Lantz, 1975)

↓

<°)))><

CJS Modeling Results

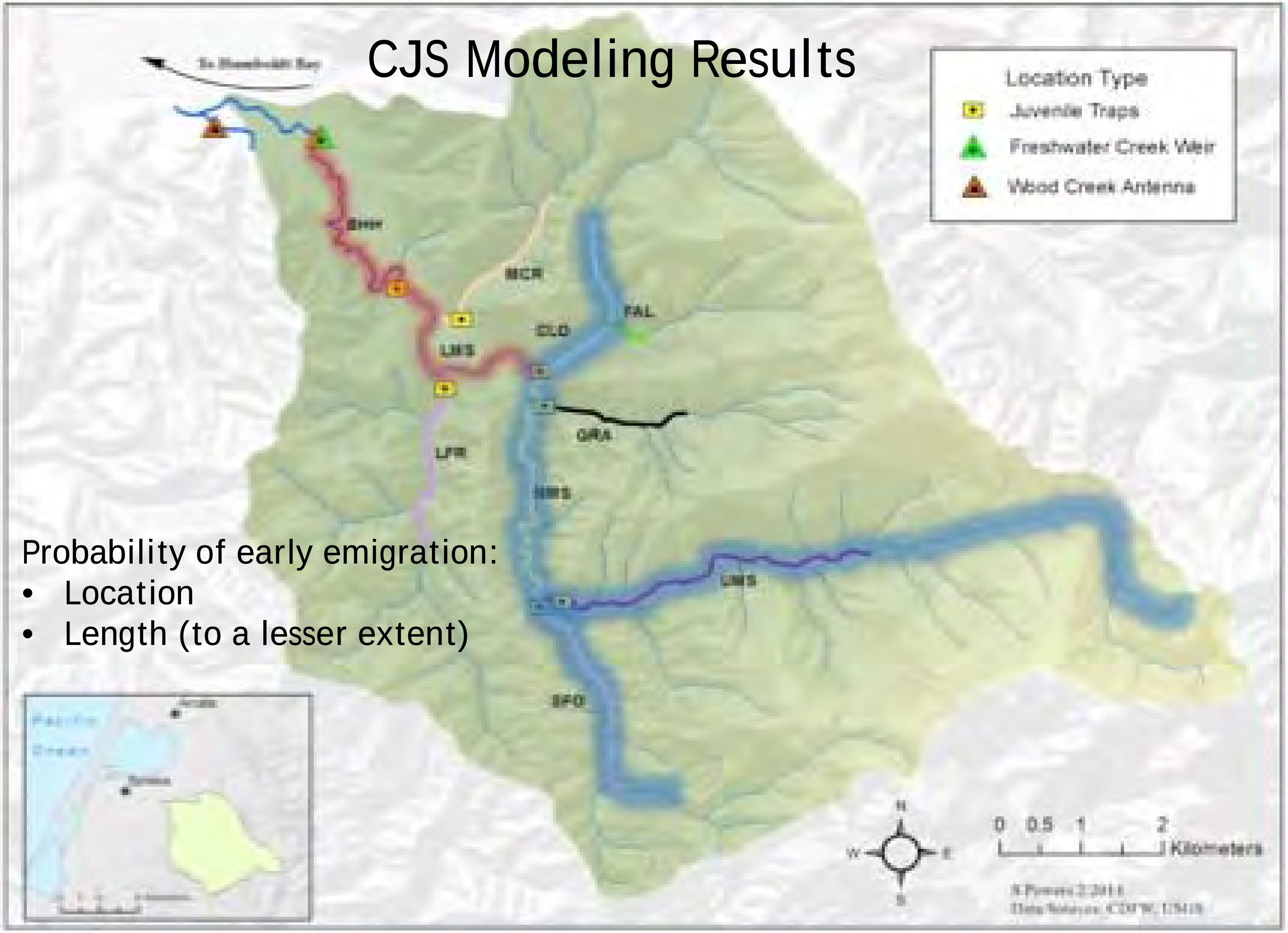
Overwinter Survival:

>

Model Notation[3]	***Delta AICc***	***QAICc Weight***	***Model Likelihood***	***No. Parameters***	***Deviance***
*Φ(RT*t* L)p(t)*	0	0.57782	1	7	1550.521
*Φ (RT*t+L)p(t)*	0.878	0.37236	0.6444	8	1549.372
*Φ (R*t*L)p(t)*	4.975	0.04802	0.0831	15	1539.174
*Φ(R*t*L)p(R*t)*	11.542	0.0018	0.0031	22	1531.269
Φ (t)p(t)	46.122	0	0	5	1600.689
*Φ (RT*t* L)p(t)*	47.246	0	0	6	1599.792
*Φ (RT*t)p(t)*	49.123	0	0	6	1601.669
*Φ (t)p(R*t)*	51.979	0	0	14	1588.23
*Φ (R*t)p(t)*	55.479	0	0	14	1591.731
*Φ(R*t)p(R*t)*	65.094	0	0	22	1584.822

[3] Model Notation includes survival (Φ), and recapture (*p*) including time (t), Reach Type (RT), Reach (R), and Fork Length (L) effect.

CJS Modeling Results



Probability of early emigration:

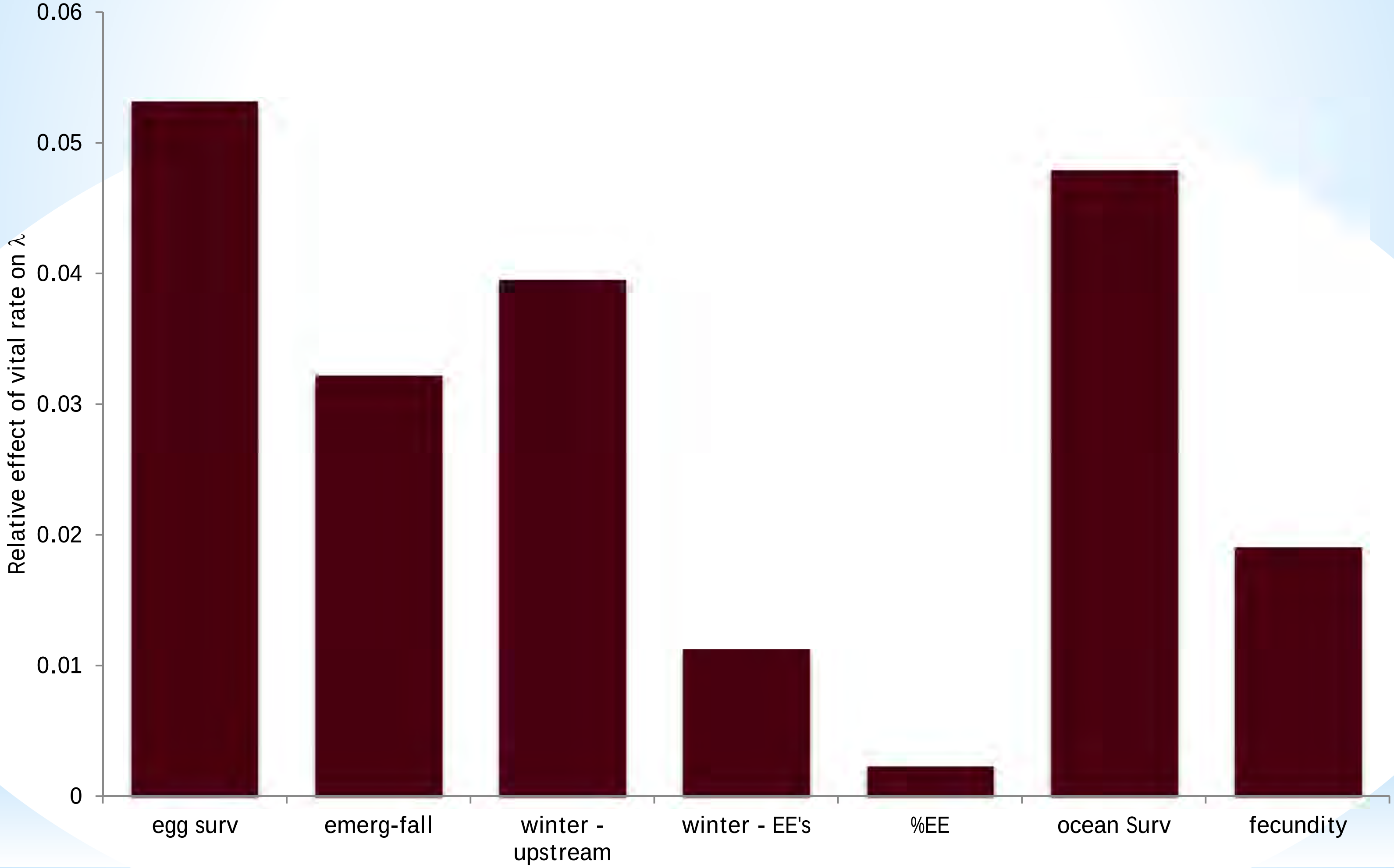
- Location
- Length (to a lesser extent)

The Code Slide

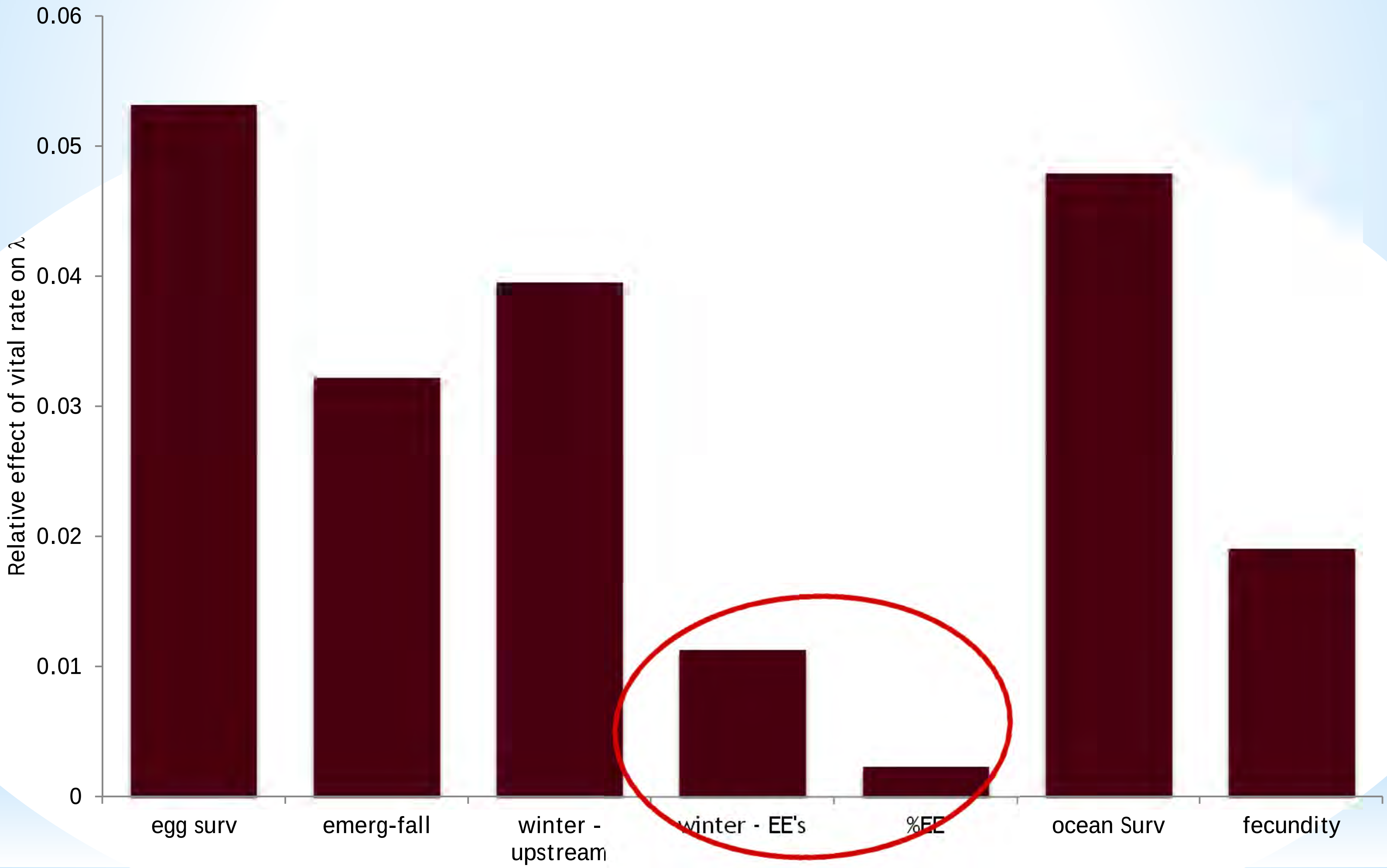
```
cor.matrix <- matrix(0,nrow=6,ncol=6)
    for(i in 1:6){
      for(ii in 1:6){
        mod <- cor.test(ow.1[,i],ow.1[,ii])
        if(mod$p.value < 0.1){
          cor.matrix[i,ii] <- mod$estimate}
      }}
    names <- c("BHH","LMS","MMS","UMS","CLO","SFO")
    rownames(cor.matrix) <- paste(names)
    colnames(cor.matrix) <- paste(names)

    cor.matrix

    corrmx <- cor.matrix# correlation matrix

    eig <- eigen(corrmx) #get them eigens
    W <- eig$vectors # Makes matrix of eigen Vectors: W
    D <- eig$values # Makes matrix of eigen Values: D
    D12 <- sqrt(abs(matrix(diag(D),nrow=np))) # D12 is a
matrix of the square root of the eigen values on
diagonal, the rest of the elements are zero

    C12 <- W%*%D12%*%t(W) # Generates the square root of
correlation matrix corrmx

results <- matrix(NA,nrow=tmax,ncol=np)
    colnames(results) <- paste(names)

    for( tt in 1:tmax){  # Loop for each years vital
rates
      normvals <- matrix(rnorm(np))  #makes a set of
random standard normal values
      corrnorms <- C12%*%normvals #make them norms into
correlated norms
      bhh.vr <-
betaval(vrmeans[1],vrvars[1],normfx(corrnorms[1]))
#converts each normal into the beta equivalent via the
Cumultive distribution value
      lms.vr <-
betaval(vrmeans[2],vrvars[2],normfx(corrnorms[2]))
```

```
if(Nt[5]>10){
        total.ad <- round(Nt[5])  #this is the total
number of adults returning to spawn
        fems <- sum(rbinom(total.ad,1,0.5)) # This is the
total number of those that are female
        if(fems<1){fems<-1} # This is just so the code
doesn't break down if by statistical anomaly there are no
females
        f.lengths <- rnorm(fems,66.90909,5.933774)
#normally distributed lengths of all the females
        egg.counts <- sapply(f.lengths,l.egg) #applying
the length to egg function to the length of each female
        f <- sum(egg.counts)/fems #getting the average
egg count for the cohort
        scour<- sum(rbinom(fems,1,0.85))/fems #
calculating the redd mortality rate due to scour
(nickelson and lawson 1998)
        if(scour==0){scour<-0.85}
        fem.pct <- fems/total.ad #percentage of the
adults that are female
        Fert <- f*fem.pct*scour  #fertility rate
      }else{Fert <- f*0.5*.85}



      M <- matrix(data=c(0,    0,   0,   0,  Fert,
                         Y1,   0,   0,   0,   0,
                         0,  Y2n,   0,   0,   0,
                         0,  Y2e,   0,   0,   0,
                         0,    0,  Y3n, Y3e,  0

      ),
```

Sensitivity Analysis



Sensitivity Analysis

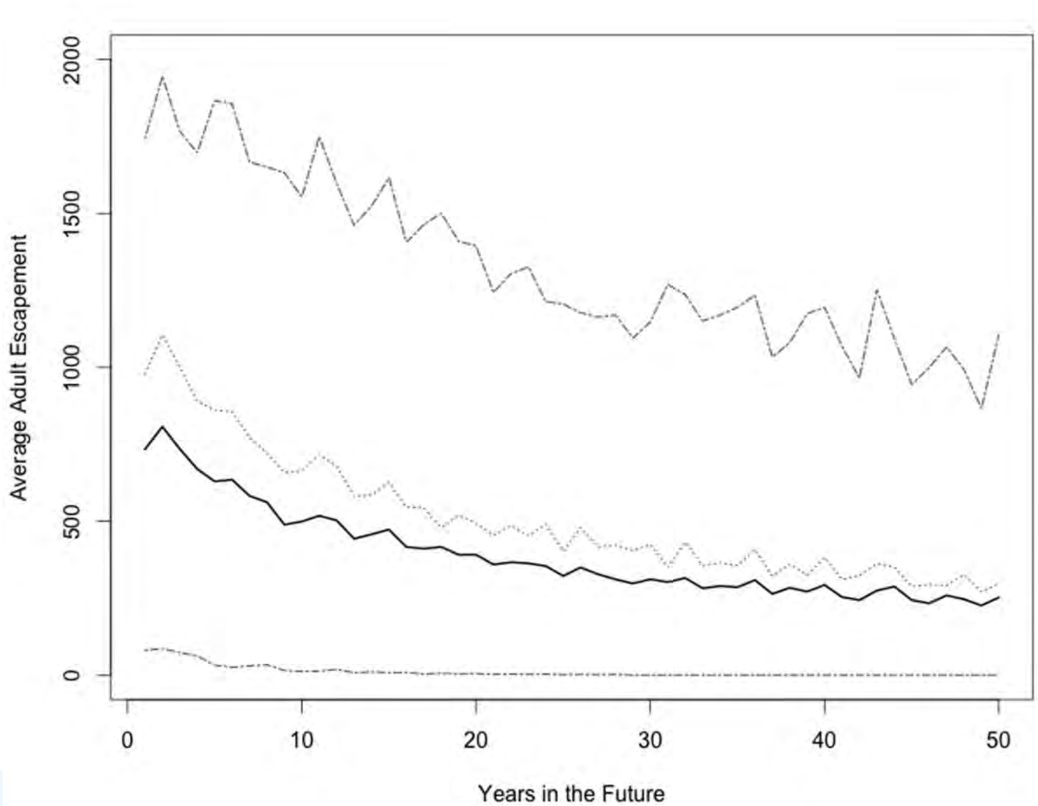


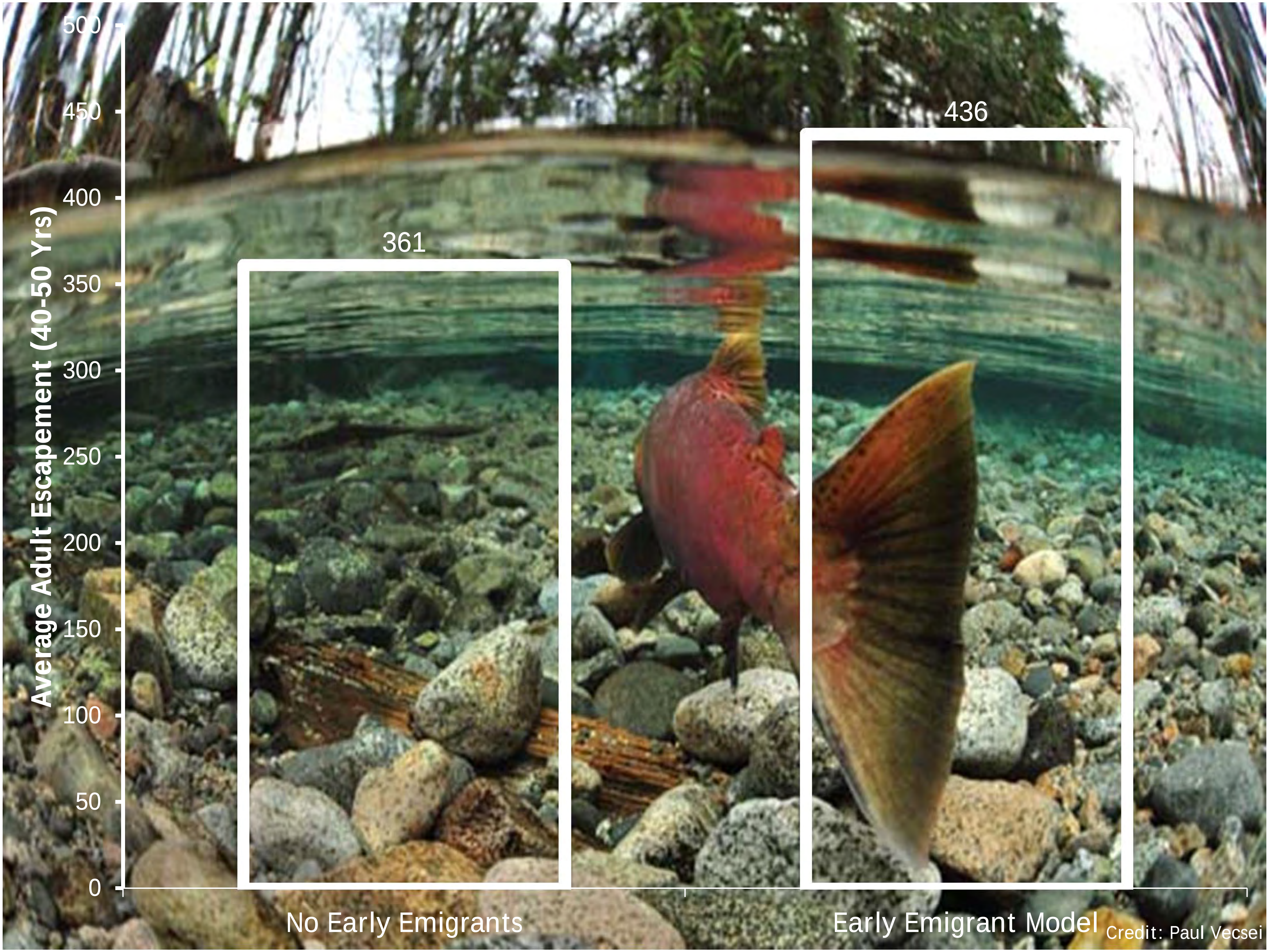
Minimal relative effect of EE parameters on population growth

Simulation Analysis: Population Trajectory and Extinction Probability

Metrics:

- Quasi-Extinction= 20 > Spawners for 3 consecutive years
- Average spawner escapement over the last 10 years of simulation




Average Adult Escapement (40-50 Yrs)
500
450
400
350
300
250
200
150
100
50
0
361
436
No Early Emigrants
Early Emigrant Model
Credit: Paul Vecsei

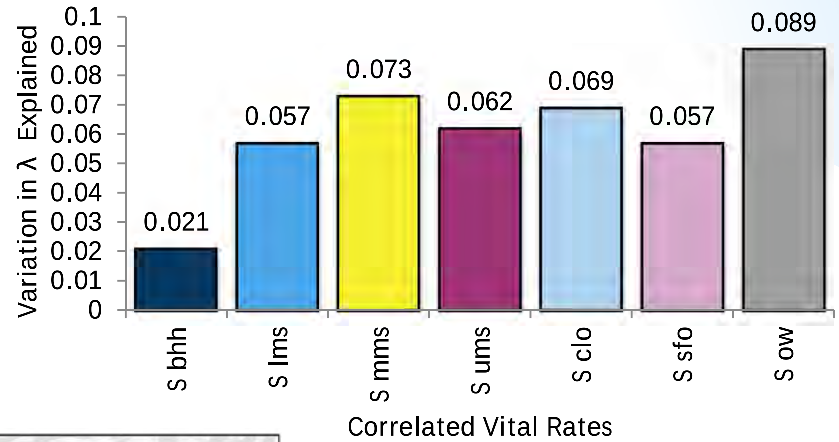
Probability of Extinction (50 Yrs)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.3643
0.1306
No Early Emigrants
Early Emigrant Model

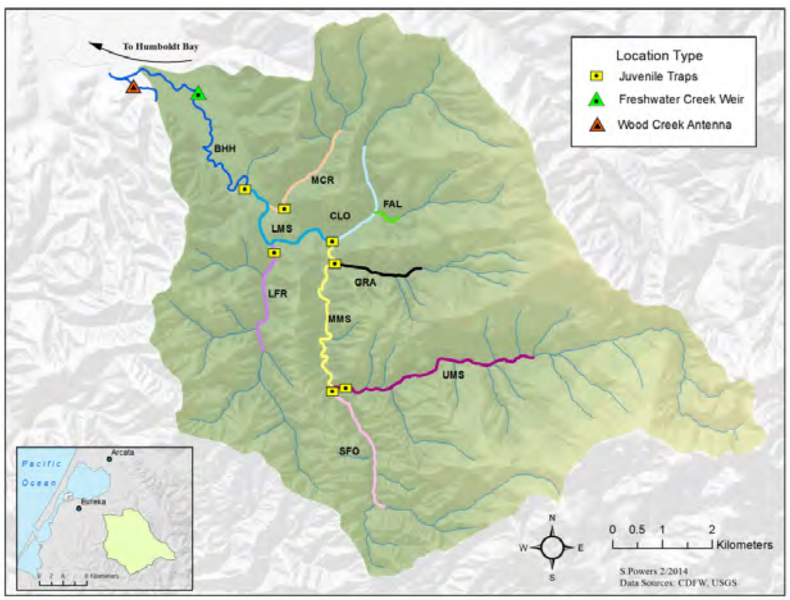
Slow water – Survival Relationship and Restoration Scenarios

- Winter slow water habitat associated with overwinter survival (In prep: John Deibner-Hansen Masters Thesis)
- 10 backwater alcoves incorporated into model (Solazzi 2000)
- Variable configurations
- Little data for how estuary restoration affects early emigrants
  - Modeled under three scenarios:
    - + Productivity
    - + Capacity
    - +Productivity + Capacity

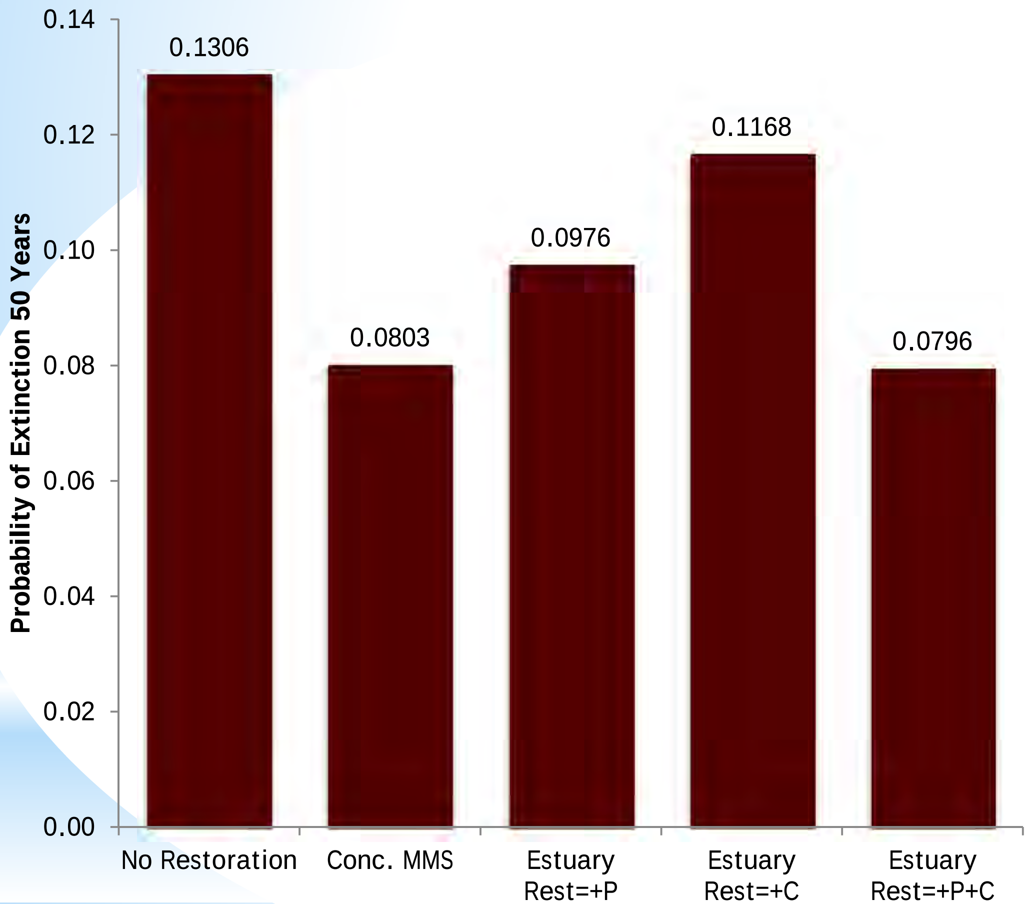
Credit: Molly Gorman

Reach Scale OW Survival Sensitivities





Simulated Restoration Scenarios



Conclusions:

Early emigrant life history is important for population viability

Restoration scenarios produce similar results regardless of where they are located

Early emigrant parameters represent minimums:

- Stream estuary ecotone provides productive habitat for smolt emigrants on their way to the ocean
- Estuary restoration efforts provide additional off channel refugia during winter high flows

Further study of coho usage of SEE needed to improve parameter estimates (+productivity? +capacity? Overwinter survival?)


Acknowledgments
• Darren Ward - HSU
• Seth Ricker - CDFW
• Mike Wallace - CDFW
• Eric Bjorkstedt - NOAA SWFSC
• Chris Dugaw - HSU
• The Lab Family (Molly, Justin, Michelle, John, and Sean)
• John Deibner-Hansen
• California Department of Fish and Wildlife
• NOAA
• Humboldt Fishin' LumberJacks
• Danielle Zumbrun Memorial Scholarship
• The R Development Core Team


Questions?

Illuminating Population Consequences of Disparate Survival & Behavior Between Hatchery & Wild Chinook Salmon: The Role of Salmon Life-Cycle Models

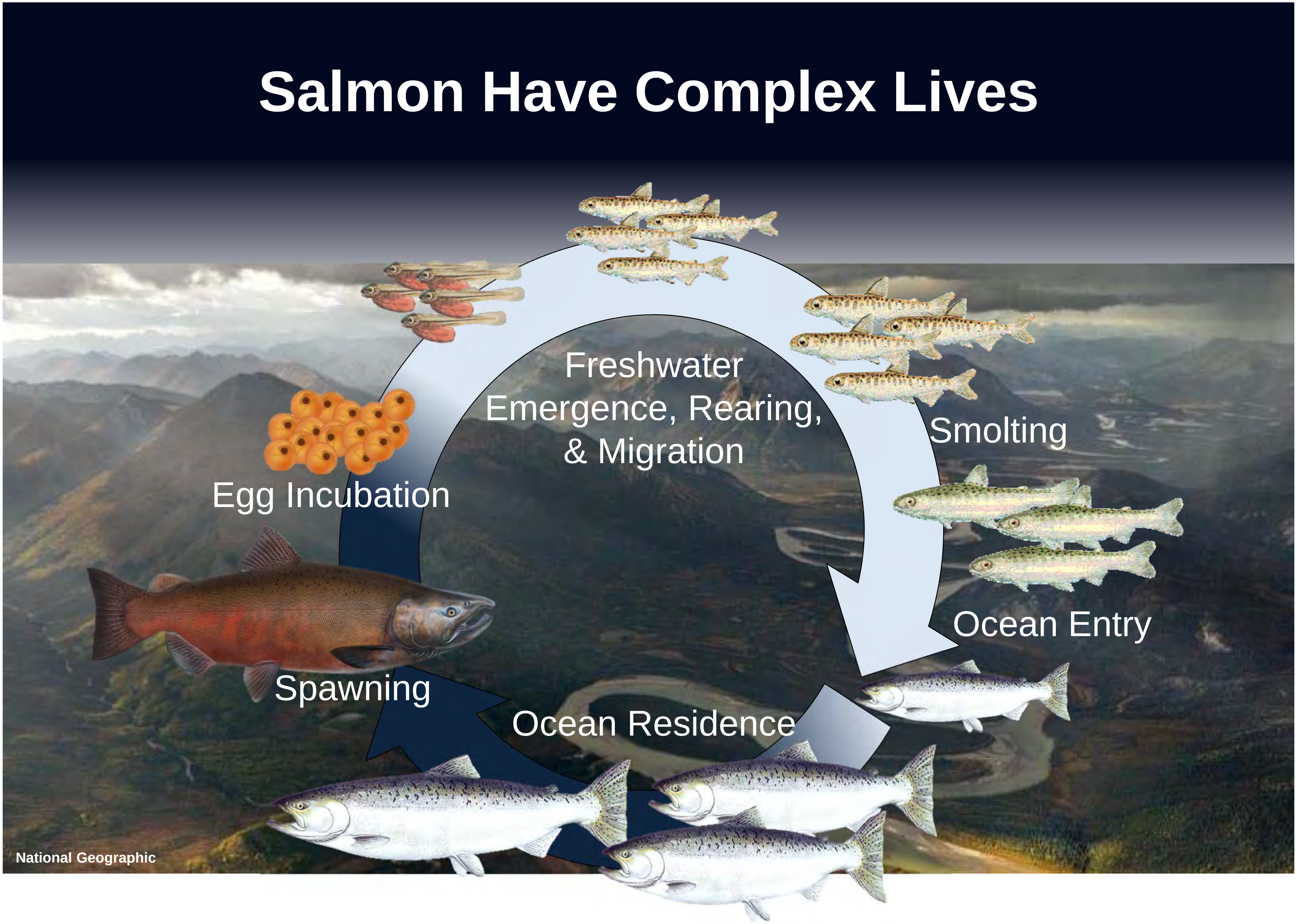
Michael Beakes[1,2]

Coauthors: William H. Satterthwaite[1], Colleen M. Petrik[1], Eric Danner[1], & Steve Lindley[1]

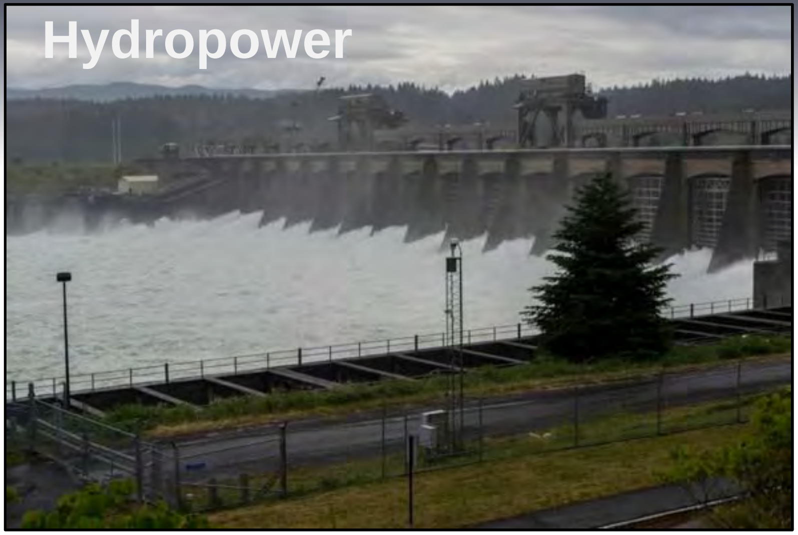
34th Annual Salmon Restoration Conference
April 6-9, 2016

[1]NOAA Southwest Fisheries Science Center
[2]Cramer Fish Sciences

Salmon Integrate Across Riverscapes


Salmon Have Complex Lives
Freshwater
Emergence, Rearing,
& Migration
Egg Incubation
Smolting
Ocean Entry
Spawning
Ocean Residence
National Geographic

“4Hs” of Salmon Population Decline in the Pacific Northwest



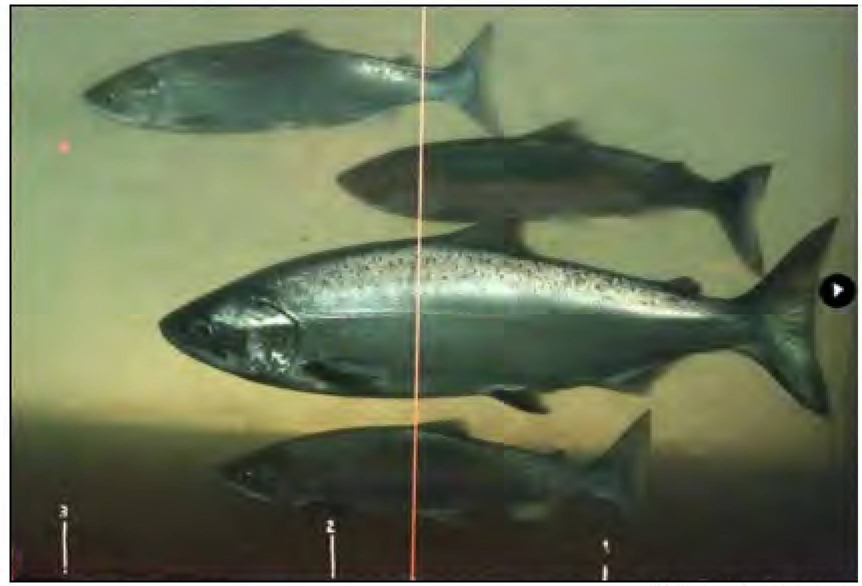
We Invest Millions To Restore Salmon

COLUMBIA RIVER SALMON THRIVE ON $500 MILLION ANNUAL SUBSIDY

July 12, 2014 - by Russ George - in Bizzare News For The Planet, Business News

$250 per fish is spent each year to keep Columbia river golden salmon coming back!

Feds spent $700 million on habitat restoration in Columbia River Basin



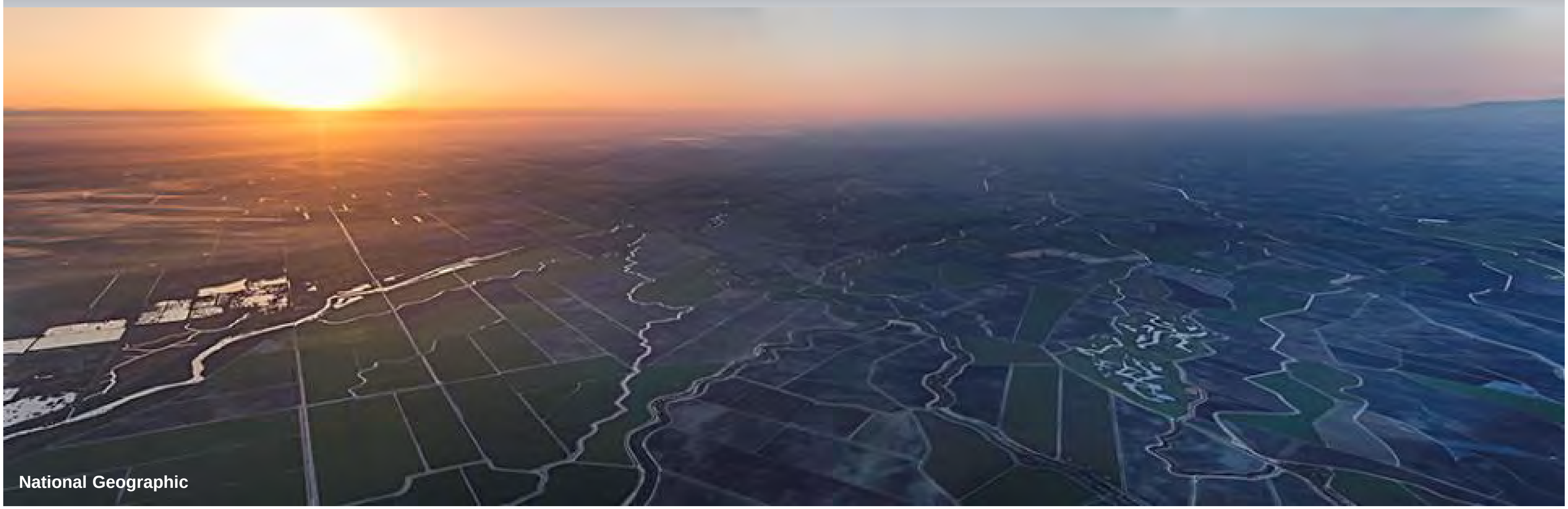
Rick Bowmer / Associated Press file

In this June 27, 2012 photo, a chinook salmon, second from the bottom, swims with sockeye salmon at the Bonneville Dam fish-counting window near North Bonneville, Washington, on the Columbia River. Plans for various iterations of salmon restoration in the Columbia River Basin have been litigated in court for more than two decades and the battle is about to resume.

"…$550 million for fiscal years 2016-2017. That annual spending has risen from about $330 million during the 2007-2009 time frame."

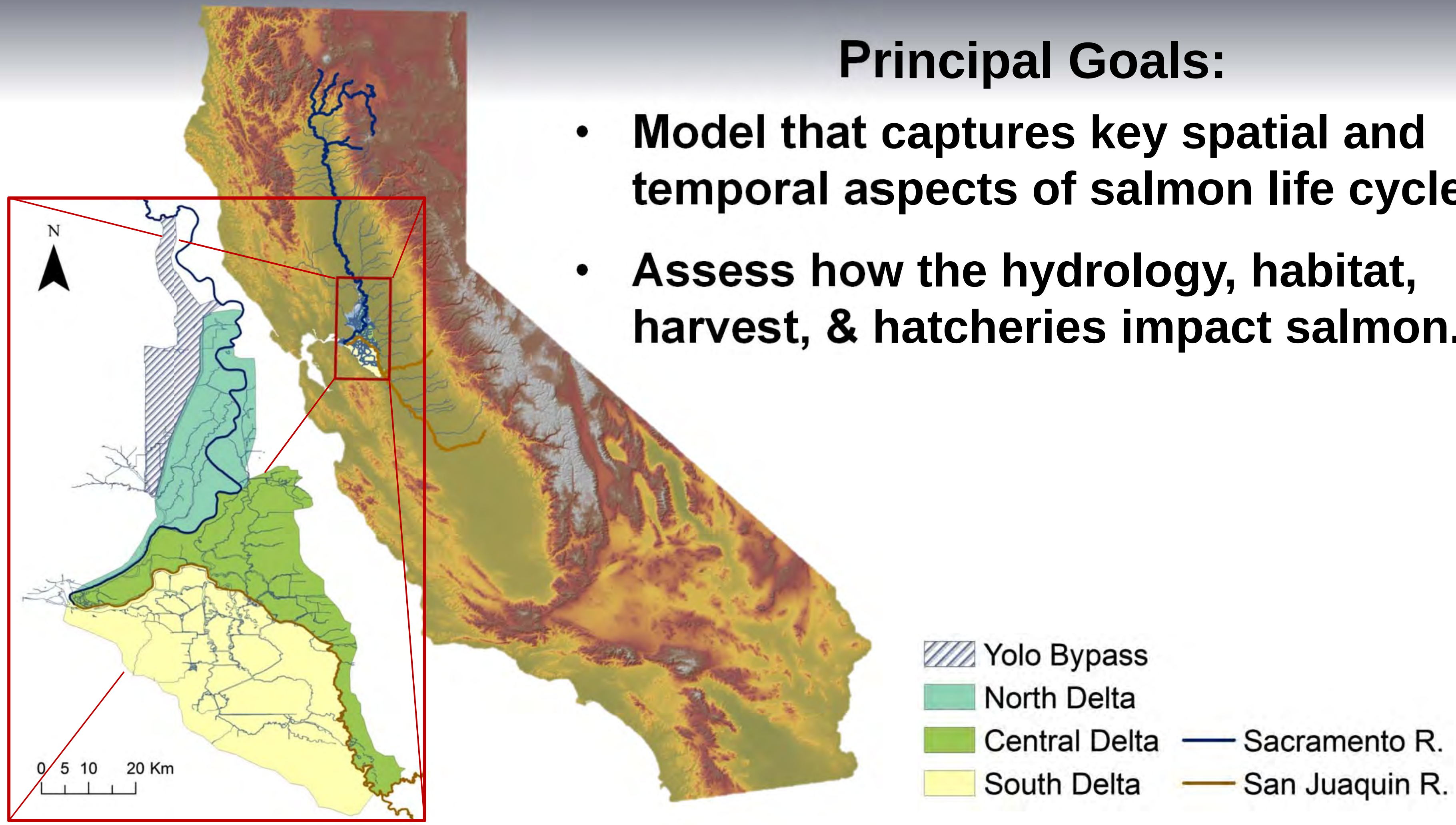
- The Columbia Basin Fish & Wildlife News Bulletin

California Salmon Live In A Radically Transformed World



We need better tools to examine how salmon interact with this environment.

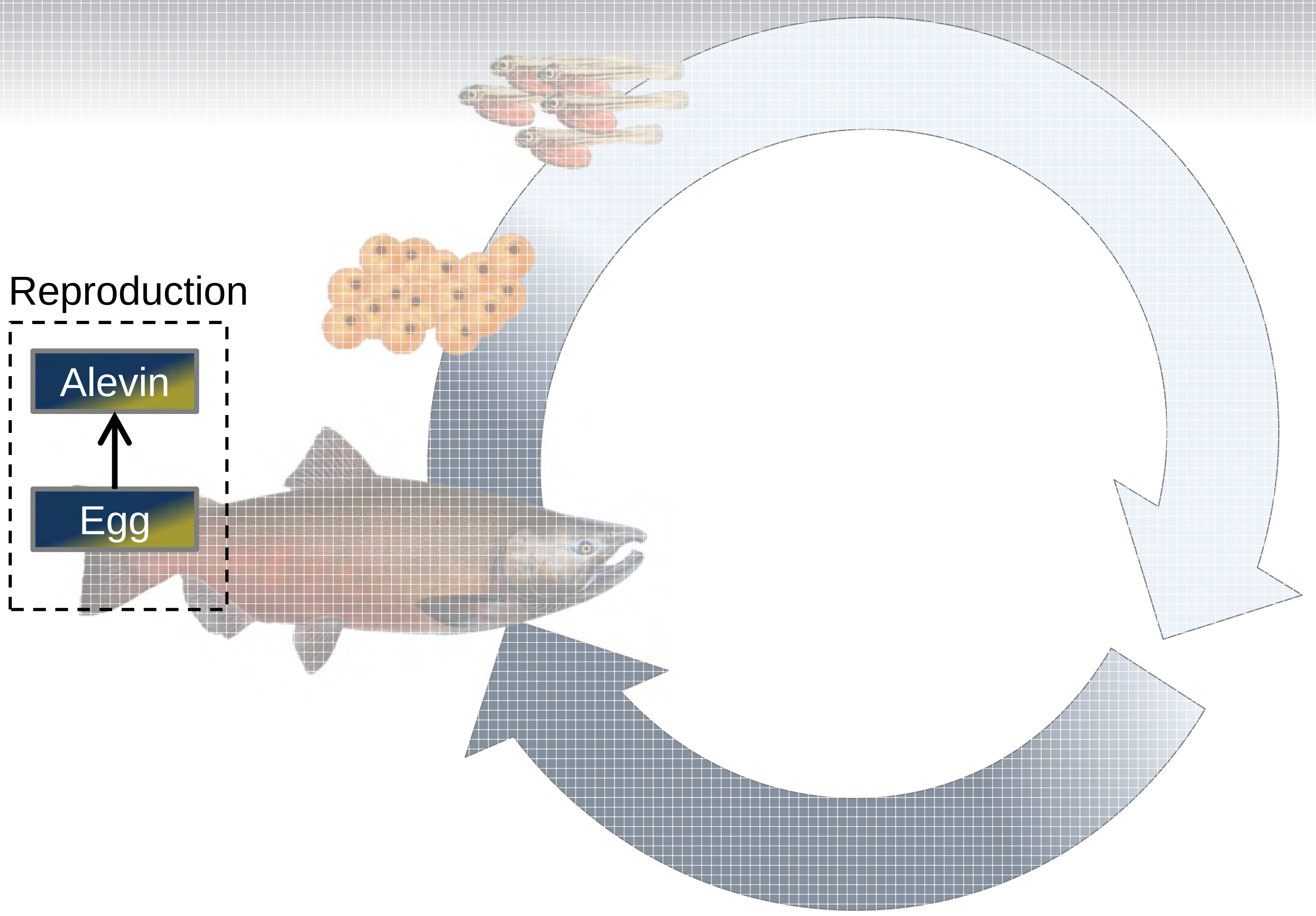
Building Models For Salmon In The California Central Valley



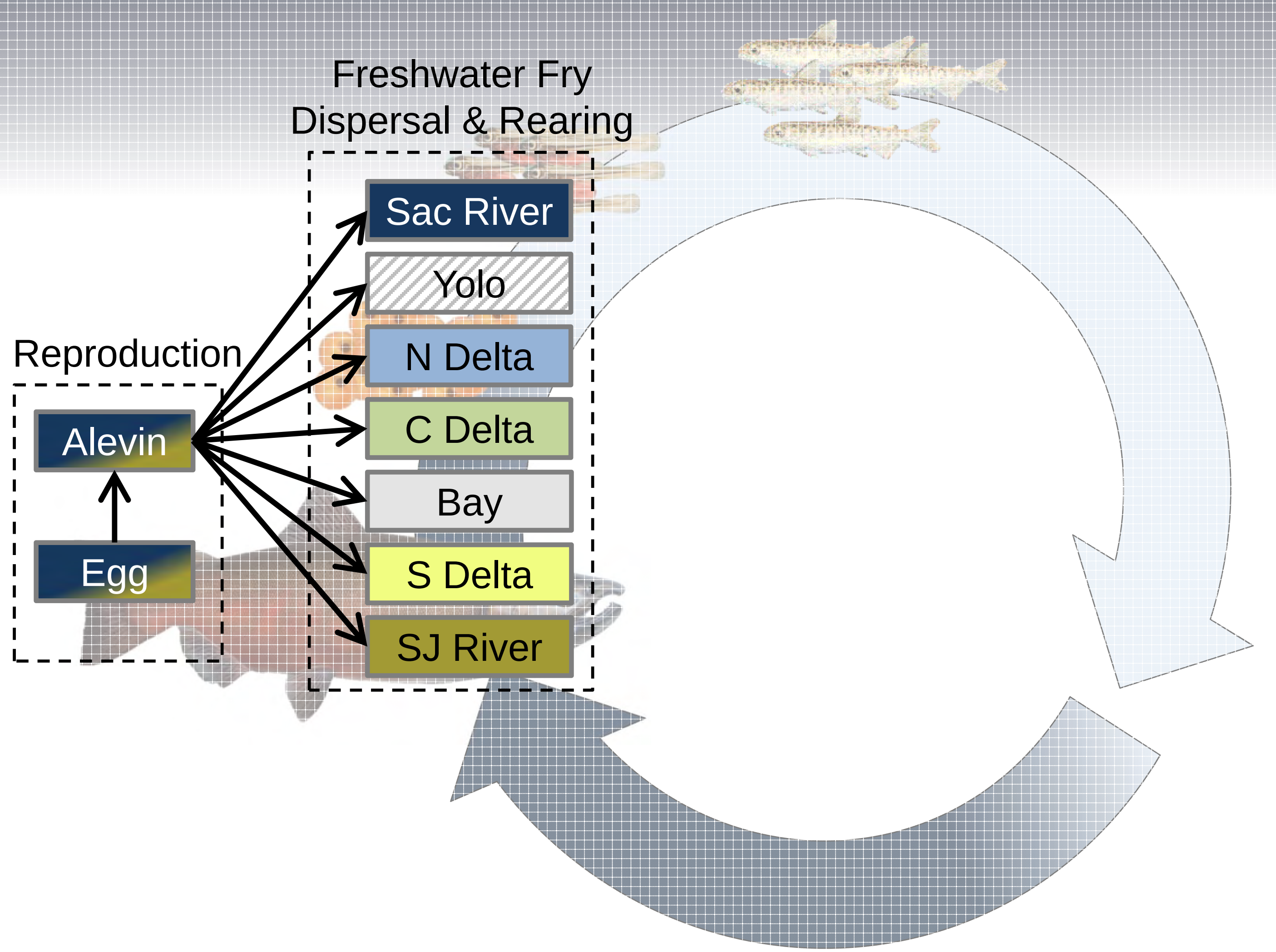
Principal Goals:

- **Model that captures key spatial and temporal aspects of salmon life cycle.**
- **Assess how the hydrology, habitat, harvest, & hatcheries impact salmon.**

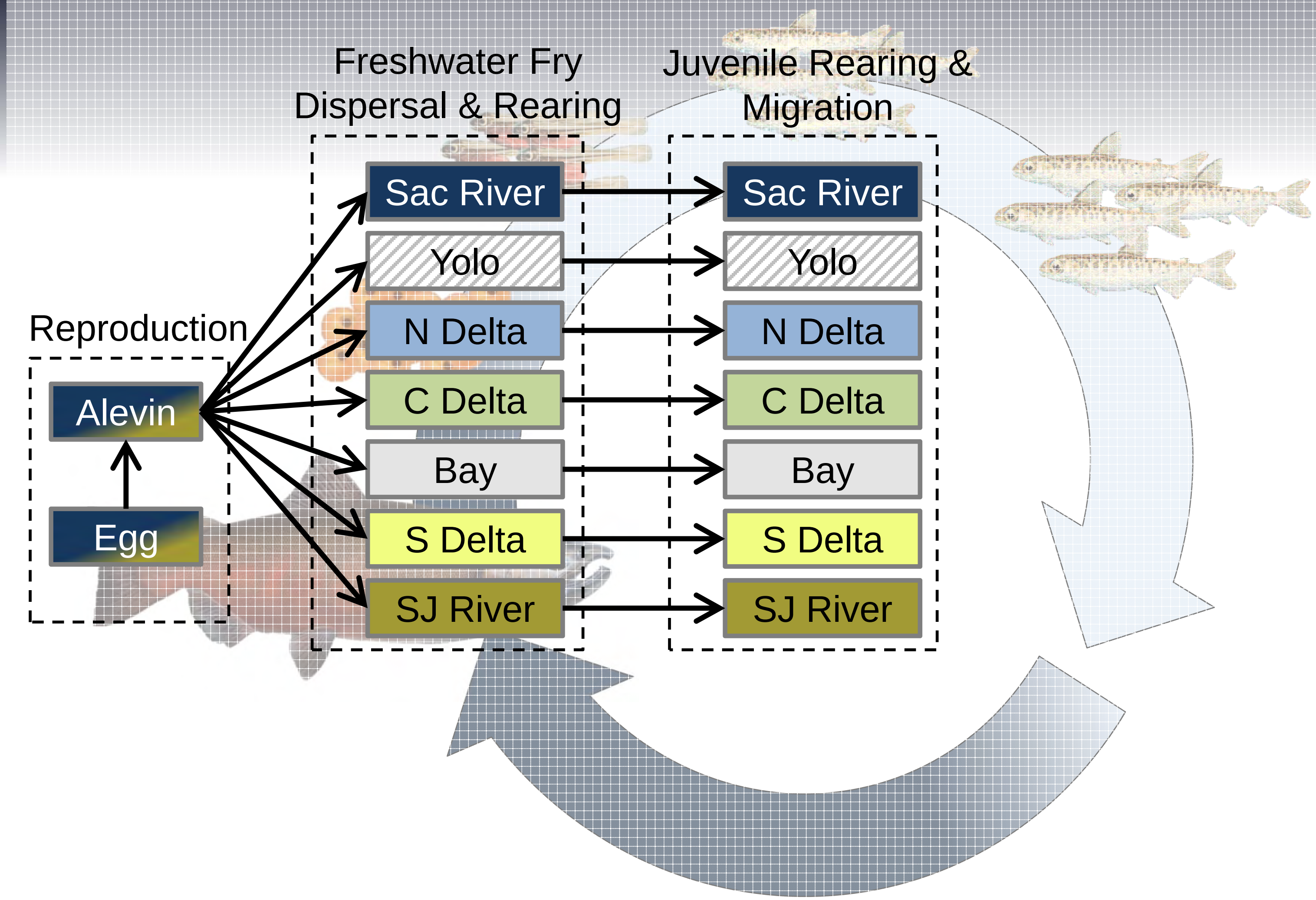
Adult Abundance & Environment Predicts Alevin Production



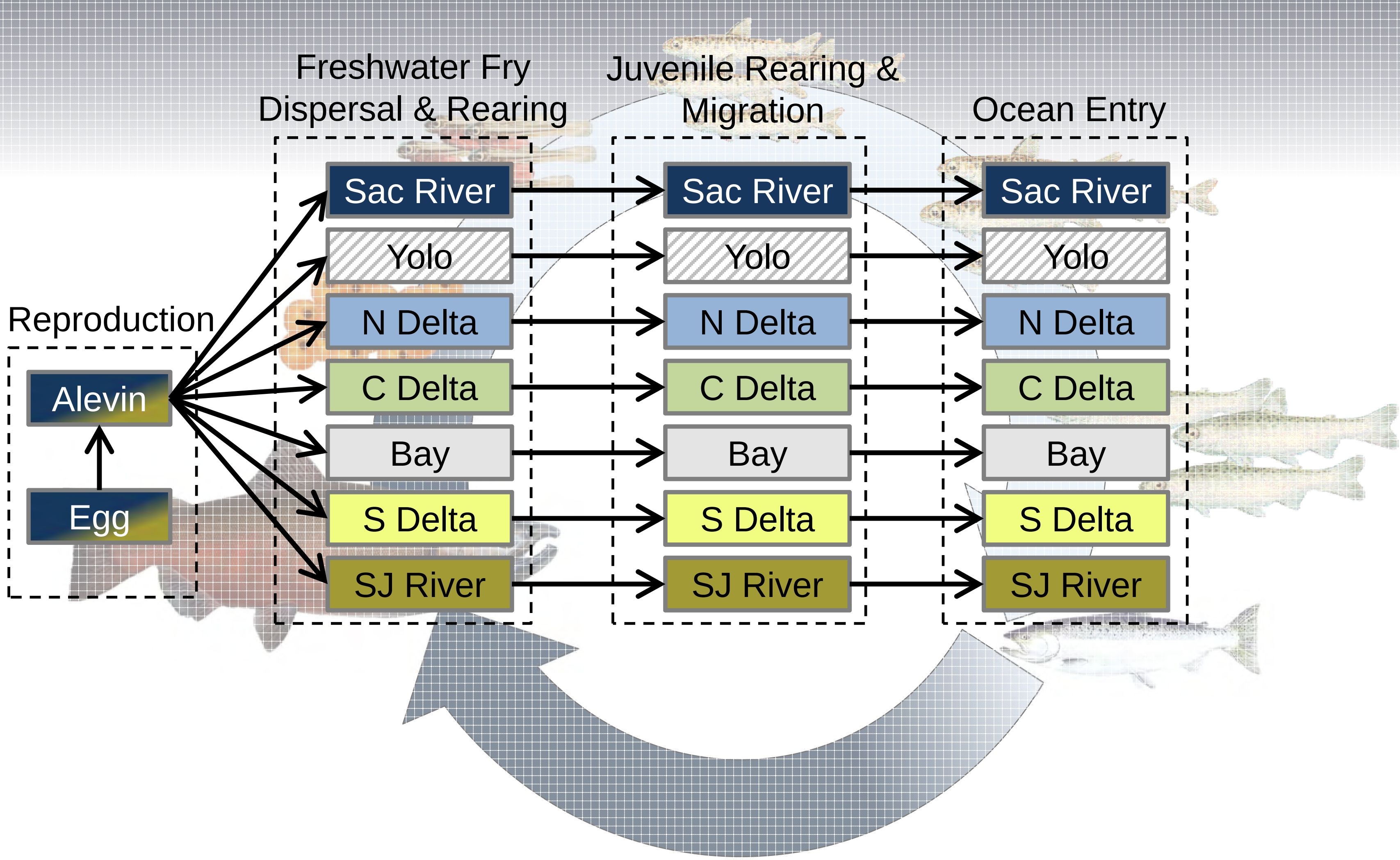
Habitat & Density Drive Fry Rearing, Dispersal, & Survival



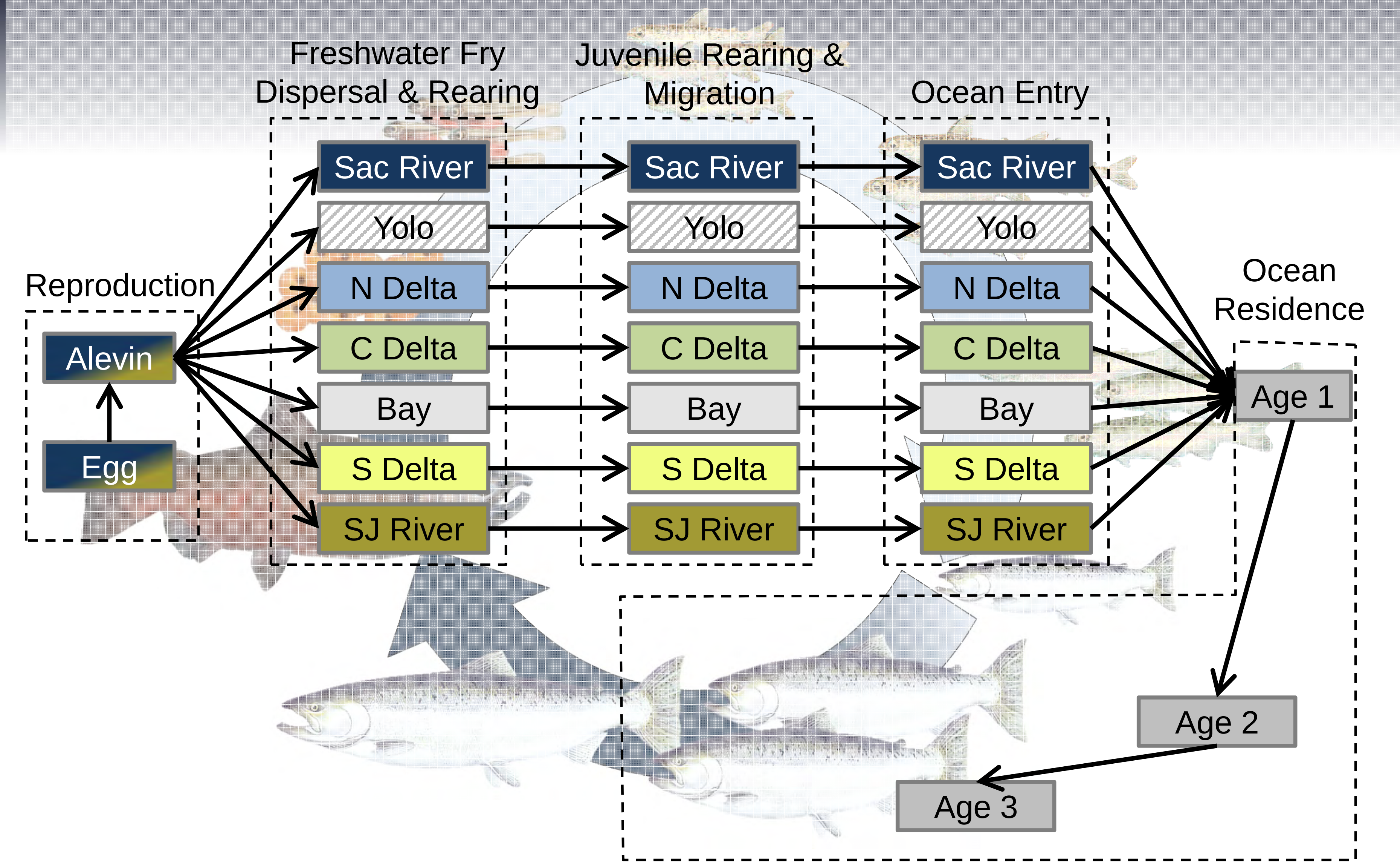
Habitat & Density Drive Parr Rearing, Dispersal, & Survival



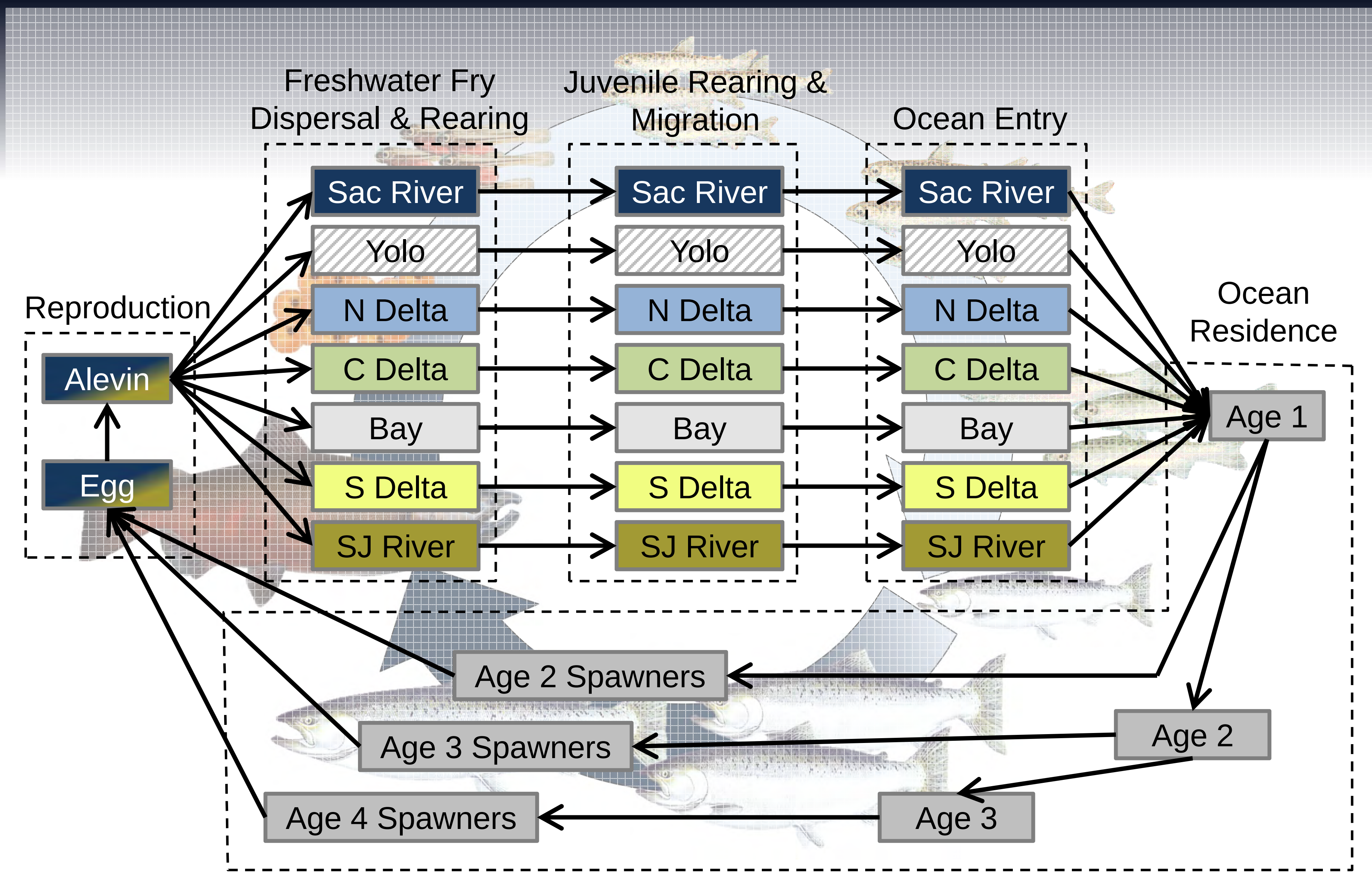
Environment Drives Timing Of Outmigration & Survival



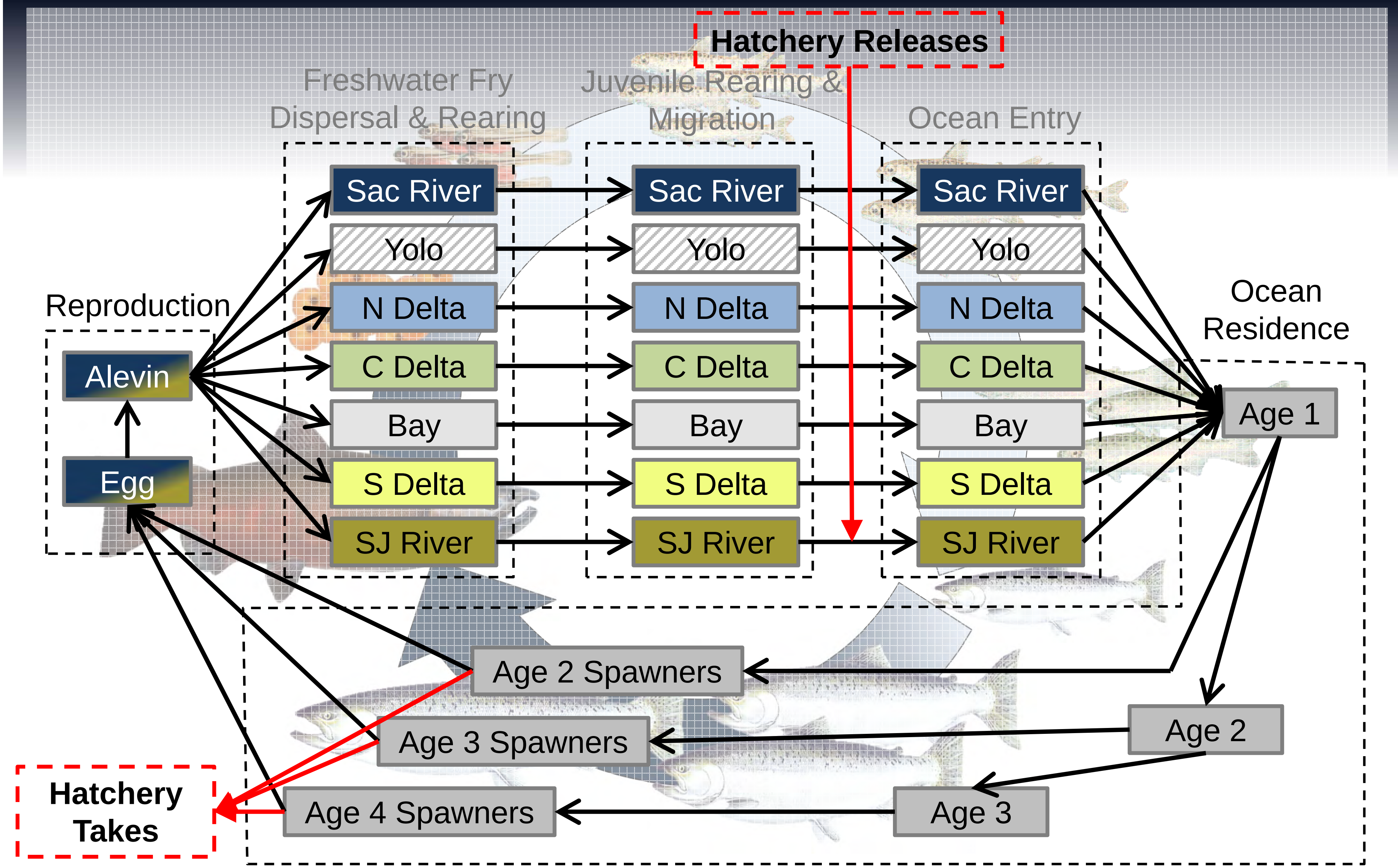
Ocean Productivity Dictates Early Ocean Survival & Residence



Fish Escaping The Fishery Return To Spawn



Hatchery Releases & Takes Tracked Through Space & Time



Models Can Evaluate In-River Survival Of Juvenile Salmon

February March

Cumulative Survival: ~39%

Models Can Evaluate Survival Of Juvenile Salmon Migrating Through The Delta

February March

April

Cumulative Survival: ~39%

~24%

Models Can Evaluate Survival Of Juvenile Salmon Migrating Through The Delta

February March

Cumulative Survival: ~39%

April

~24%

May

~15%

Models Can Estimate Cumulative Survival From Their Natal Rivers To The Ocean

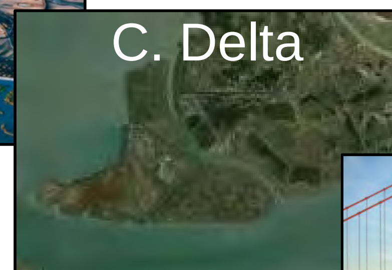
February March

Cumulative Survival: ~39%

April

~24%

May



~15%

June

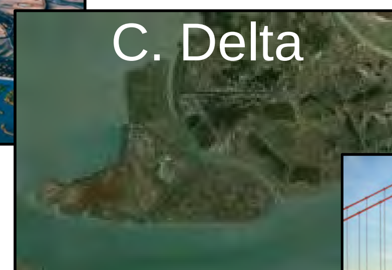
~4%

Hatchery Fish Get A Helping Hand

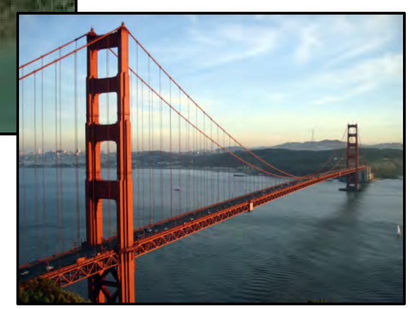
February March

April

May



June

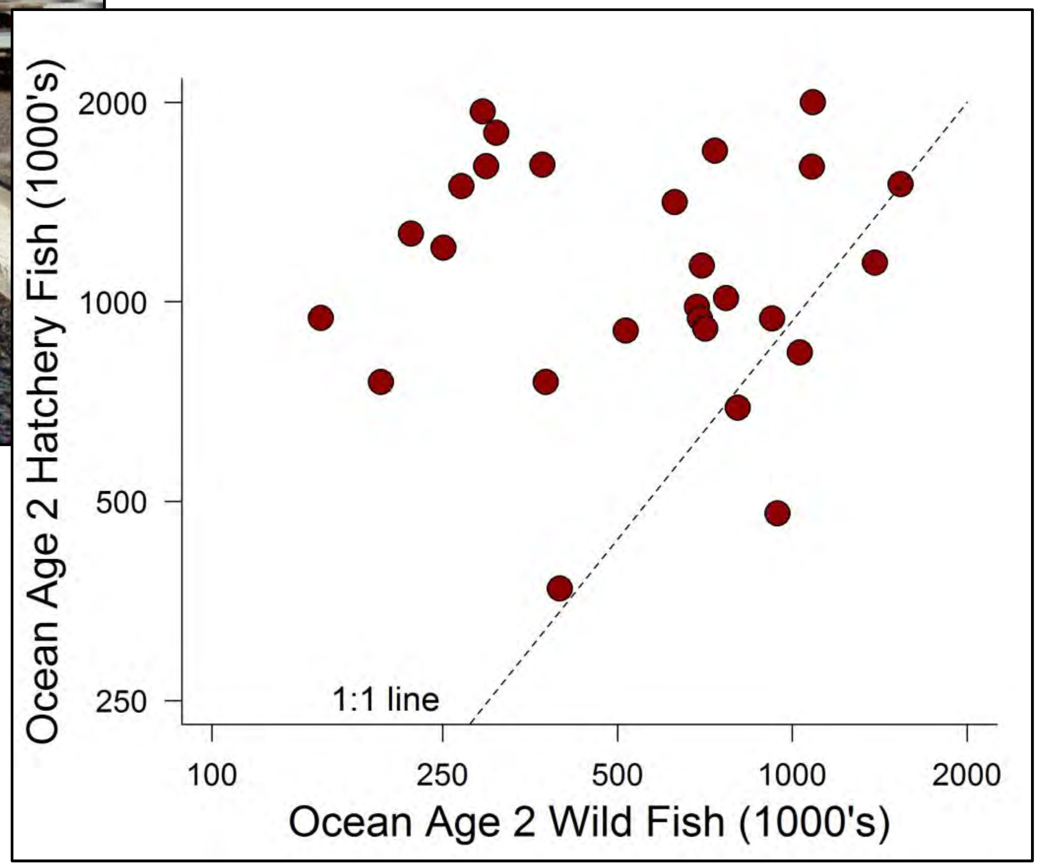


Cumulative Survival:~80-95%

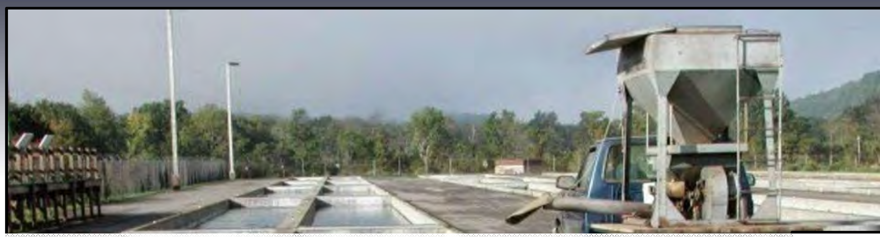
~26%

Hatchery Releases

Abundance of Hatchery & Wild Fish Unrelated

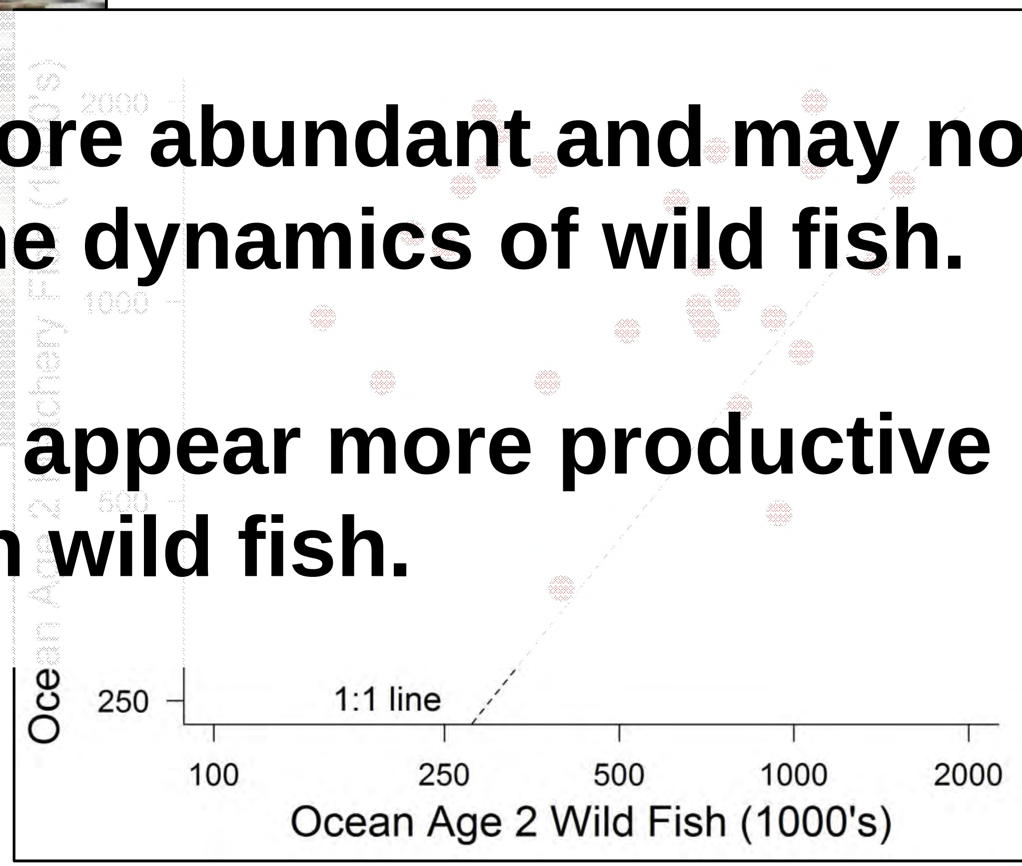


Abundance of Hatchery & Wild Fish Unrelated

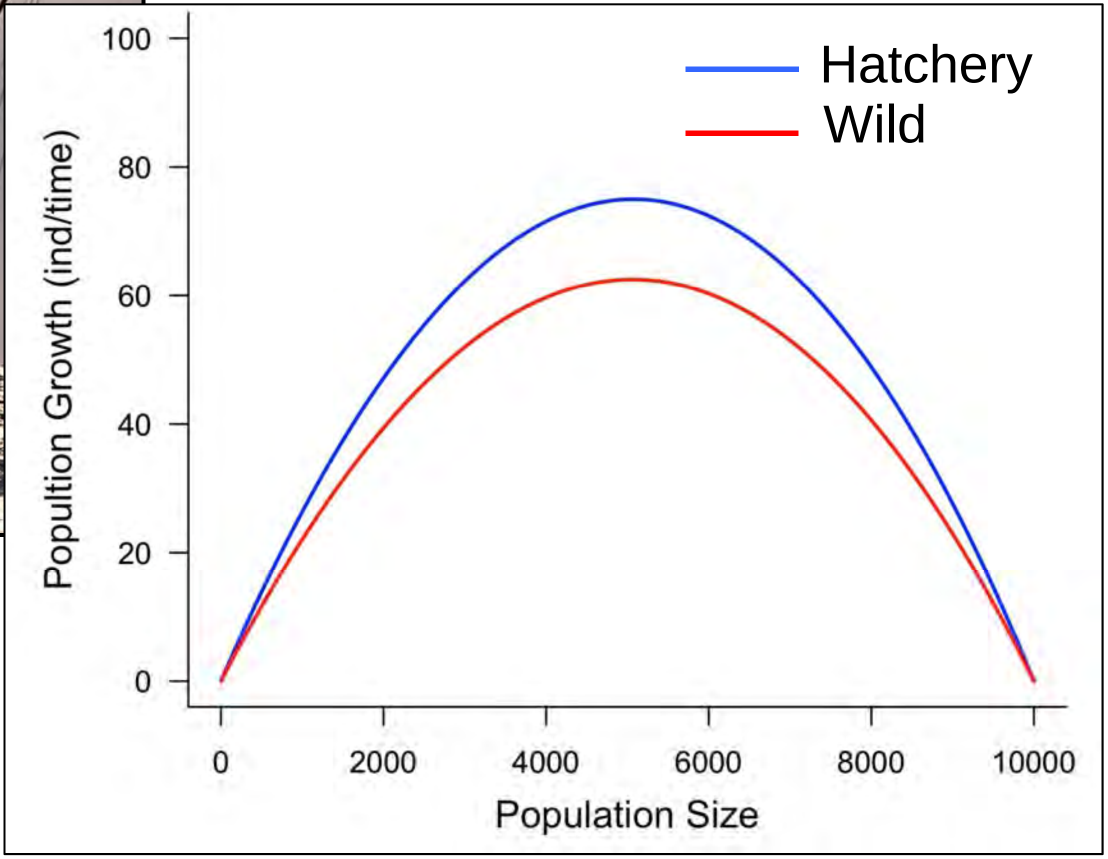


Hatchery fish are more abundant and may not fairly represent the dynamics of wild fish.

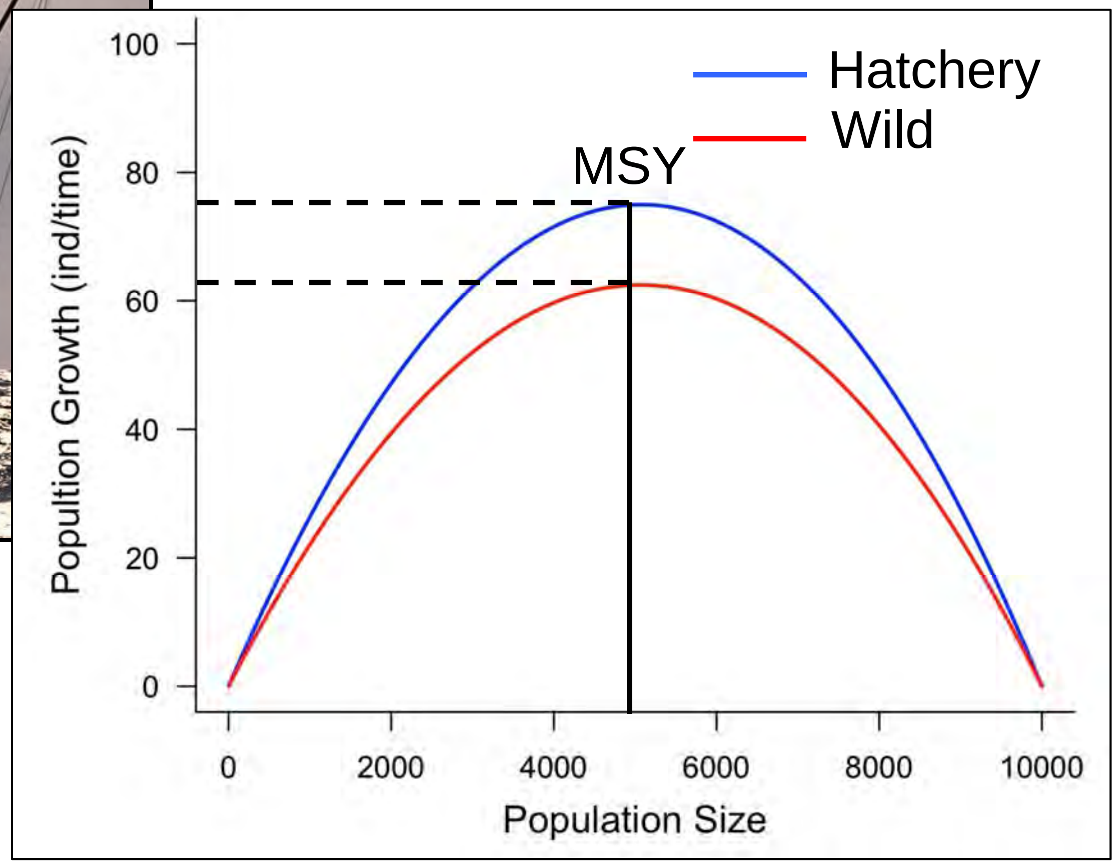
Hatchery fish may appear more productive than wild fish.



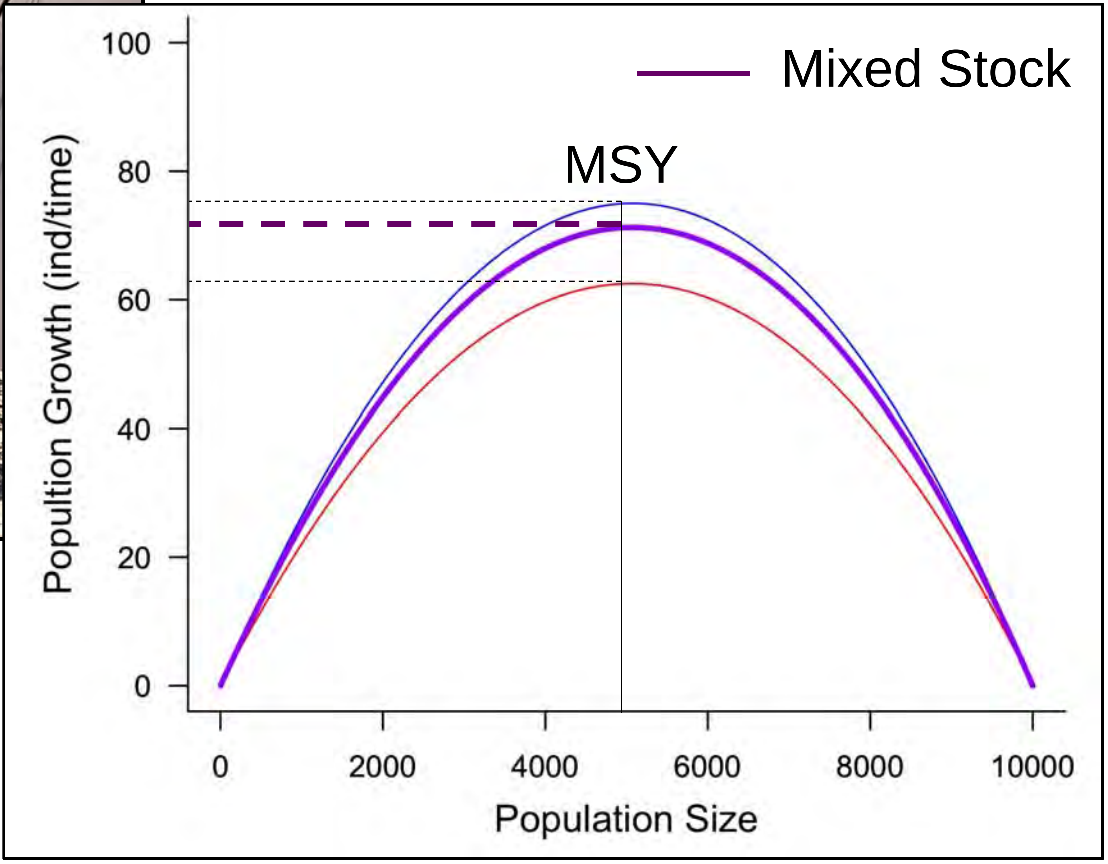
Hatchery Population Grows Faster



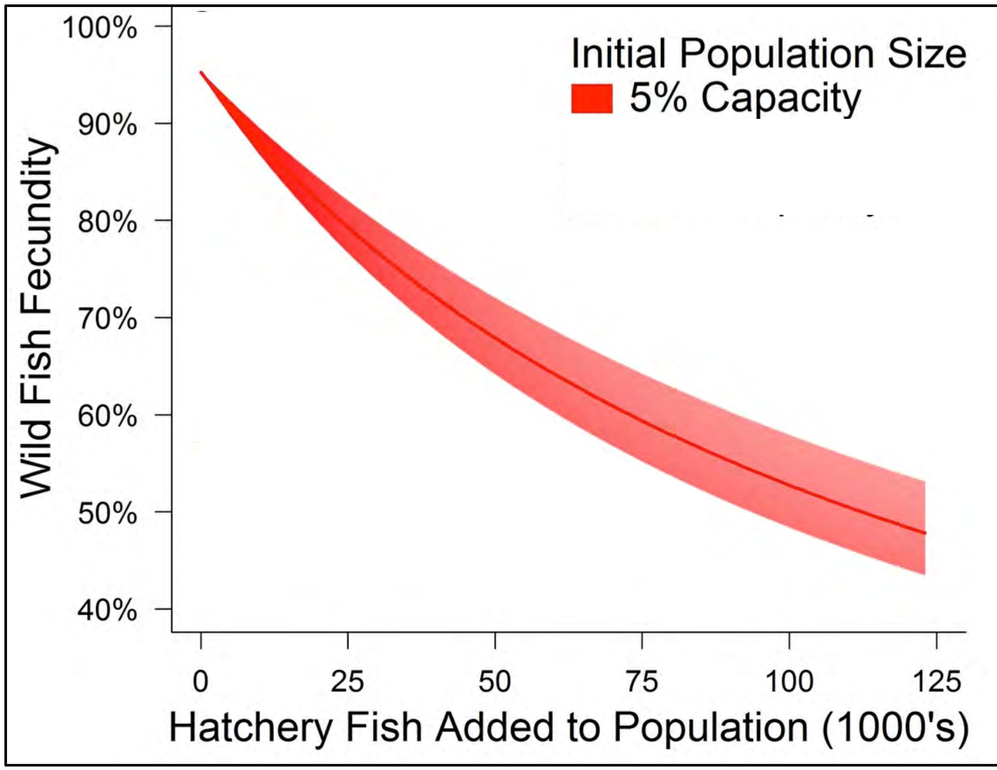
Higher MSY For Hatchery Population vs. Wild Population



Hatchery Fish Under Harvested & Wild Fish Over Harvested

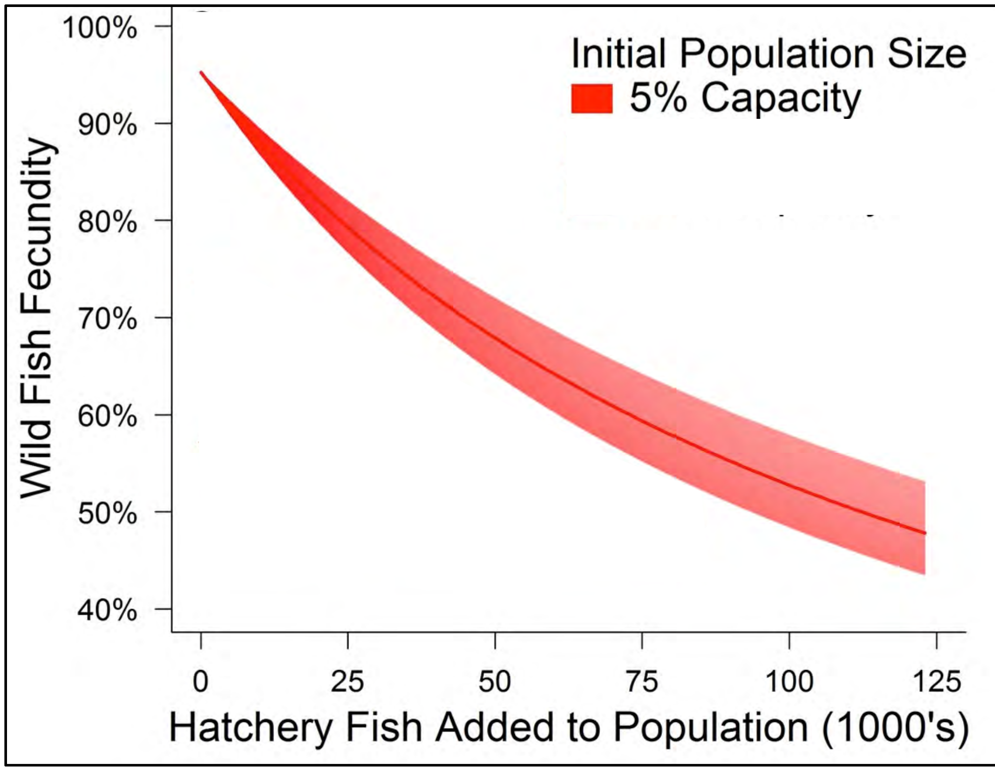


Hatchery Spawners Impede Wild Fish Fecundity



Hatchery Spawners Impede Wild Fish Fecundity

Leslie-Grower Model

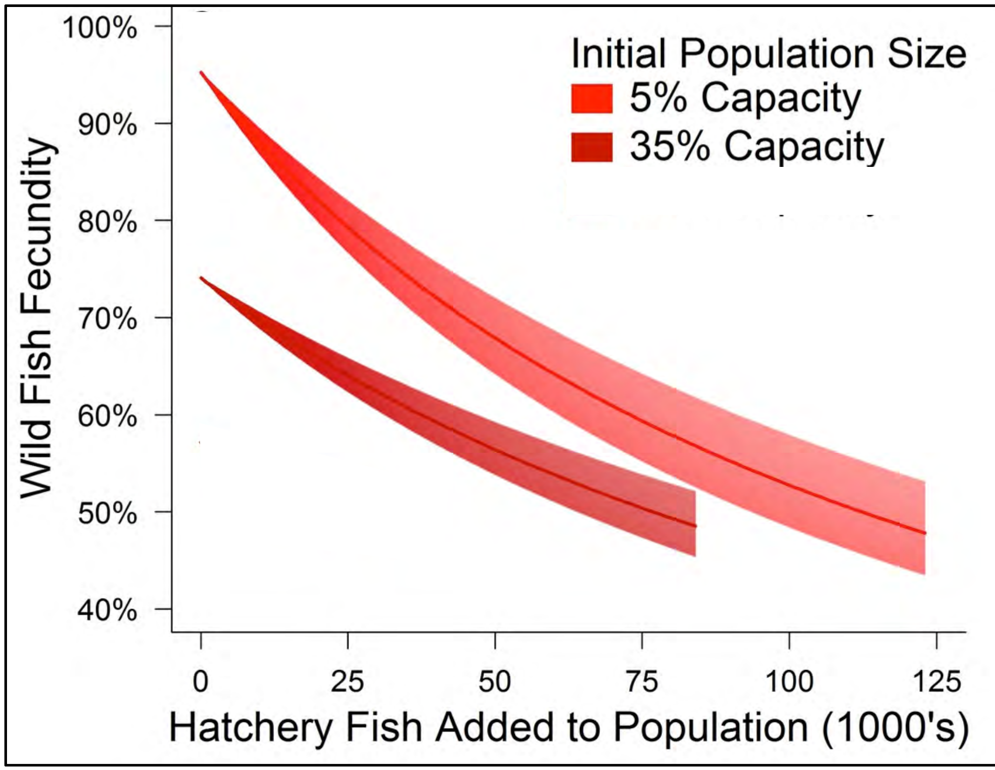


$$Eggs_w = \frac{Eggs_w}{1 + \frac{Eggs_w + Eggs_h \times \alpha_h}{\text{Habitat Capacity}}}$$

α_h = Hatchery Effect

Hatchery Spawners Impede Wild Fish Fecundity

Leslie-Grower Model

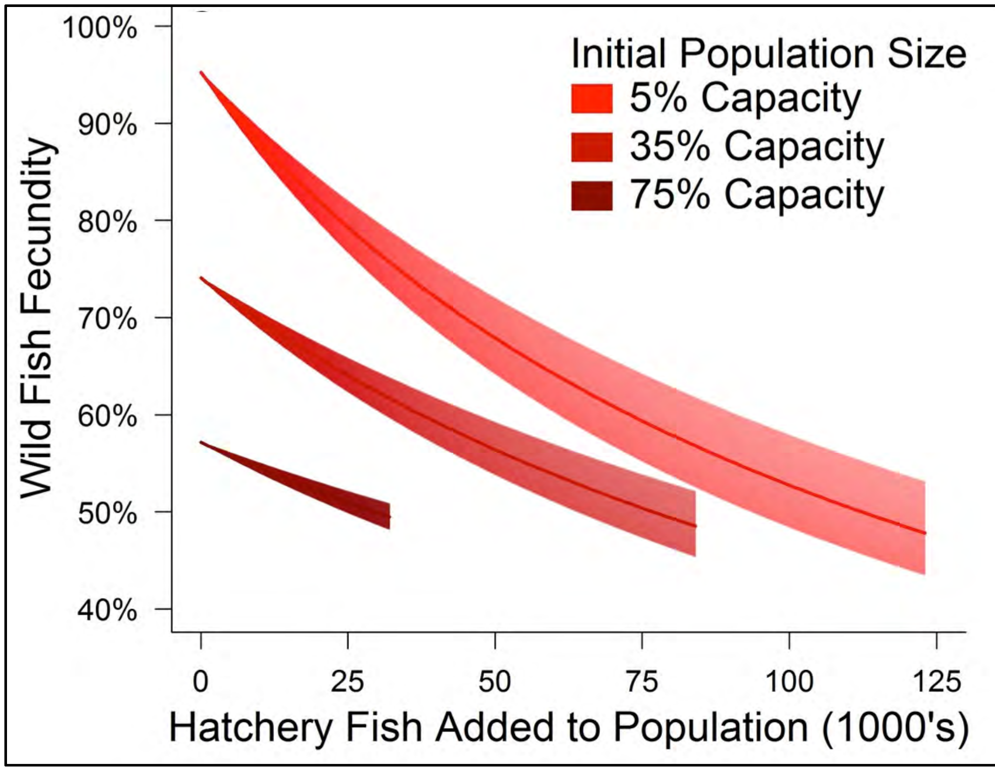


$$Eggs_w = \frac{Eggs_w}{1 + \frac{Eggs_w + Eggs_h \times \alpha_h}{\text{Habitat Capacity}}}$$

α_h = Hatchery Effect

Hatchery Spawners Impede Wild Fish Fecundity

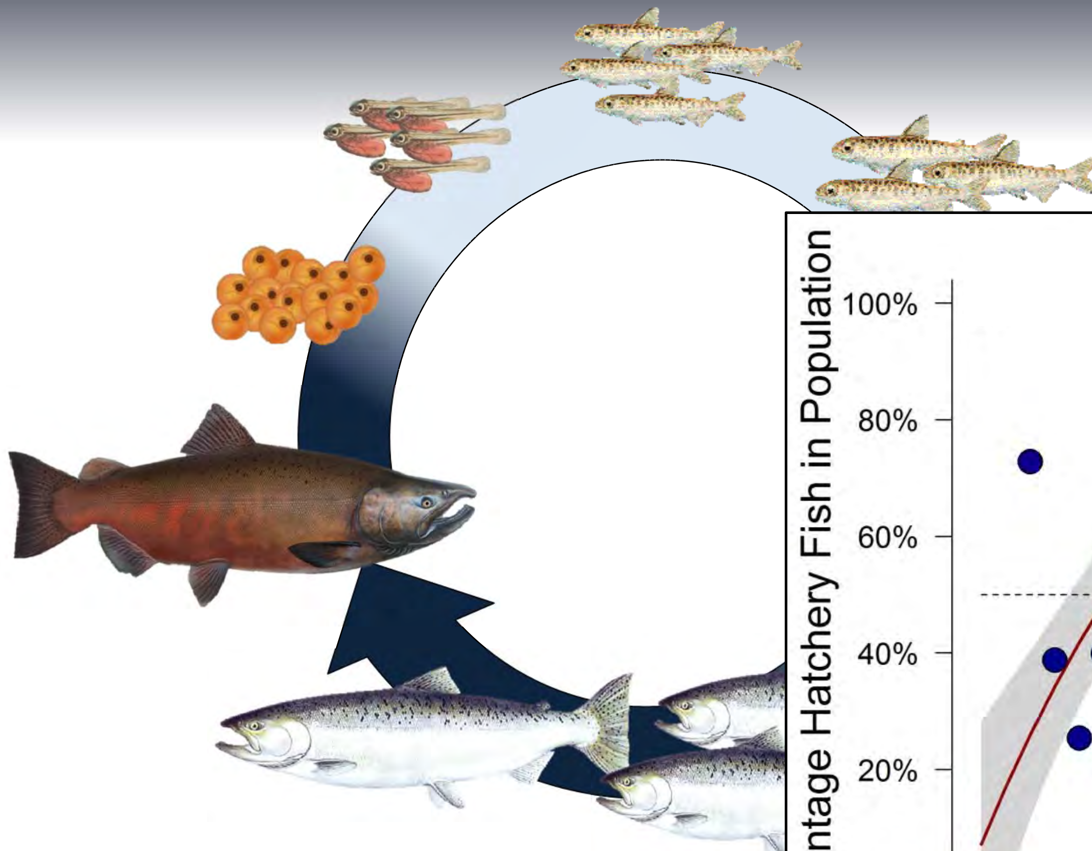
Leslie-Grower Model

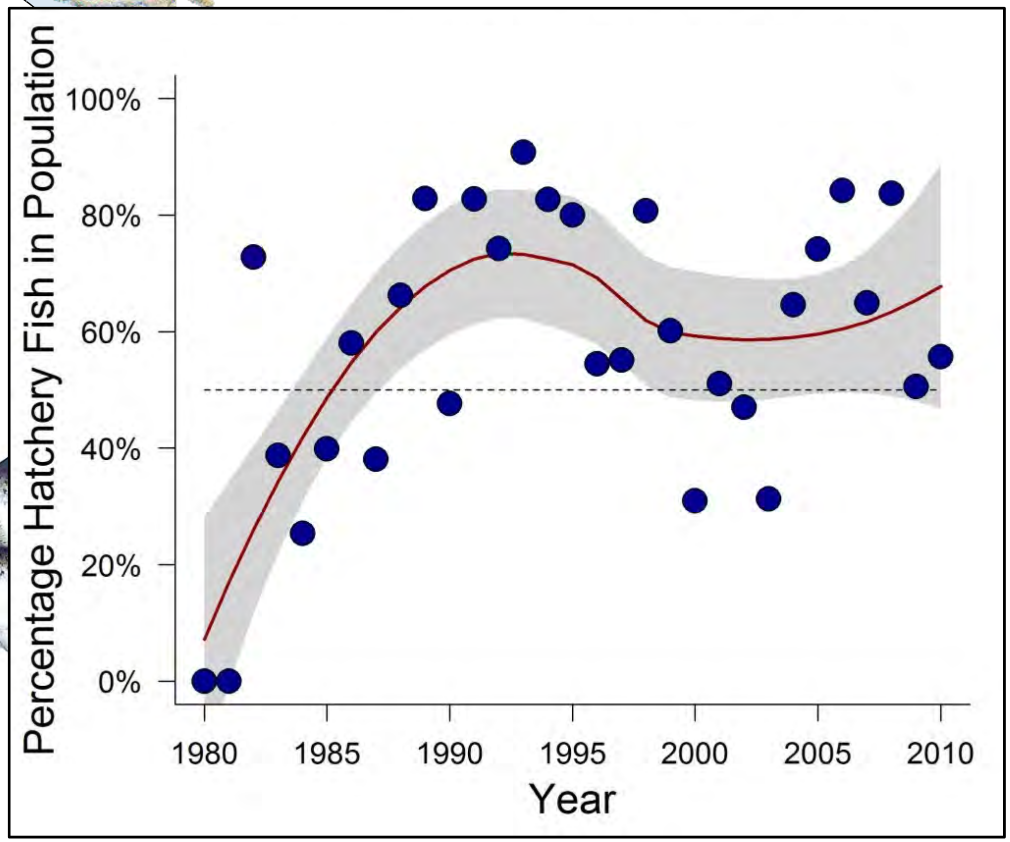


$$Eggs_w = \frac{Eggs_w}{1 + \frac{Eggs_w + Eggs_h \times \alpha_h}{\text{Habitat Capacity}}}$$

α_h = Hatchery Effect

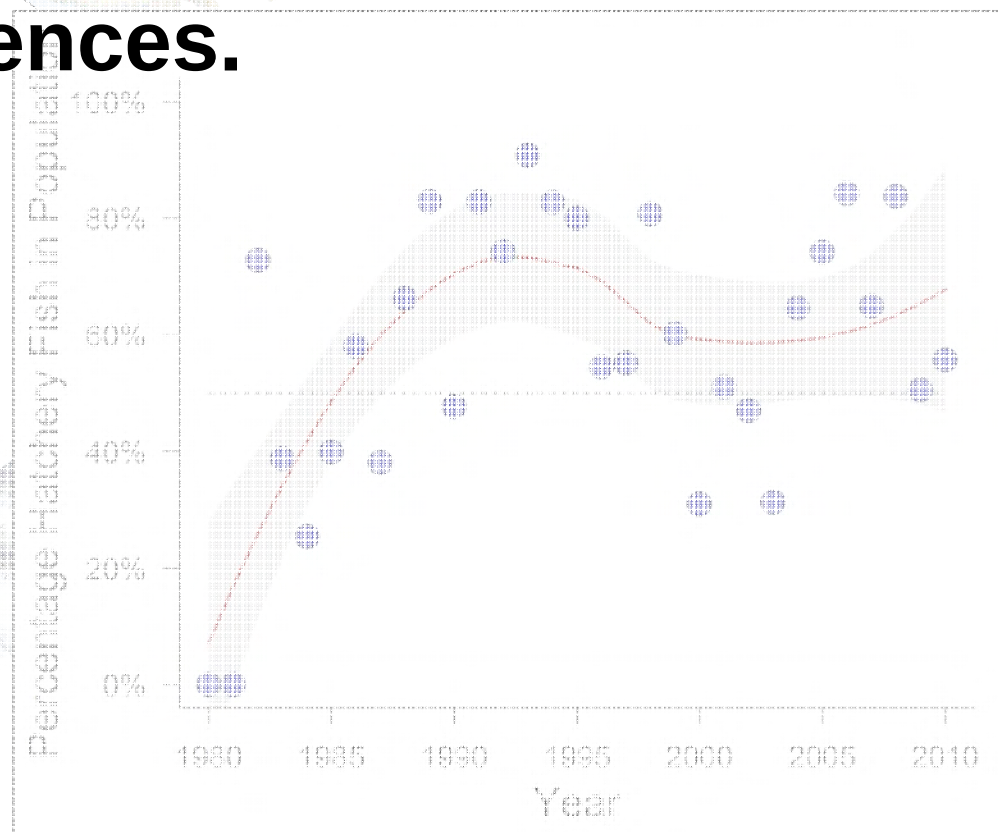
Population Will Be Dominated By Hatchery Fish





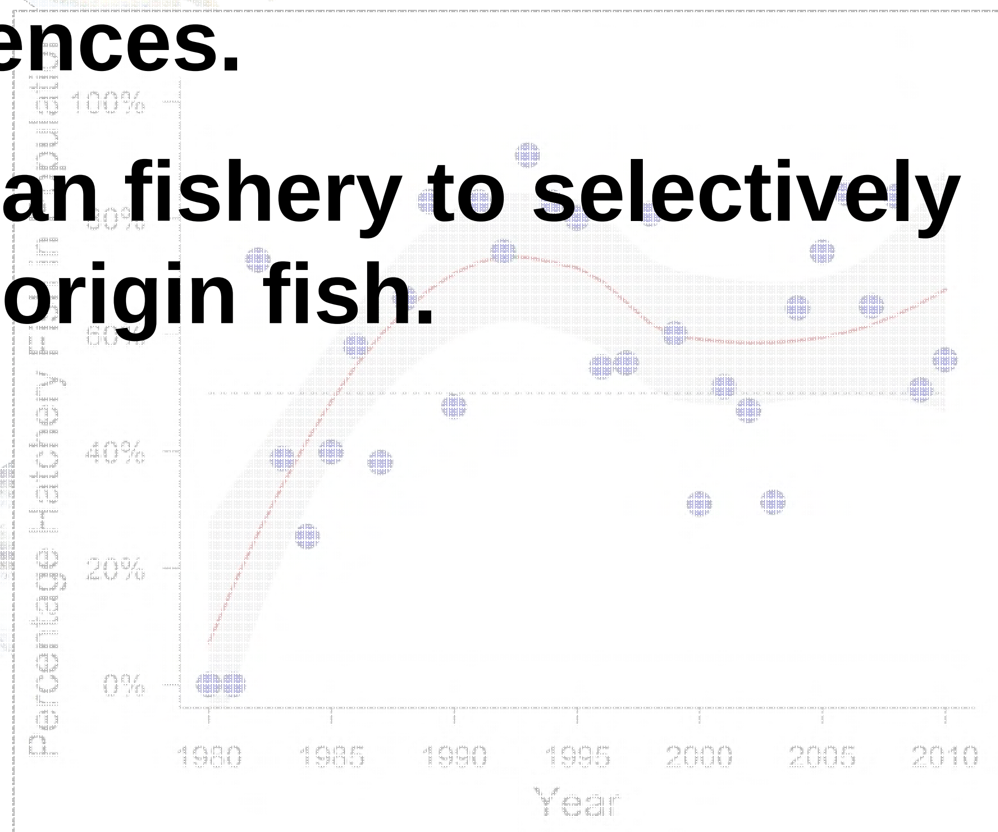
We Have Management Options

- **Promote hatchery practices that mimic wild fish experiences.**



We Have Management Options

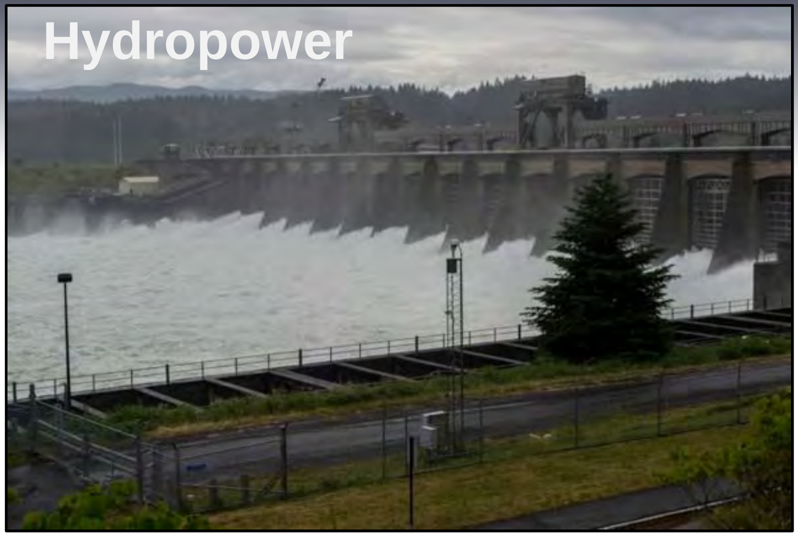
- **Promote hatchery practices that mimic wild fish experiences.**
- **Manage the ocean fishery to selectively target hatchery origin fish.**



We Have Management Options

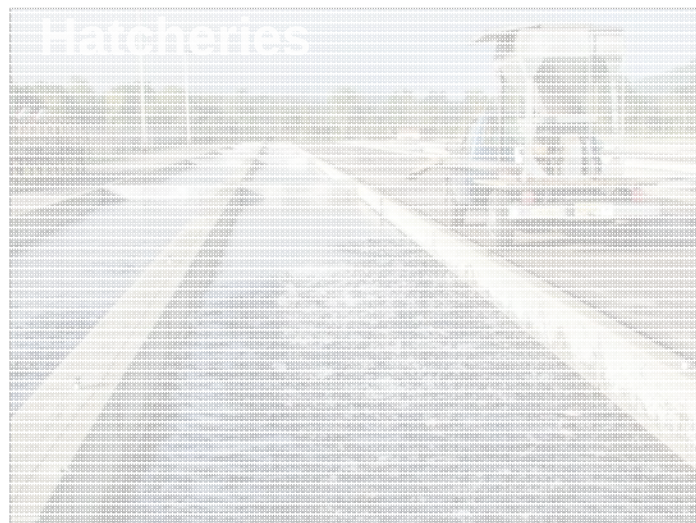
- **Promote hatchery practices that mimic wild fish experiences.**
- **Manage the ocean fishery to selectively target hatchery origin fish.**
- **Prevent hatchery origin fish from spawning with wild origin salmon.**

"4Hs" of Salmon Population Decline in the Pacific Northwest



Life-Cycle Models Can Assess The “4Hs” Impact On Salmon

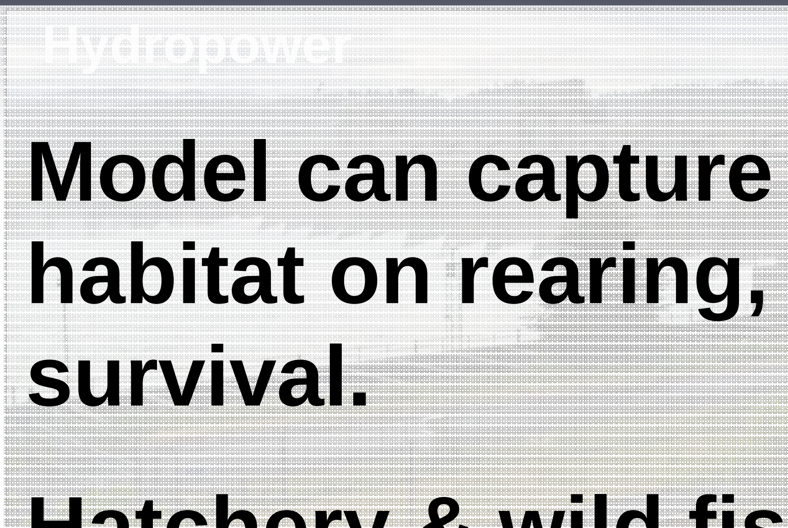
- **Model can capture the impacts of flow & habitat on rearing, migration, and survival.**

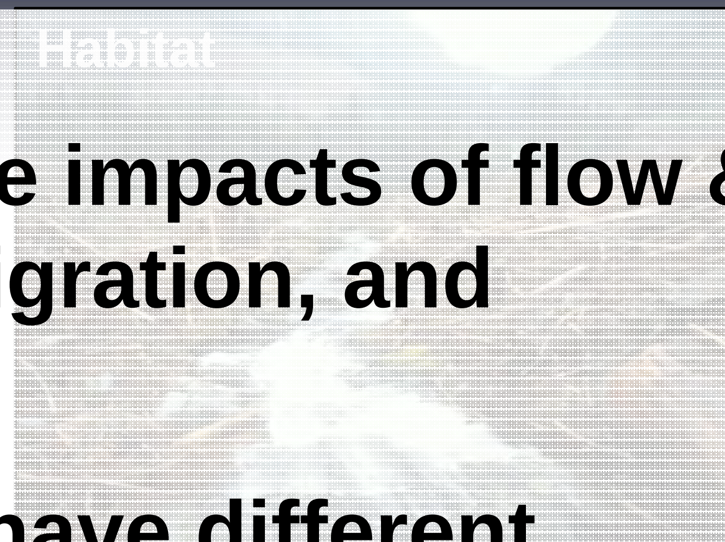


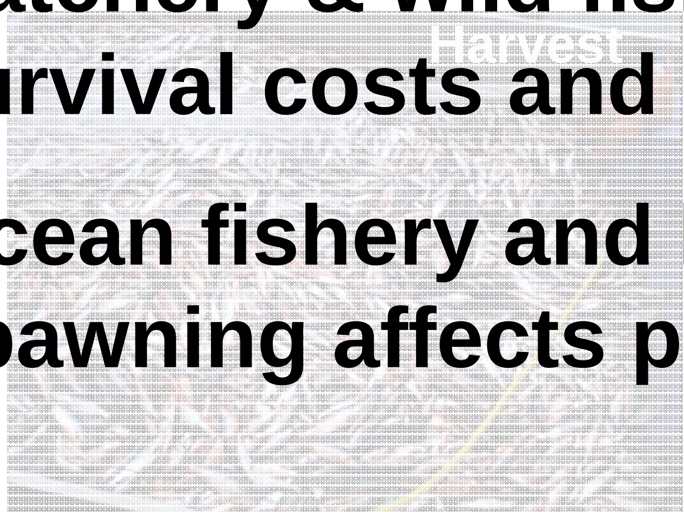
Life-Cycle Models Can Assess The "4Hs" Impact On Salmon

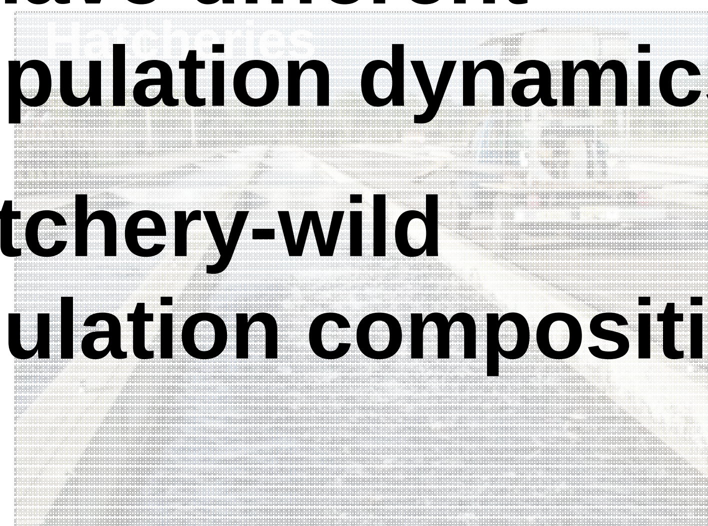
- **Model can capture the impacts of flow & habitat on rearing, migration, and survival.**
- **Hatchery & wild fish have different survival costs and population dynamics.**

Life-Cycle Models Can Assess The “4Hs” Impact On Salmon









- **Model can capture the impacts of flow & habitat on rearing, migration, and survival.**
- **Hatchery & wild fish have different survival costs and population dynamics.**
- **Ocean fishery and hatchery-wild spawning affects population composition.**

Acknowledgements

US Bureau of Reclamation
Cooperative Institute for Marine Ecosystems and Climate

National Marine Fisheries Service - SWFSC
Landscape Ecology – Life-Cycle Modeling Team

Anne Criss

Flora Cordoleani

Noble Hendrix

Andrew Pike

Kerrie Pipal

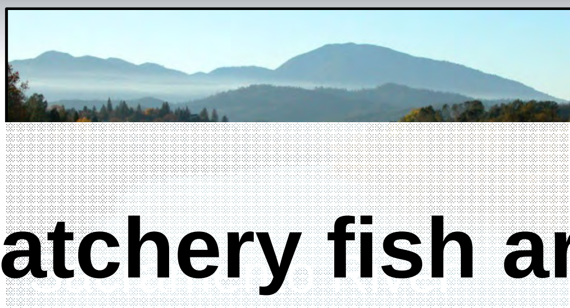
Vamsi Sridharan

Sara John

Questions?

Different Survival Rates Of Hatchery & Wild Fish Has Population Implications

February March



April

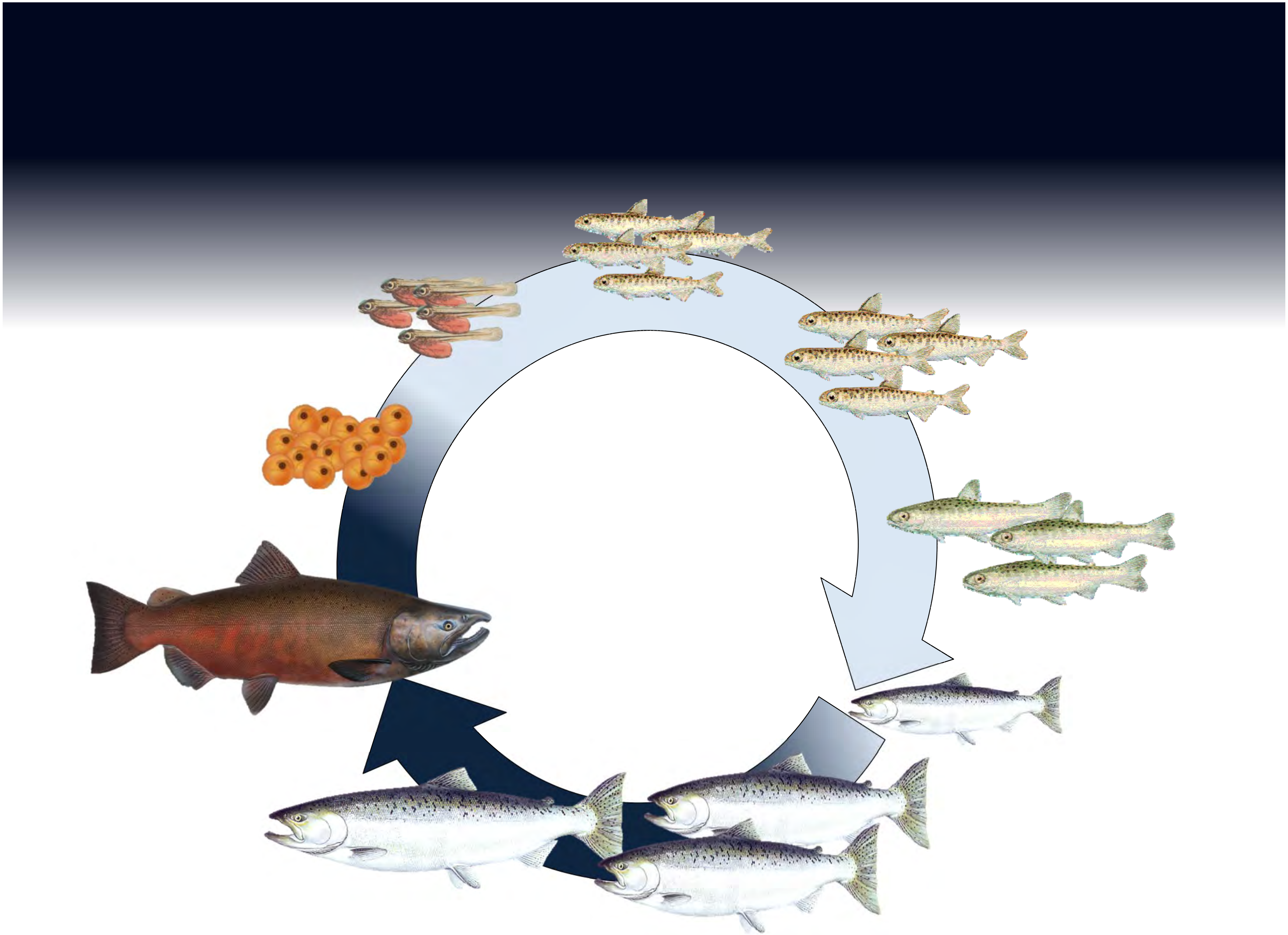
May

Hatchery fish are more abundant and may not fairly represent the dynamics of wild fish.

Hatchery fish may appear more productive than wild fish?

Hatchery Releases

~26%



Models Track Fish Abundance Through Time & Space

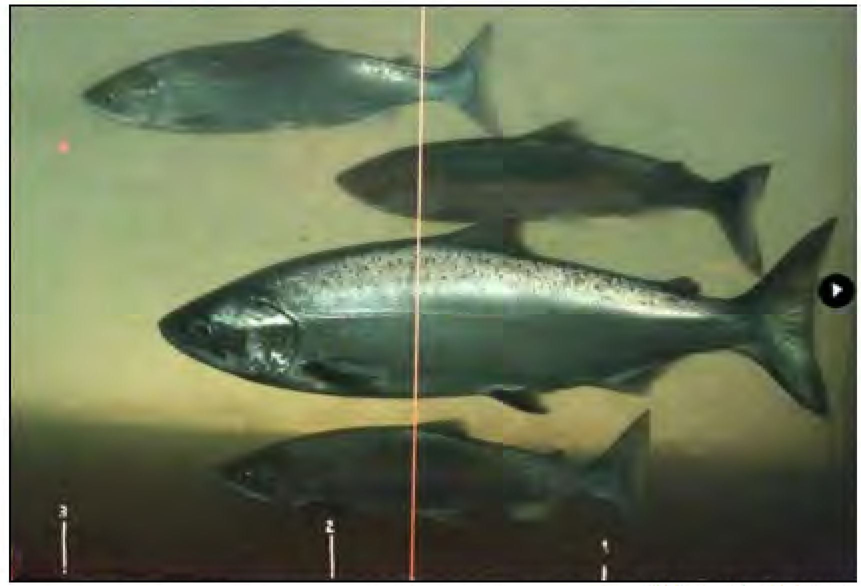
February	March	April	May	June	July
In River	In River	In River	In River	Delta	Ocean
In River	Delta	Delta	Delta	Delta	Ocean
In River	Yolo	Delta	Delta	Bay	Ocean

COLUMBIA RIVER SALMON THRIVE ON $500 MILLION ANNUAL SUBSIDY

July 12, 2014 · by Russ George · in Bizzare News For The Planet, Business News

$250 per fish is spent each year to keep Columbia river golden salmon coming back!

Feds spent $700 million on habitat restoration in Columbia River Basin

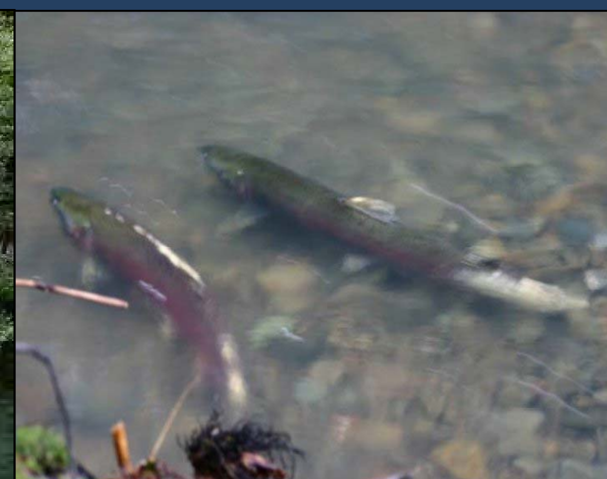


Rick Bowmer / Associated Press file

In this June 27, 2012 photo, a chinook salmon, second from the bottom, swims with sockeye salmon at the Bonneville Dam fish-counting window near North Bonneville, Washington, on the Columbia River. Plans for various iterations of salmon restoration in the Columbia River Basin have been litigated in court for more than two decades and the battle is about to resume.

Synergistic Benefits:
Coupling Salmon Life-Cycle Monitoring and Population Models in Context





Joshua Strange, PhD
Stillwater Sciences

34th Annual Salmon Restoration Conference


Paul Vecsie

Population Trends

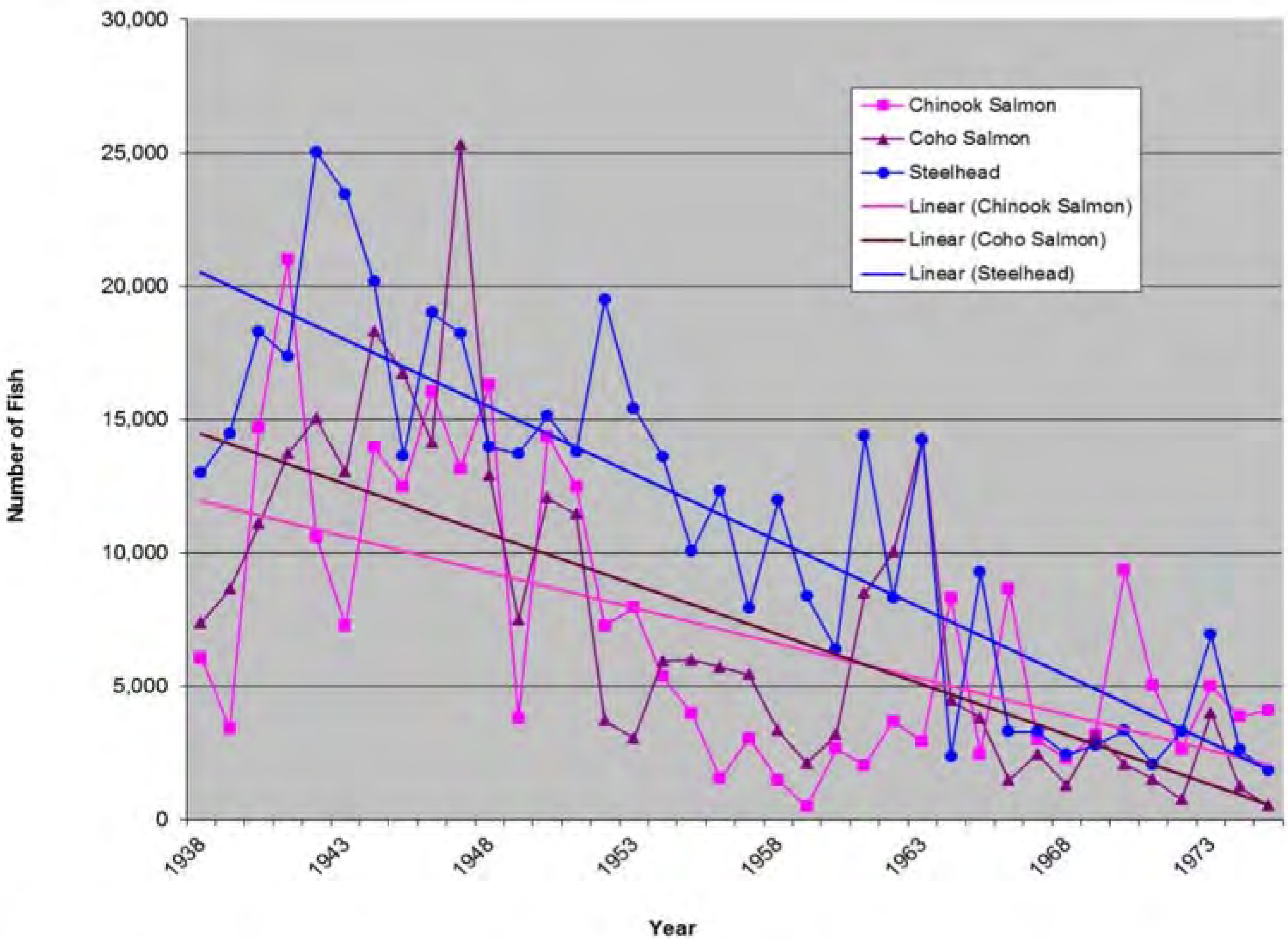
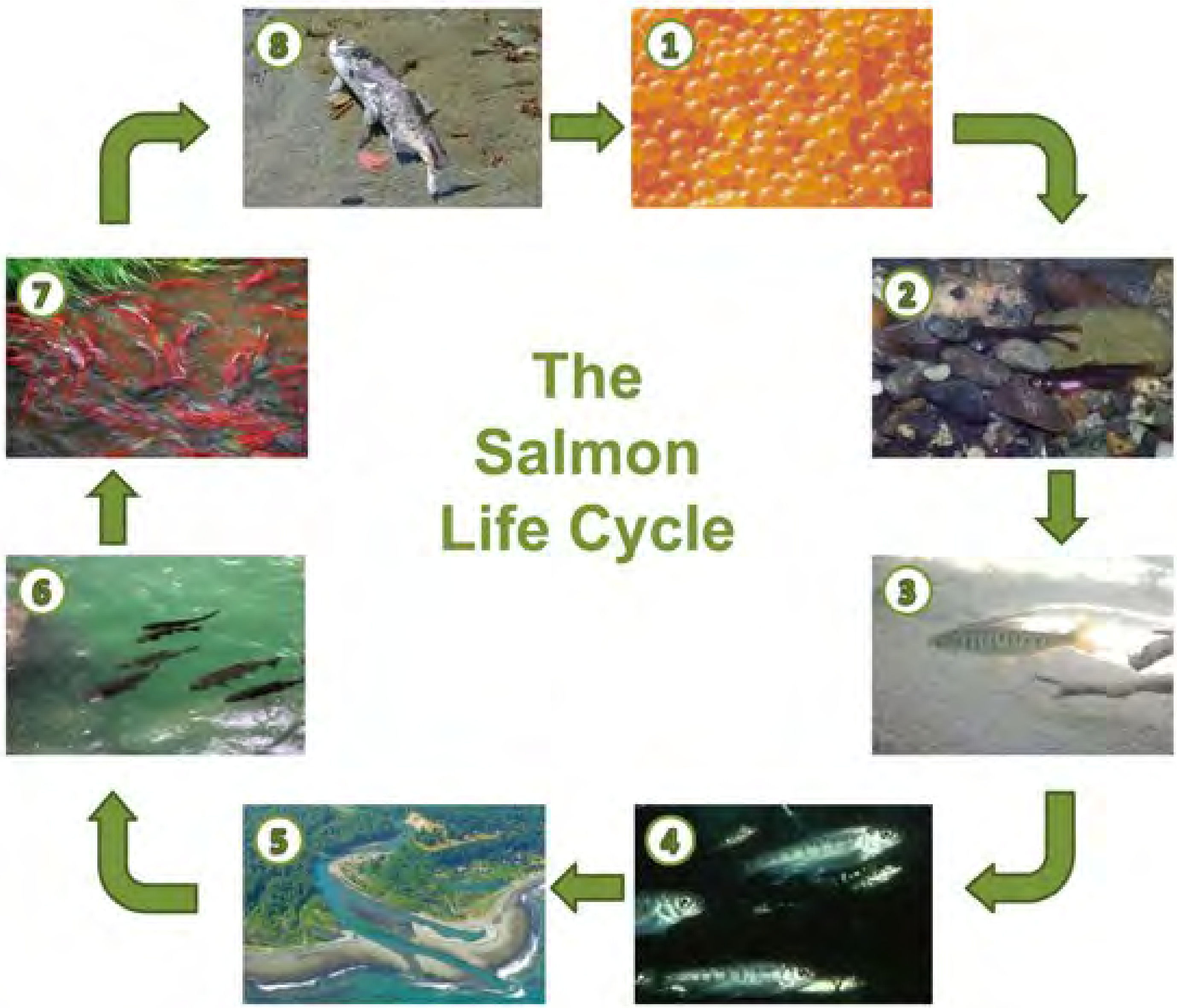
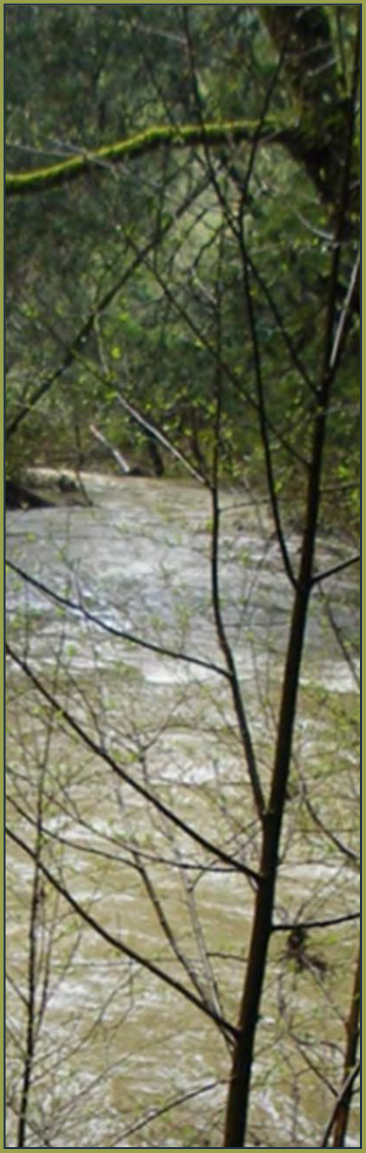


Figure 30. Counts of migrating Chinook salmon, coho salmon, and steelhead at the Benbow Dam fish ladder between 1938 and 1976. Regression lines for all three species show declines over time.

Life-Cycles



Salmon Conceptual Models



Coho Salmon Conceptual Model

- **Late-fall (summer) juvenile abundance sets the upper limit of a watersheds coho smolt production (capacity is a function of the amount and quality of pool and run habitat, food supply, and water temperatures)**
- **However, due to non-territoriality of coho in winter and disproportionate degradation, winter habitat often limits coho population size (off-channel and sheltered, low-gradient habitat especially)**
- **Spawning habitat quality and quantity rarely limits coho population size (but very low adult abundance can lead to under-seeding)**

Population Trends

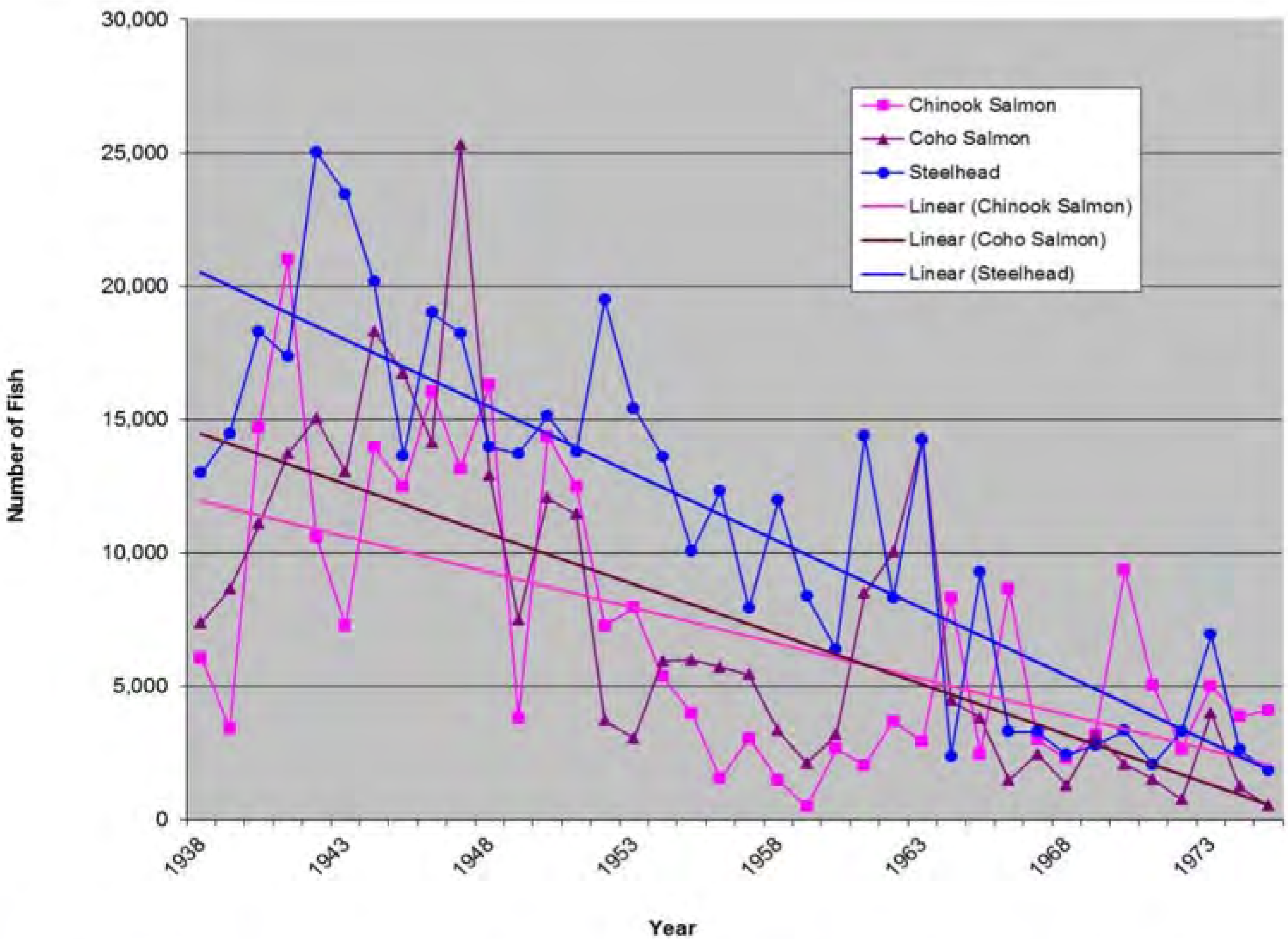


Figure 30. Counts of migrating Chinook salmon, coho salmon, and steelhead at the Benbow Dam fish ladder between 1938 and 1976. Regression lines for all three species show declines over time.

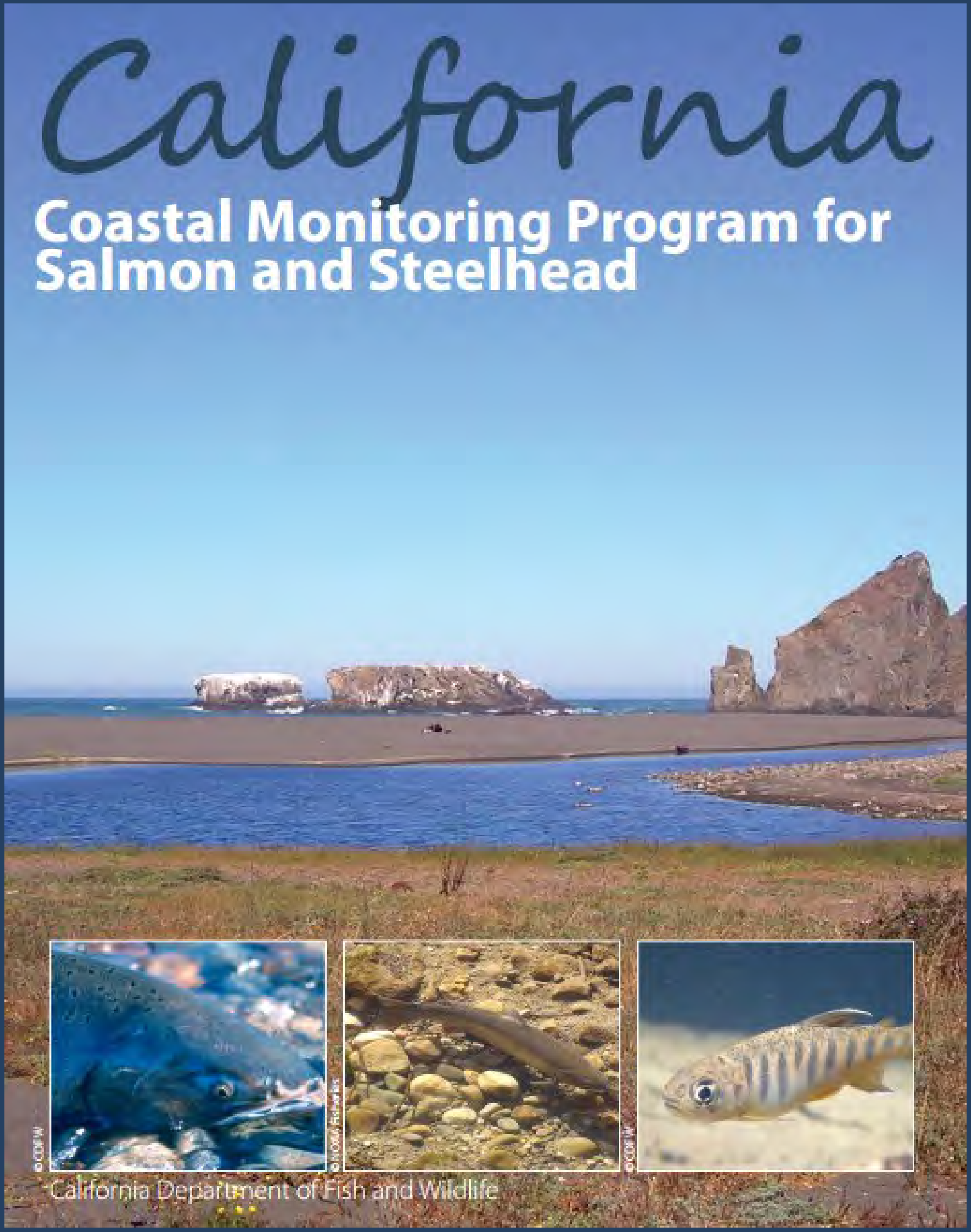
Salmon Species

Winter Steelhead
December-April

Coho Salmon
October-December

Fall Chinook
October-December.

Life-cycle Monitoring



Monitoring

What is the California Coastal Monitoring Program?

It's the most comprehensive program to date that provides a complete understanding of California's salmon and steelhead populations, utilizing statistically-rigorous modeling in combination with a variety of in-river sampling and survey methods.

Monitoring

Current Activities

DEVELOPING A STATE-WIDE DATABASE

This database allows information to be entered remotely, quality-controlled, securely stored, and reports to be down-loaded from one's office or home computer. This will allow public viewing of all information collected.

ESTABLISHING THE SAMPLING FRAMEWORK

We are developing a sampling framework at the appropriate scale that allows us to evaluate adult salmon and steelhead population status over time.

RESEARCHING AND REFINEMENT OF FIELD METHODS

We are establishing standardized field protocols, data collection, and data reporting to ensure that data are comparable and compatible within and across geographic regions.

LINKING HABITAT AND FISH RESPONSE

We are generating protocols to improve efficiencies in restoring habitat and managing changing landscapes for fish.

COMMUNICATING WITH THE PUBLIC

We are producing materials with several goals to: (1) educate the public about the state of salmon and steelhead; (2) demonstrate the progress of restoration and recovery efforts; (3) and get permission to access streams for monitoring.

BUILDING PARTNERSHIPS

We are working collaboratively and establishing partnerships for stream access, assistance in monitoring and data analysis, funding, and public outreach.

LOOKING FOR FUNDING

Long term success of this Program is dependent on building a stable and consistently reliable funding base from a broad spectrum of sources, complemented by a fully-trained volunteer force.

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Life-Cycle Monitoring

State of California
The Natural Resources Agency
Department of Fish and Game

FISH BULLETIN 180

CALIFORNIA COASTAL SALMONID POPULATION MONITORING: STRATEGY, DESIGN, AND METHODS

Peter B. Adams [1]
L.B. Boydstun [2]
Sean P. Gallagher [3]
Michael K. Lacy [4]
Trent McDonald [5]
and
Kevin E. Shaffer [6]

2011

Coho Salmon

October-December, though it's illegal to retain coho.

Life-Cycle Monitoring

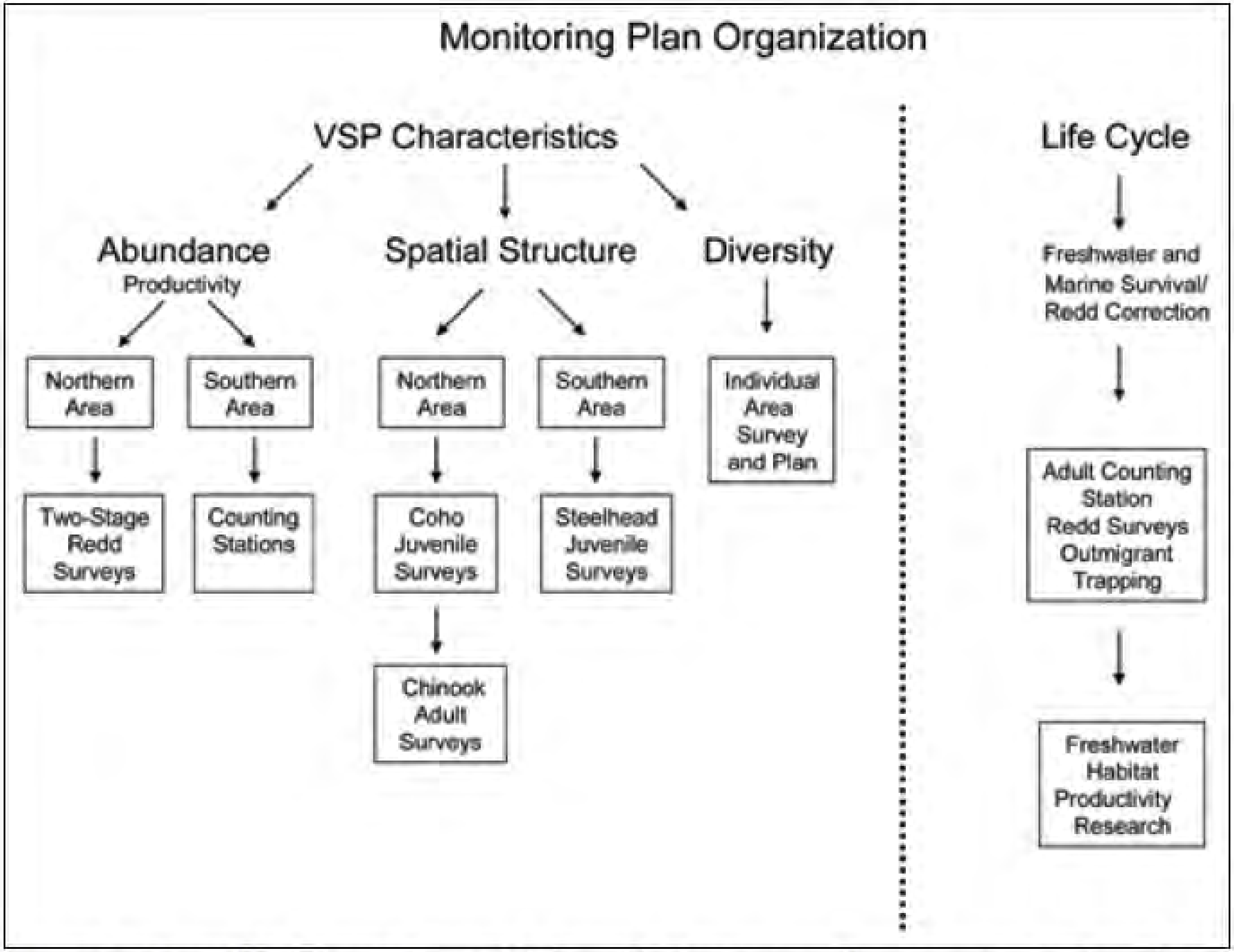
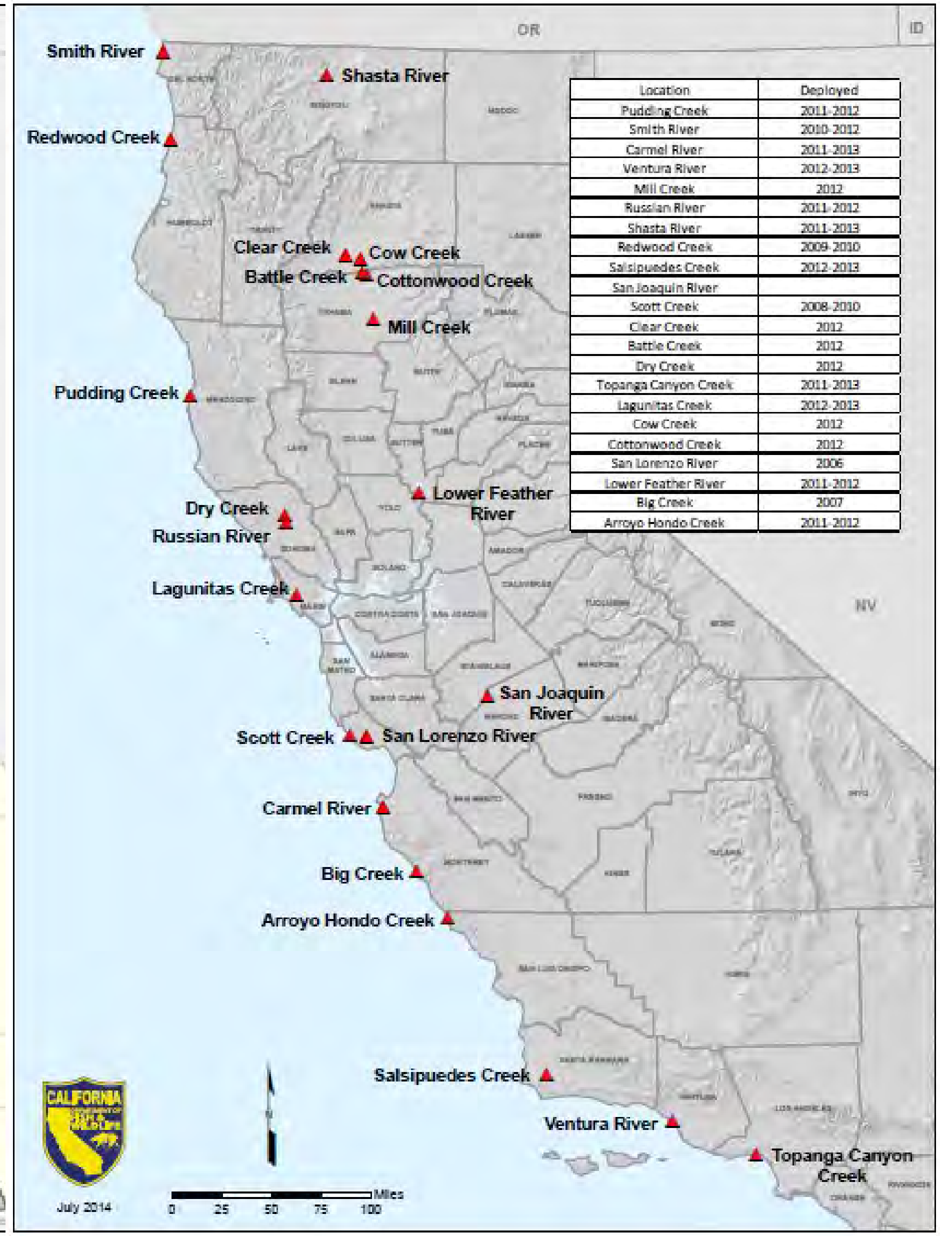


Figure 2. Overall California Coastal Salmonid Monitoring Plan organization based on VSP parameters and Life-Cycle Monitoring.

Life-Cycle Monitoring

Life Cycle Monitoring (LCM) stations will provide estimates of freshwater and ocean survival, essential to understanding whether changes in salmonid numbers are due to recovery from improvements in freshwater habitat conditions or changes in ocean conditions. An LCM station will include an absolute measure of adult abundance from a counting facility, a spawning survey estimate of adult abundance, and an estimate of outmigrating smolts. The adult counts and outmigrant smolt counts will provide estimates of fish in and fish out, that can be used to provide relative estimates of freshwater and marine survival. The counting station data and adult survey estimates will be used to develop an estimation factor between redds and adults for calibration of adult surveys conducted in other watersheds. The LCM sites are also expected to be magnets for other kinds of recovery-oriented research, particularly studies of fish habitat-productivity relationships and evaluations of habitat restoration effectiveness.

Life-Cycle Monitoring



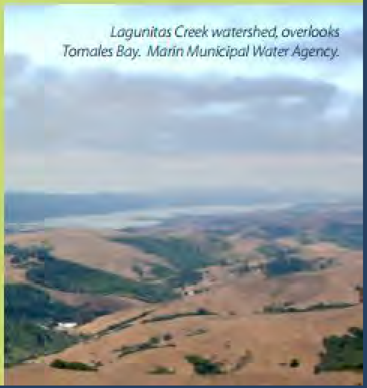
Location	Deployed
Pudding Creek	2011-2012
Smith River	2010-2012
Carmel River	2011-2013
Ventura River	2012-2013
Mill Creek	2012
Russian River	2011-2012
Shasta River	2011-2013
Redwood Creek	2009-2010
Salsipuedes Creek	2012-2013
San Joaquin River	
Scott Creek	2008-2010
Clear Creek	2012
Battle Creek	2012
Dry Creek	2012
Topanga Canyon Creek	2011-2013
Lagunitas Creek	2012-2013
Cow Creek	2012
Cottonwood Creek	2012
San Lorenzo River	2006
Lower Feather River	2011-2012
Big Creek	2007
Arroyo Hondo Creek	2011-2012

Examples

LAGUNITAS CREEK *Marin County*

As in other coastal streams of central California, spawning populations of coho salmon and steelhead have declined significantly from historic numbers in Lagunitas Creek. The declines in abundance have been documented in Lagunitas Creek for almost 20 years.

There is still hope--Within the last three years, coho salmon have experienced improved survival and abundance. Additionally, with the recent implementation of the California Monitoring Program at Lagunitas Creek, fisheries managers at the California Department of Fish and Wildlife and NOAA Fisheries are better able to track the status of the population and make decisions on watershed restoration and coho salmon recovery activities. Monitoring of salmon and steelhead in Lagunitas Creek is a coordinated effort involving many entities, including the Department , NOAA Fisheries, National Park Service, Marin Municipal Water District, and the Salmon Protection and Watershed Network.



Lagunitas Creek watershed, overlooks Tomales Bay. Marin Municipal Water Agency.

Scott Creek coho salmon and steelhead. NOAA Fisheries.

SCOTT CREEK *Santa Cruz County*

Living on the edge of their natural range, Scott Creek in Santa Cruz County is one of the southern-most streams where coho salmon and steelhead have persisted for centuries. Within the last two decades, the coho salmon population nearly collapsed. While causes for the dramatic decline are being studied, it appears that human-induced impacts in combination with recent poor ocean conditions were the main driving factors.

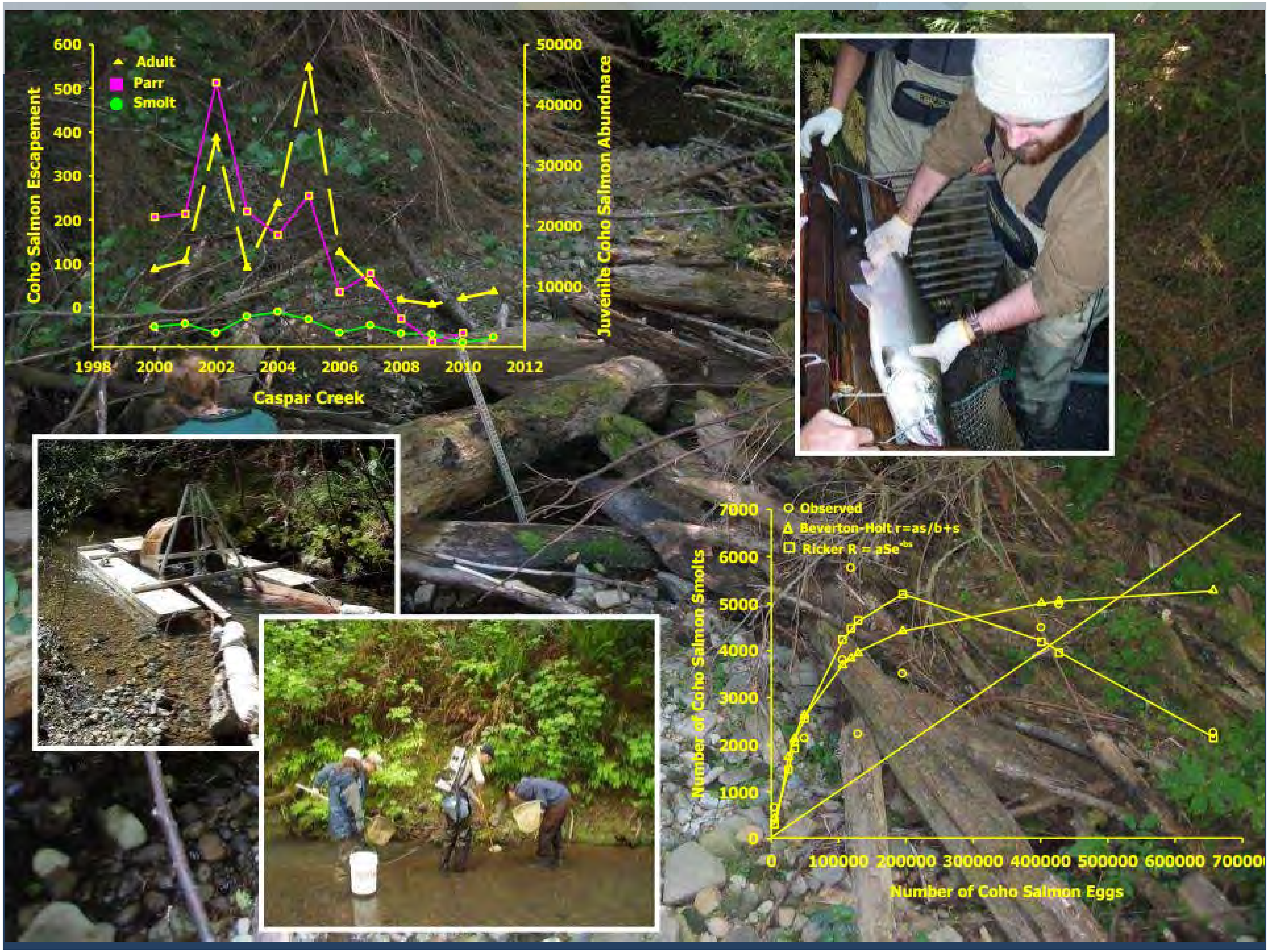
Monitoring this watershed's coho salmon and steelhead populations is critical in helping fishery biologists and resource managers understand the effects of human activities and natural phenomena on habitat so that we can effectively implement restoration and management strategies to recover these iconic species. Under the Coastal Monitoring Program, scientists from the University of California, Santa Cruz, monitor the life cycle of coho salmon and steelhead populations, generating crucial data on marine and freshwater survival, fish movement throughout the watershed, as well as genetic factors affecting the health of the population.

PUDDING CREEK *Mendocino County*

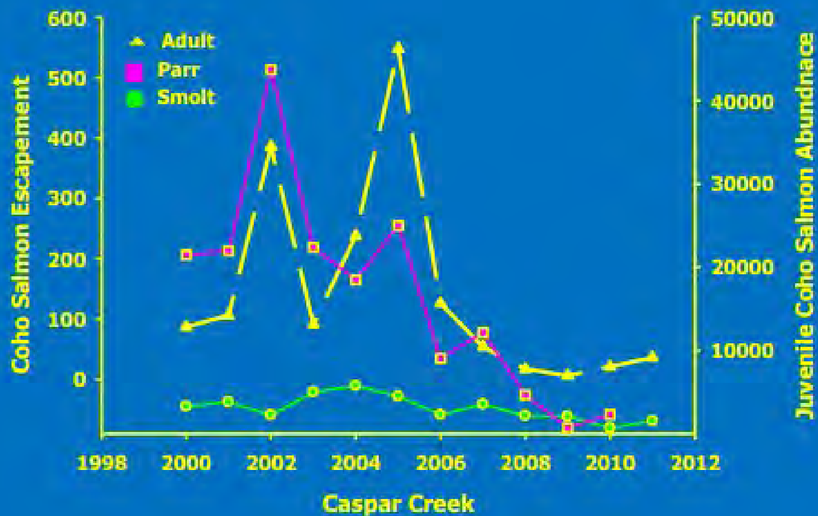
The Pudding Creek Salmon and Steelhead Life Cycle Monitoring Station is a component of the larger Mendocino County Coastal Salmonid Monitoring Project. This Station was conceptualized by the Department and Campbell Timberland Management, with oversight from NOAA's Southwest Fisheries Science Center, and in association with the Pacific States Marine Fisheries Commission. This Project's goals include determining marine and freshwater survival of salmon and steelhead, as well as estimating the ratio of redds (salmon and steelhead nests) to adult fish so that a total population estimate can be determined for the broader Mendocino County Region. The monitoring work began in fall 2005 and includes methods such as adult trapping, spawning surveys, tagging, electrofishing, and smolt (juveniles migrating to ocean) trapping.

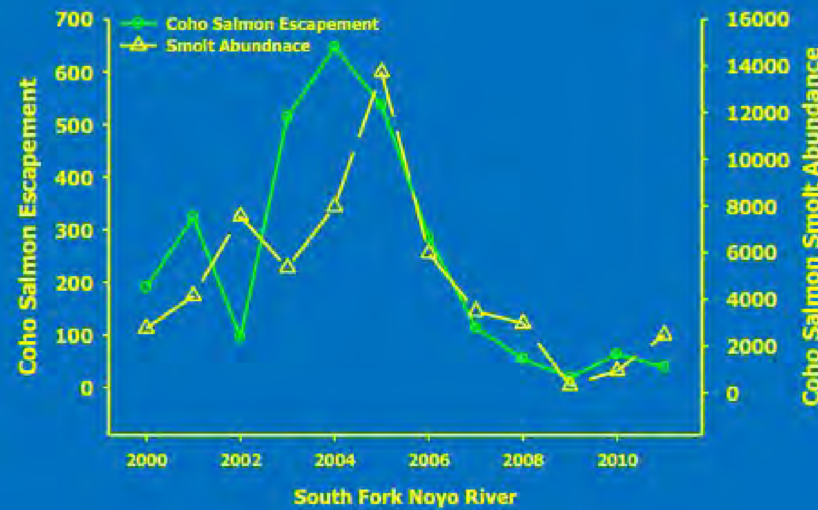
Campbell Timberlands Management Fisheries Technician releasing male Coho Salmon at the Pudding Creek fish ladder. ©CDFW

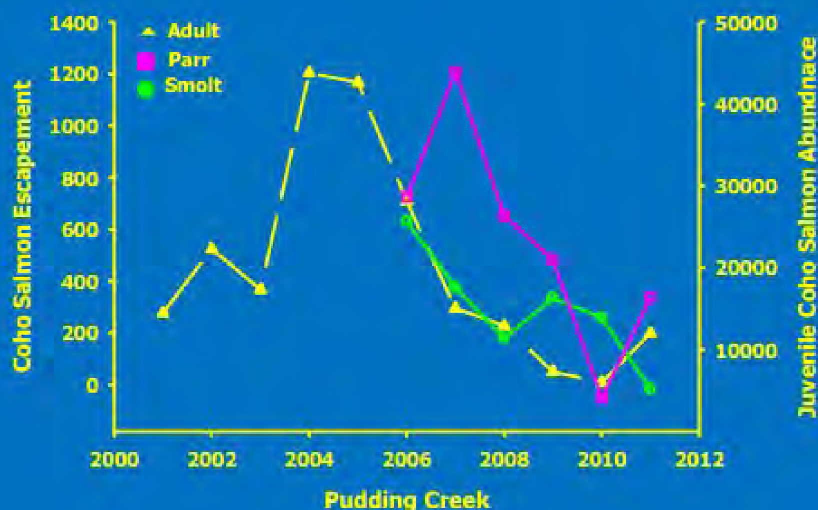
In 2011, the Department, in collaboration with its partners, expanded this study to include researching the linkages between implementing specific restoration actions (i.e. adding large woody debris to streams) and increasing fish abundance at Mendocino County streams. The ultimate goal is to improve efficiencies of restoring fish habitat to gain increases in fish populations over time. For this study, addition collaborators, The Nature Conservancy and Trout Unlimited, joined the effort. Other collaborators involved in this monitoring include two Humboldt State University graduate student projects, the National Council for Air and Stream Improvement, the United States Geological Survey, California Department of Fire, United States Forest Service, and NOAA's Stream Restoration Center. This broad coalition is critical for adaptive management of these endangered salmon and trout.


Adult
Parr
Smolt
Coho Salmon Escapement
Juvenile Coho Salmon Abundnace
600
500
400
300
200
100
0
50000
40000
30000
20000
10000
1998
2000
2002
2004
2006
2008
2010
2012
Caspar Creek
Observed
Beverton-Holt r=as/b+s
Ricker R = aSe-bs
Number of Coho Salmon Smolts
7000
6000
5000
4000
3000
2000
1000
0
0
100000
200000
300000
400000
500000
600000
700000
Number of Coho Salmon Eggs

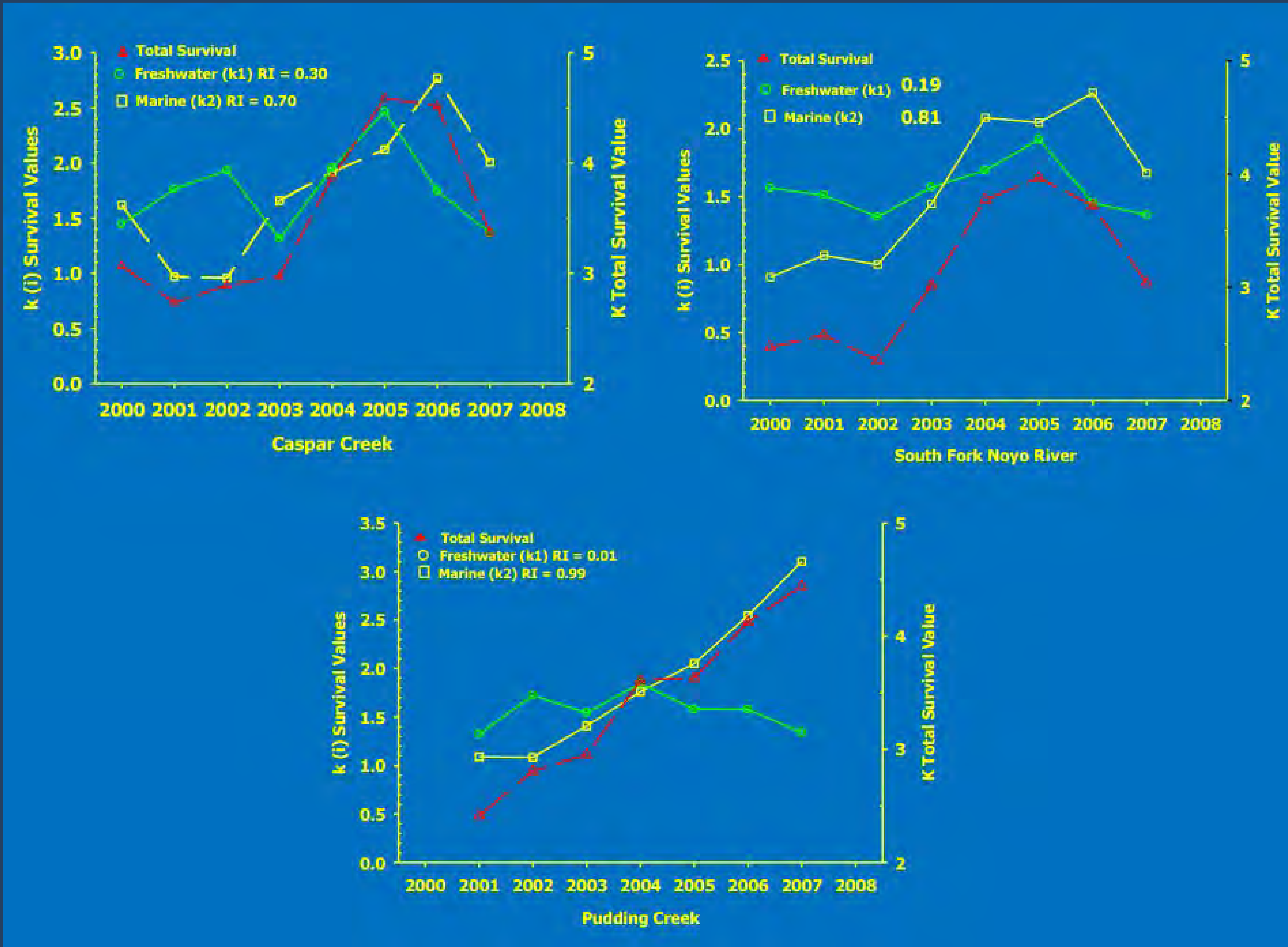
Life-Stage Abundance







Survival


Total Survival
Freshwater (k1) RI = 0.30
Marine (k2) RI = 0.70
k (i) Survival Values
K Total Survival Value
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
4
3
2
2000 2001 2002 2003 2004 2005 2006 2007 2008
Caspar Creek
Total Survival
Freshwater (k1) 0.19
Marine (k2) 0.81
k (i) Survival Values
K Total Survival Value
2.5
2.0
1.5
1.0
0.5
0.0
5
4
3
2
2000 2001 2002 2003 2004 2005 2006 2007 2008
South Fork Noyo River
Total Survival
Freshwater (k1) RI = 0.01
Marine (k2) RI = 0.99
k (i) Survival Values
K Total Survival Value
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5
4
3
2
2000 2001 2002 2003 2004 2005 2006 2007 2008
Pudding Creek

Estuarine Monitoring

Fully Seeded or Not

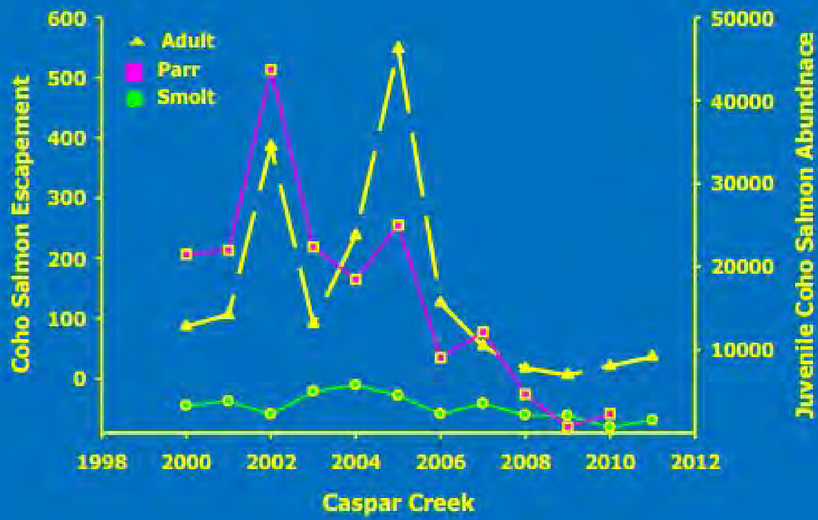
Trend Analysis

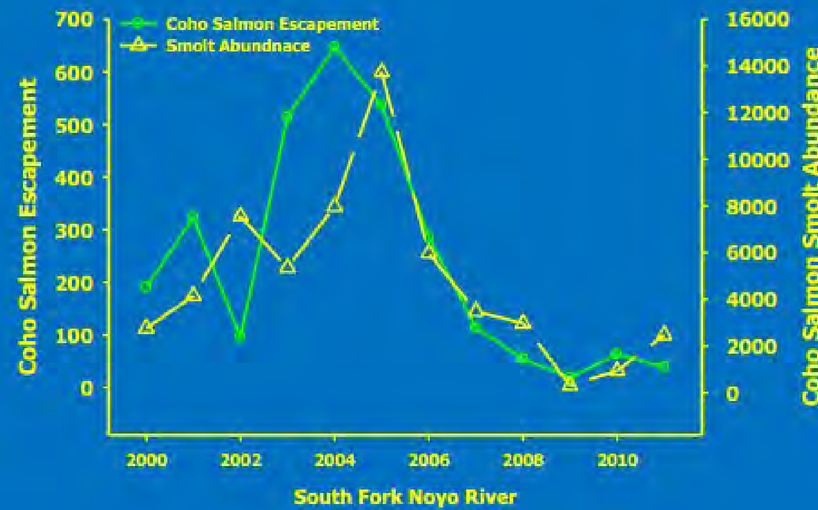
Applying time series models with spatial correlation to identify the scale of variation in habitat metrics related to threatened coho salmon (*Oncorhynchus kisutch*) in the Pacific Northwest

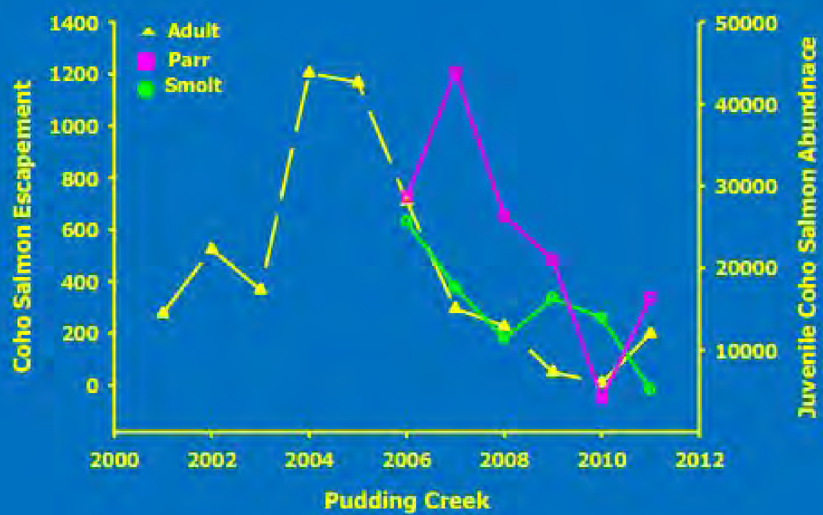
Eric J. Ward, George R. Pess, Kara Anlauf-Dunn, and Chris E. Jordan

Abstract: Trend analyses are common in the analysis of fisheries data, yet the majority of them ignore either observation error or spatial correlation. In this analysis, we applied a novel hierarchical Bayesian state-space time series model with spatial correlation to a 12-year data set of habitat variables related to coho salmon (*Oncorhynchus kisutch*) in coastal Oregon, USA. This model allowed us to estimate the degree of spatial correlation separately for each habitat variable and the importance of observation error relative to environmental stochasticity. This framework allows us to identify variables that would benefit from additional sampling and variables where sampling could be reduced. Of the eight variables included in our analysis, we found three metrics related to habitat quality correlated at large spatial scales (gradient, fine sediment, shade cover). Variables with higher observation error (pools, active channel width, fine sediment) could be made more precise with more repeat visits. Our spatio-temporal model is flexible and extendable to virtually any spatially explicit monitoring data set, even with large amounts of missing data and no repeated observations. Potential extensions include fisheries catch data, abiotic indicators, invasive species, or species of conservation concern.

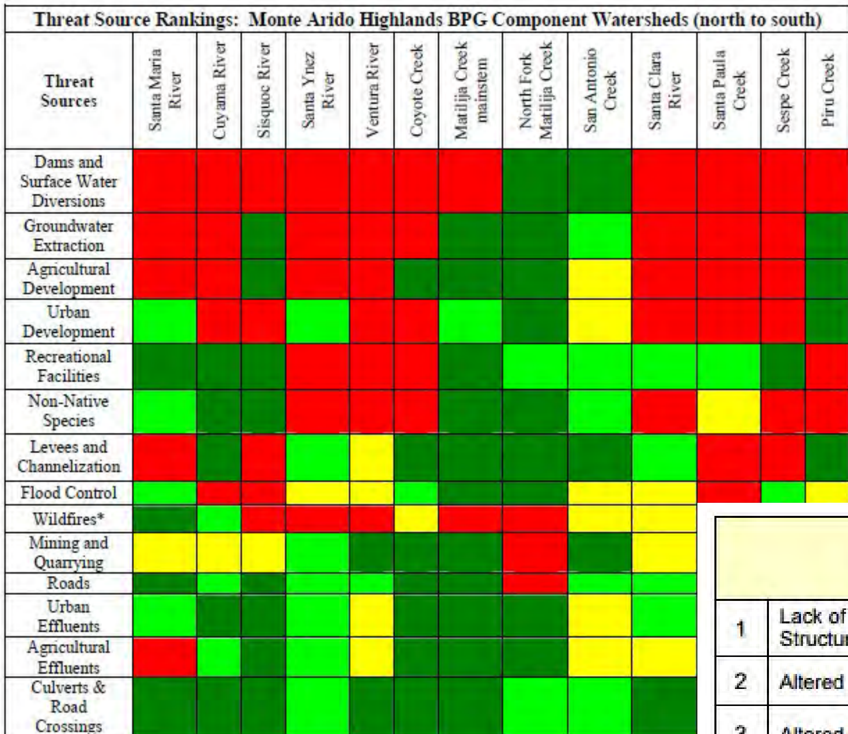
Life-Stage Abundance







Restoration Prioritization & Mitigation



Key: Red = Very High threat; Yellow = High threat; Light green = Medium threat; Dark green = Lo
Threat cell colors represent threat rating from Conservation Planning (CAP) Workbooks.

	Stresses	Egg	Fry	Juvenile[1]	Smolt	Adult	Overall Stress Rank
1	Lack of Floodplain and Channel Structure[1]	High	Very High	Very High[1]	Very High	Very High	Very High
2	Altered Sediment Supply	Very High	Very High	Very High	High	Very High	Very High
3	Altered Hydrologic Function[1]	Medium	High	Very High[1]	High	Medium	High
4	Degraded Riparian Forest Conditions	-	High	High	High	Medium	High
5	Impaired Water Quality	Medium	High	High	High	Medium	High
6	Barriers	-	High	High	Medium	High	High
7	Increased Disease/Predation/Competition	Low	High	High	High	Low	High
8	Impaired Estuary/Mainstem Function	-	Low	High	High	Medium	High
9	Adverse Fishery- and Collection-Related Effects	-	-	Low	Low	Medium	Low
10	Adverse Hatchery-Related Effects	Low	Low	Low	Low	Low	Low

[1] Key limiting stresses and limited life stage

Key Limiting Stresses, Limited Life Stage, and Habitat

Why life-cycle modeling?

1. Provide a shared understanding of species, life-stage, and season-specific life-cycle dynamics and habitat needs in context of a bio-region or watershed;

2. Help identify and verify limiting life-stages (population bottlenecks) and associated key habitats and seasons to provide guidance for monitoring data collection, experimental manipulations, restoration designs, and recovery planning;

3. Allow rapid hypothesis and assumption testing and refinement of watershed or location-specific conceptual models of salmon species.

4. Cost effective investment guidance, grounded in biological and watershed-specific conditions with predictive capabilities, will help improve the effectiveness of recovery efforts.

Home Watershed What We Do Data Contacts and Resources

The Integrated Status and Effectiveness Project (ISEMP) was created nearly 10 years ago to systematically answer questions such as "what is the best way to measure stream habitat?" and "what is the best way to measure salmonid populations?". These questions are related to the management that underpins the proposed tributary habitat-based, off-site mitigation strategy of the Federal Columbia River Power System Biological Opinion (FCRPS BiOp) quantitative tools that relate habitat condition to fish populations in a framework that supports habitat and population management decision making. We develop monitoring conducted under the ISEMP project which falls into three discrete, but related, categories:

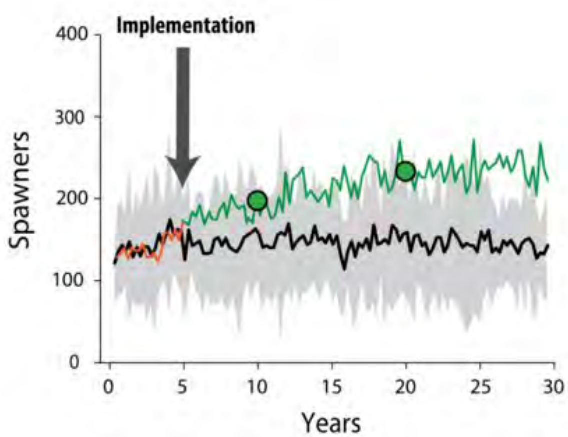
Status and trends: monitoring data on fish and habitat to track and evaluate fish-habitat relationships at the Evolutionary Significant Unit (ESU), subbasin, and population levels.

Action Effectiveness: evaluating the effect of habitat actions (both project level: i.e., type of project, and watershed level: i.e., cumulative projects in a given area) on fish populations.

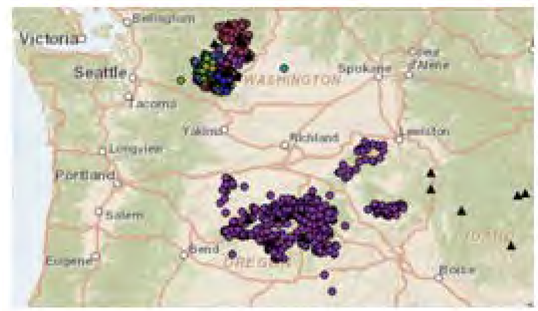
Analytical Framework: providing the context for monitoring data to address fish-habitat relationships, limiting factors, and whether management actions and restoration has led to changes in fish and their habitat.

Life Cycle Model

Within the Salmon Subbasin, we have implemented a habitat and population status and trends monitoring project in the South Fork Salmon River (SFSR) watershed and habitat action effectiveness evaluation in the Lemhi River watershed. These initiatives are joined through the application of a watershed model (QCInc 2005) that views fish vital rates (survival productivity, abundance, and condition) as a function of the quantity and quality of available habitat. These functions are constructed using both coarse (e.g., Geographic Information Systems (GIS)) and fine (e.g., reach) scale habitat measures. Once validated via the collection of empirical data within habitat classes, the model provides a statistical framework to assess the effects of different classes of habitat actions on life- stage specific vital rates (productivity/survival and condition) of anadromous and resident salmonids. Additionally, the model includes survival functions enabling the user to alter survival rates (juvenile to emigrant and emigrant to adult) as necessary to compensate for hatchery production.



Data



Data processing

- Survey and sampling designs to support population-scale inference of fish-habitat relationships.
- Data management to support population-scale inference of fish-habitat relationships.
- Spatio-temporal analysis of fish-habitat relationships to develop a quantitative rule set that links abundance and productivity to habitat quality and quantity.
- Watershed production model to evaluate the impact of management action scenarios for key populations and habitat action tactics.

Life-Cycle Population Models

Life-Cycle models of salmonid populations in the interior Columbia River Basin

June 28, 2013

Life-Cycle Population Models

2.1: Grande Ronde Spring Chinook Population Models

Thomas D. Cooney (NWFSC), Richard W. Carmichael (ODFW), Brian C. Jonasson (ODFW), Edwin W. Sedell (ODFW) & Timothy L. Hoffnagle (ODFW)

2.2 ISEMP Watershed Model for spring/summer Chinook salmon and steelhead in the Salmon River Subbasin

Jody White (Quantitative Consultants, Inc.), Chris Beasley (Quantitative Consultants, Inc.), Chris Jordan (NOAA Fisheries), Matt Nahorniak (South Fork Research, Inc.), Claire McGrath (Quantitative Consultants, Inc.), Joe Benjamin (Quantitative Consultants, Inc.)

2.3 Upper Columbia River spring Chinook salmon

Jeff Jorgensen (NOAA Fisheries, NWFSC, Seattle), Andrew Murdoch (WDFW), Jeremy Cram (WDFW), Charlie Paulsen (Paulsen Environmental Research), Tom Cooney (NOAA Fisheries, NWFSC, Portland), Rich Zabel (NOAA Fisheries, NWFSC, Seattle), and Chris Jordan (NOAA Fisheries, NWFSC, Newport)

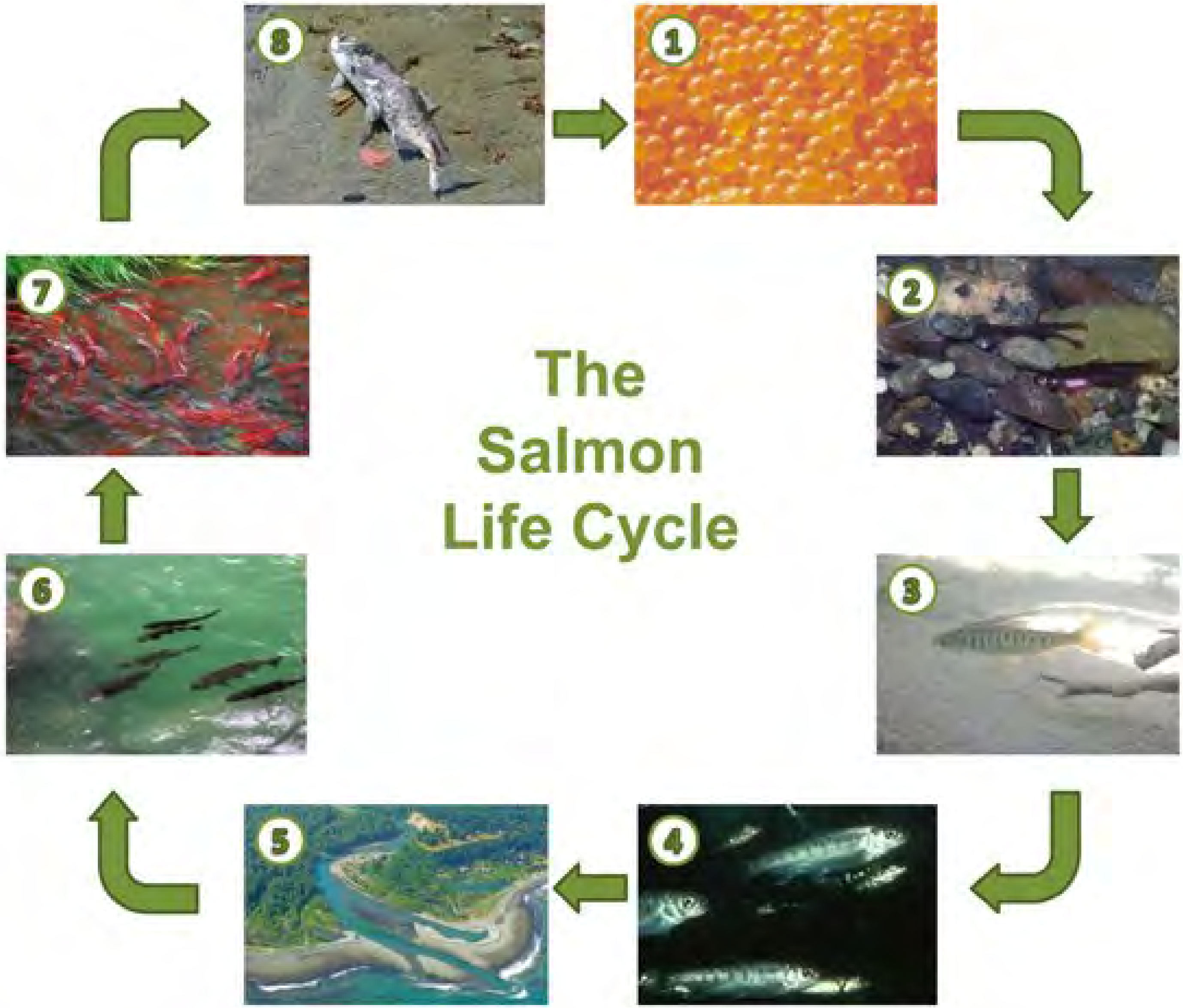
2.4 Population responses of spring/summer Chinook salmon to projected changes in stream flow and temperature in the Salmon River Basin, Idaho

Lisa G. Crozier (NWFSC) and Richard W. Zabel (NWFSC)

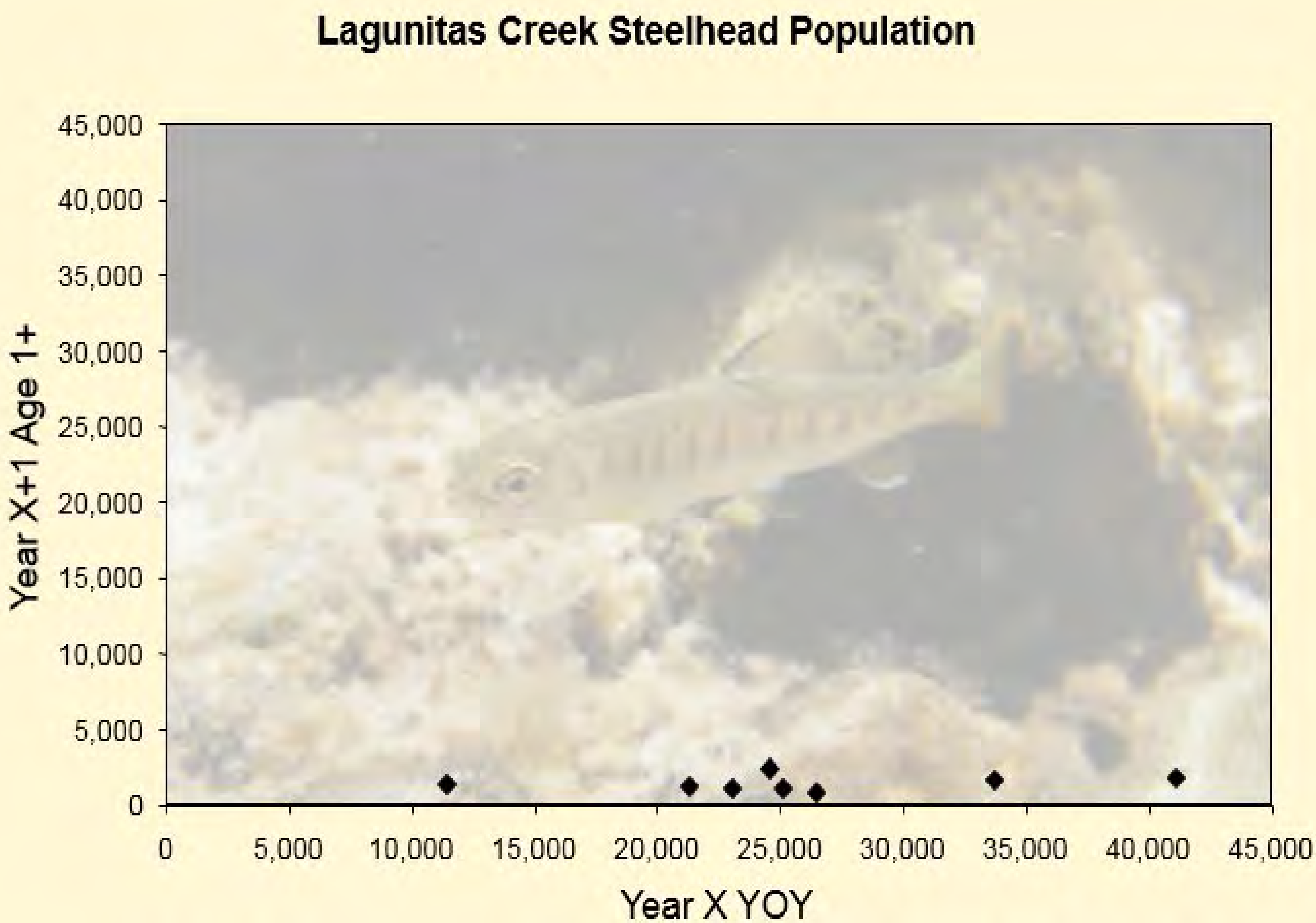
2.5 Life cycle matrix models to evaluate productivity and abundance under alternate scenarios for steelhead populations

Neala Kendall (NOAA Fisheries, Northwest Fisheries Science Center and Washington Department of Fish and Wildlife), Rich Zabel (NOAA Fisheries, Northwest Fisheries Science Center), and Tom Cooney (NOAA Fisheries, Northwest Fisheries Science Center)

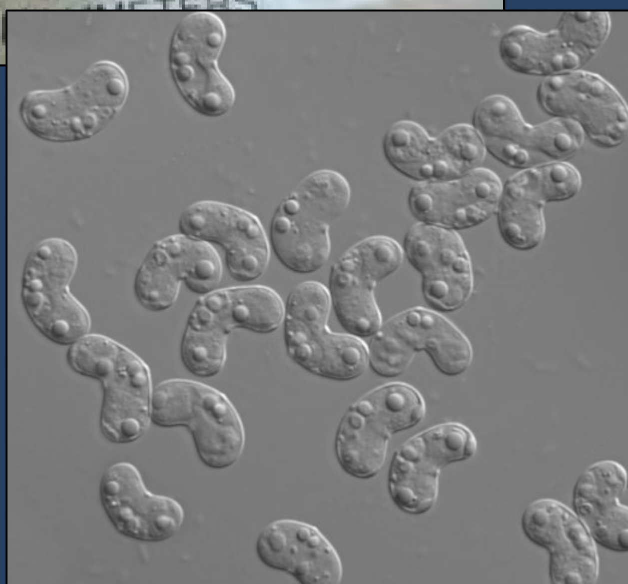
Life-Cycle Population Models



Density Dependence - Capacity

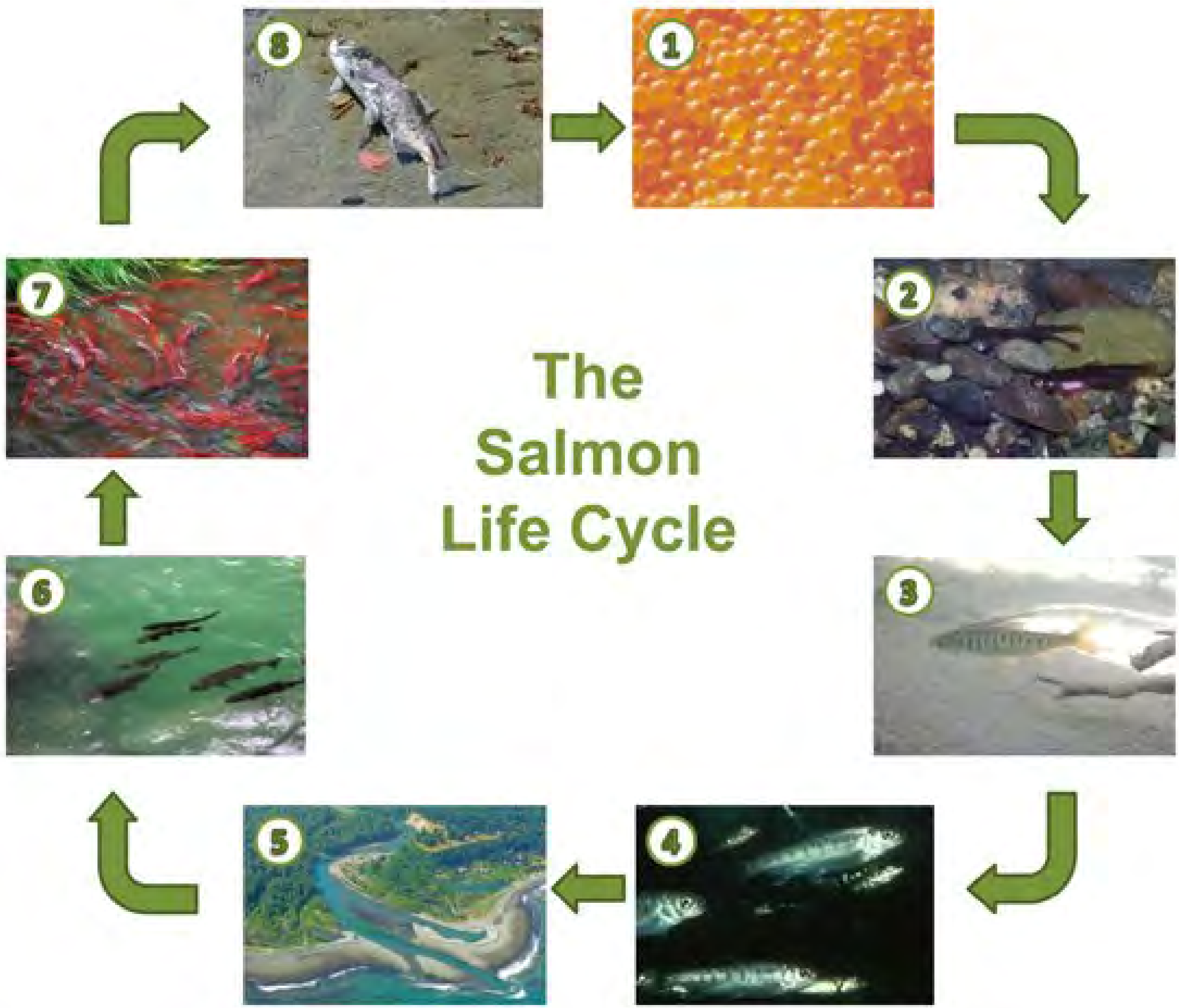


Density Independent - Survival



Year	Histology (% Positive)	QPCR (% Positive)
2006	21	34
2007	21	31
2008	37	49
2009	54	45
2010	15	17
2011	2[1]	17
2012	9[1]	30
2013	16[1]	46
2014	42[1]	81
2015	62[1]	91
Mean	**28**	**44**

Life-Cycle Population Models



Life-Cycle Population Models

SLAM

RIPPLE
A Digital Terrain-Based
Population Dynamics to

EDT3

Ecosystem Diagnosis + Treatment

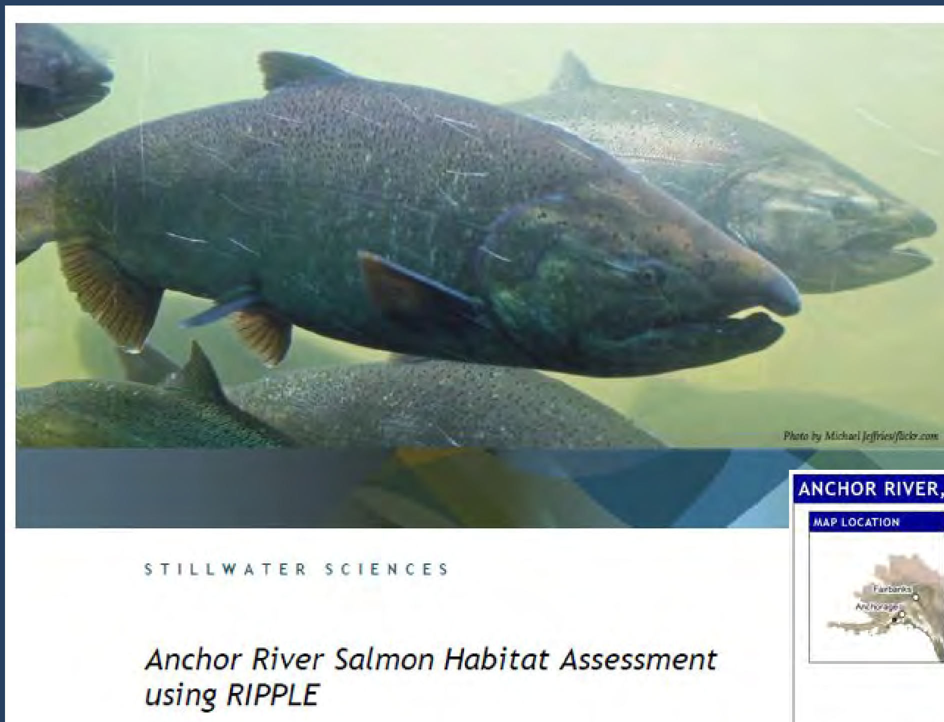
Categorized Under: Environment

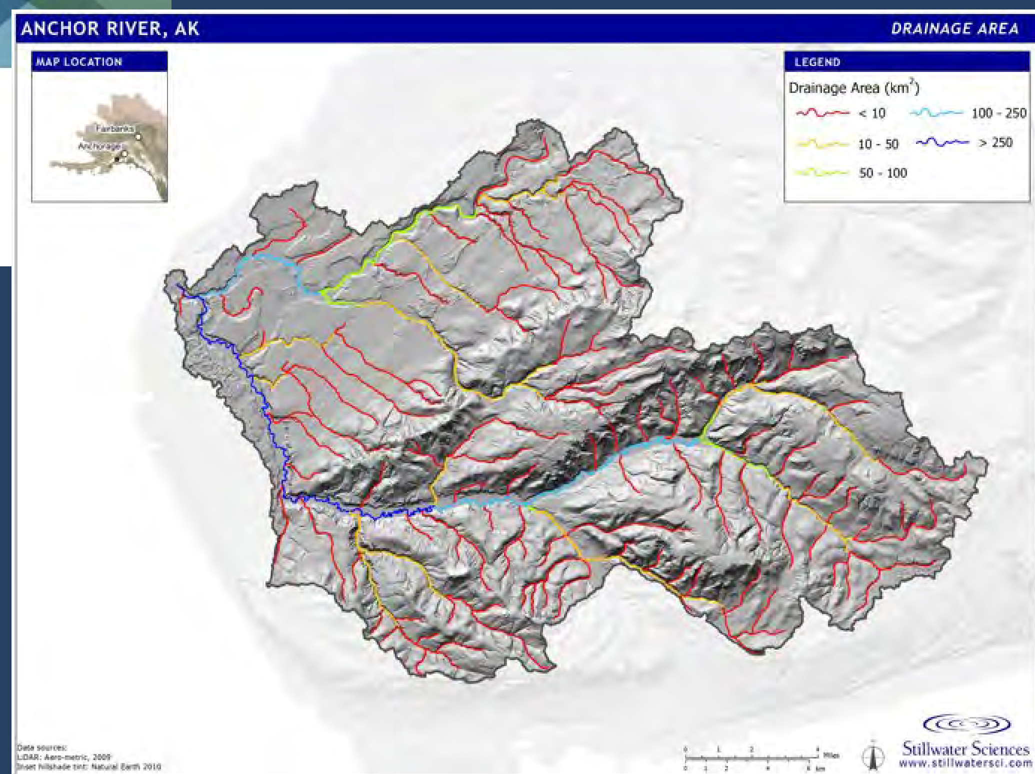
ICF International's Ecosystem Diagnosis and Treatment system (EDT) was developed more than 15 years ago as an application of the medical model of diagnosis and treatment to watershed management issues.

The first EDT tool was developed in an offline database environment and focused almost exclusively on Chinook, coho, and steelhead in their freshwater life stages.

The second version of EDT included its evolution to a web-based environment, and provided a shared system for cooperative basin planning.
EDT has been used throughout much of the Columbia Basin and Puget Sound in the Pacific Northwest of the United States. While there was much strength in these systems, modern ecosystem management problems present ever increasing challenges for flexibility, integration, and transparency.

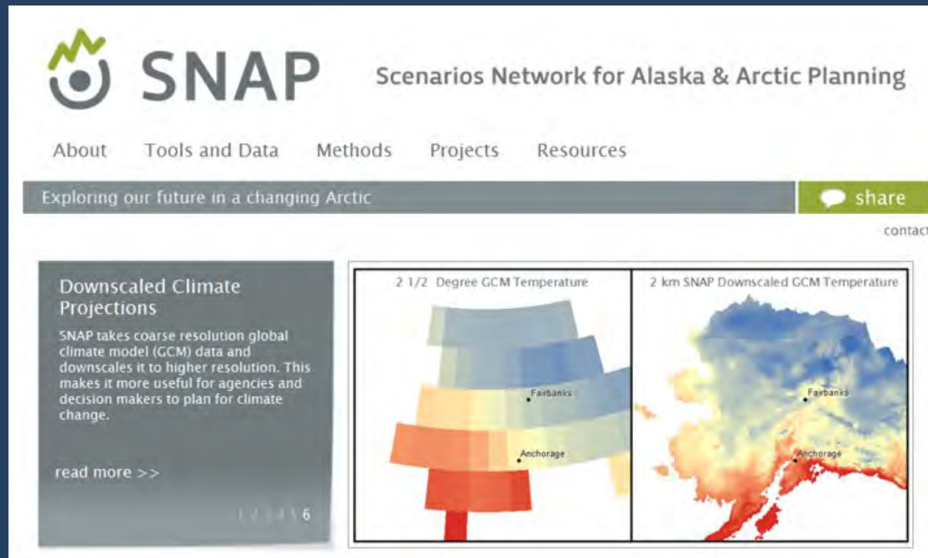
Synergy: Life-Cycle Monitoring and Population Models

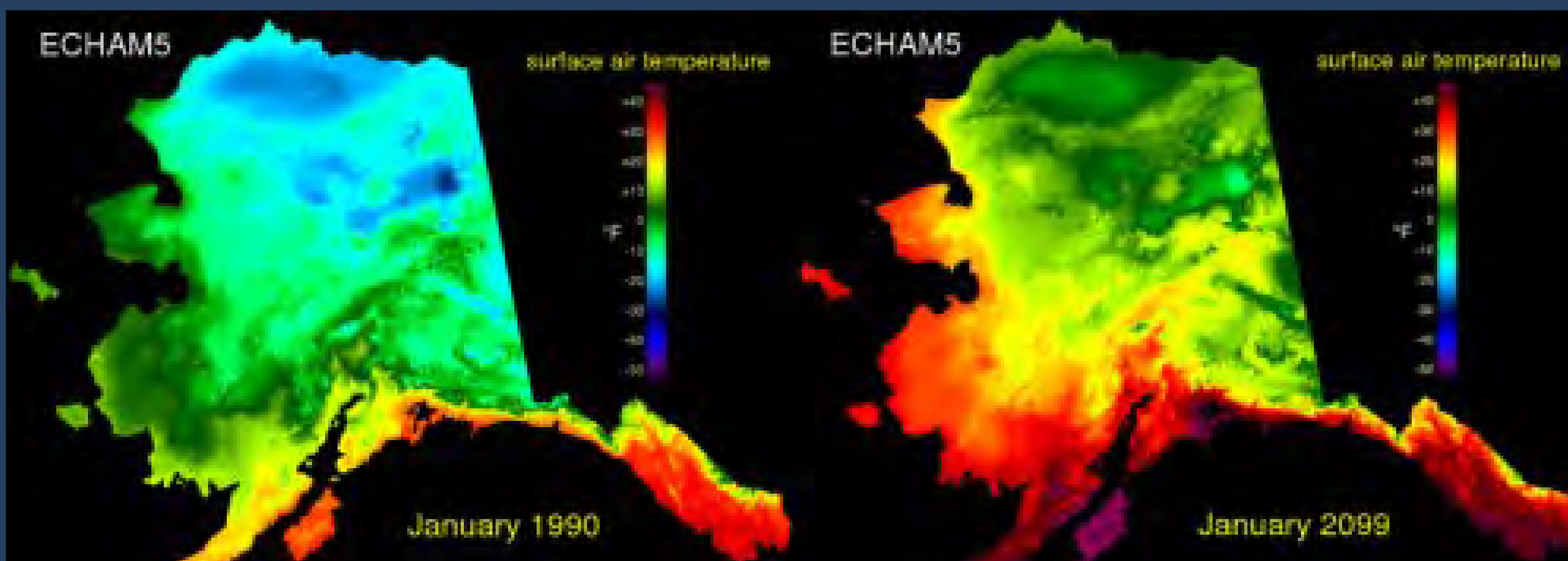




Identification of Monitoring Needs

Future Scenarios





Reintroduction Planning

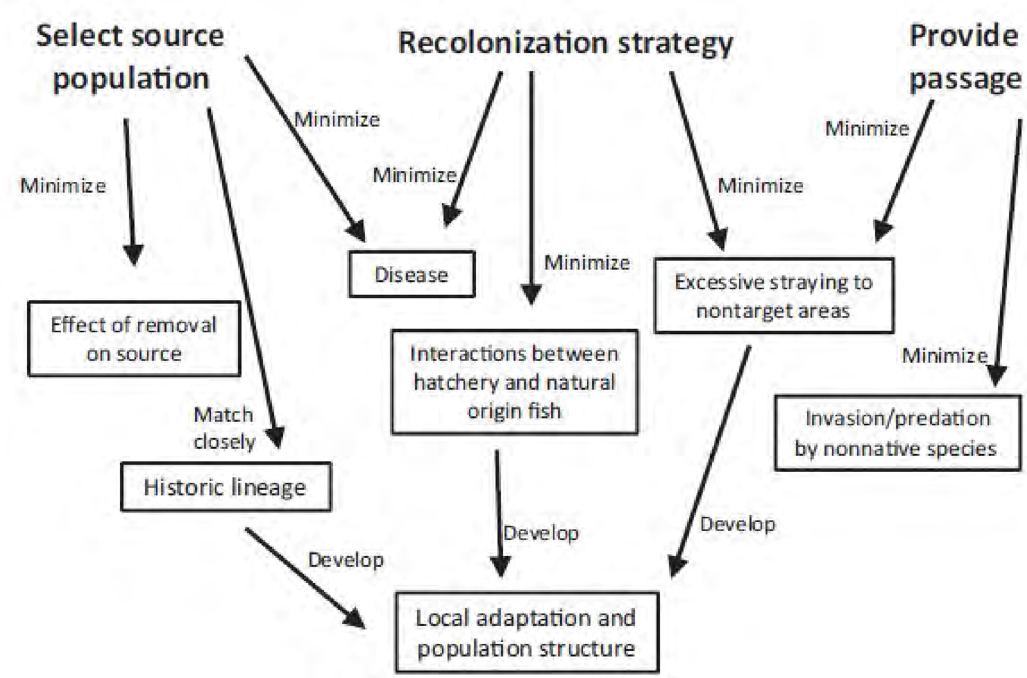
North American Journal of Fisheries Management 34:72–93, 2014

ISSN: 0275-5947 print / 1548-8675 online
DOI: 10.1080/02755947.2013.847875

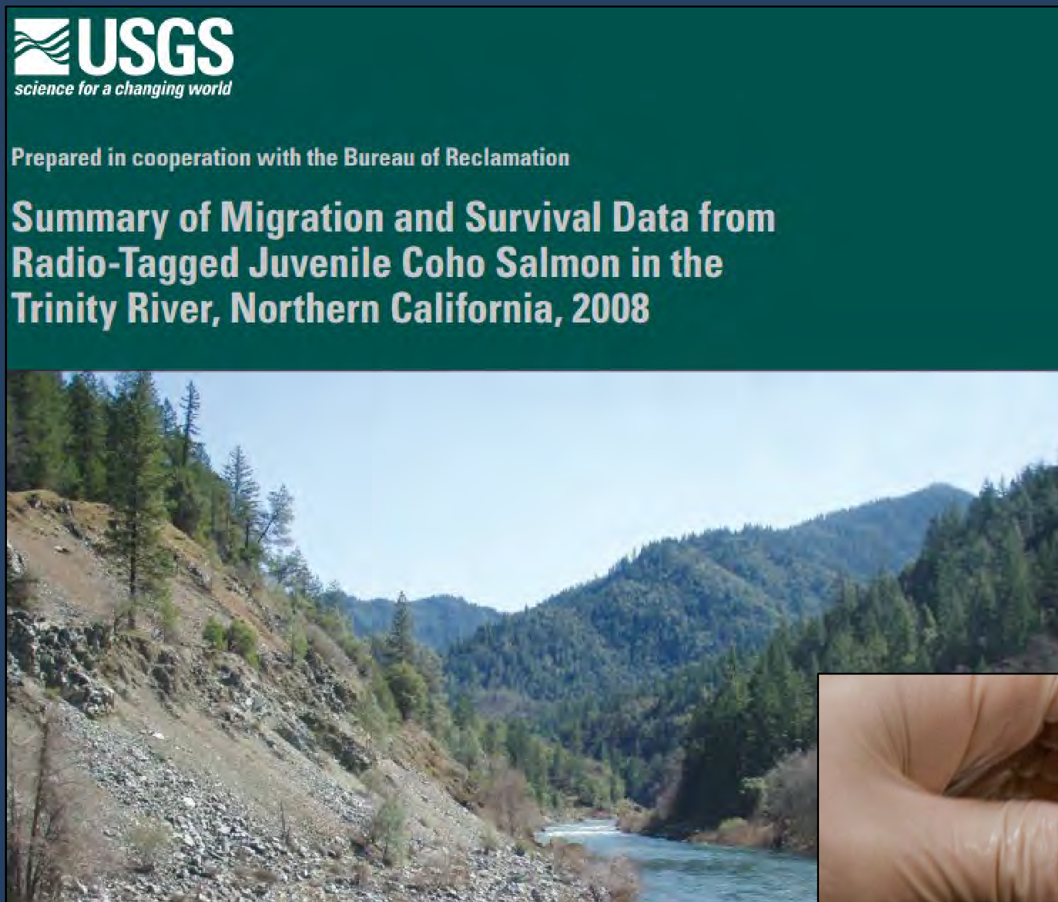
ARTICLE

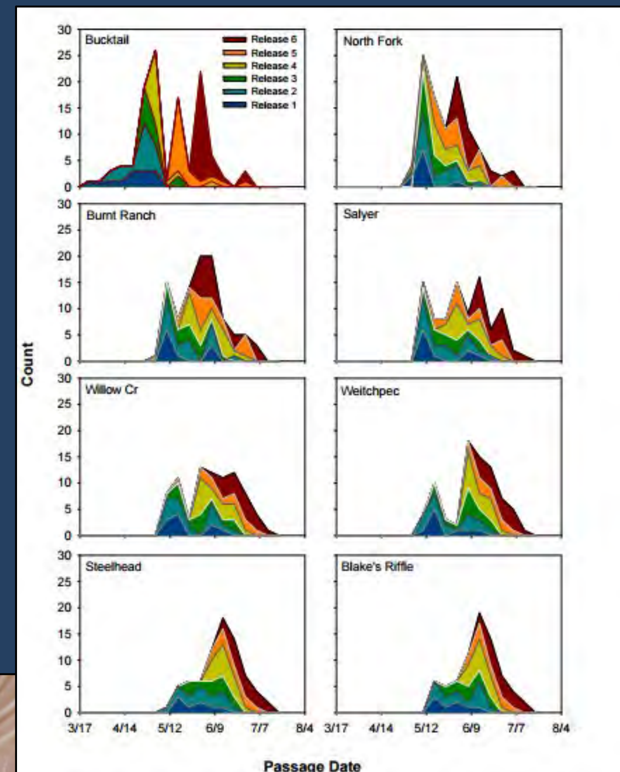
Planning Pacific Salmon and Steelhead Reintroductions Aimed at Long-Term Viability and Recovery

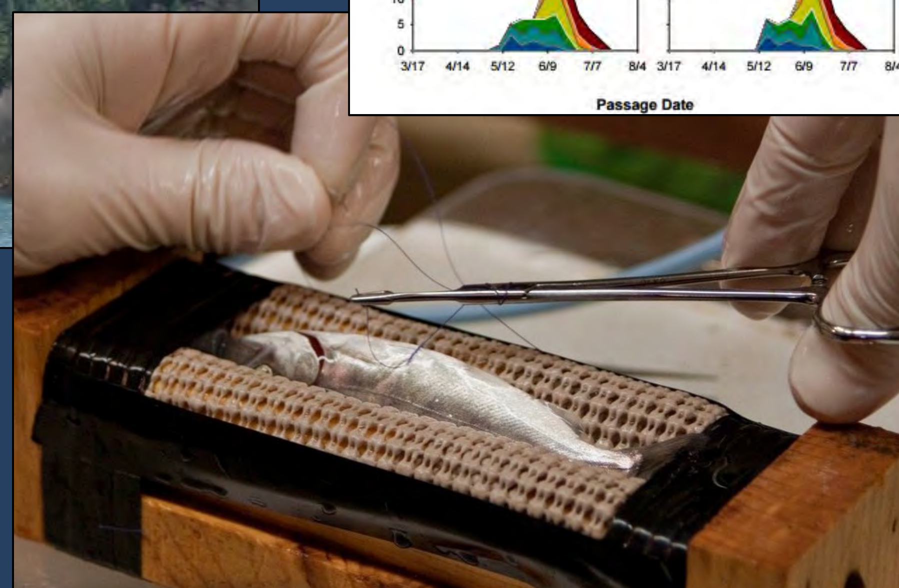
Joseph H. Anderson*[1] and George R. Pess
National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, Washington 98112, USA



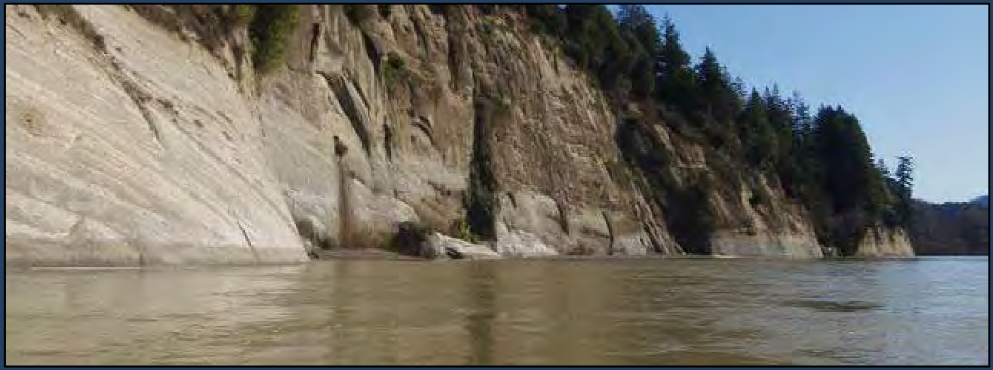
Hypothesis Testing: Key Studies and Experiments



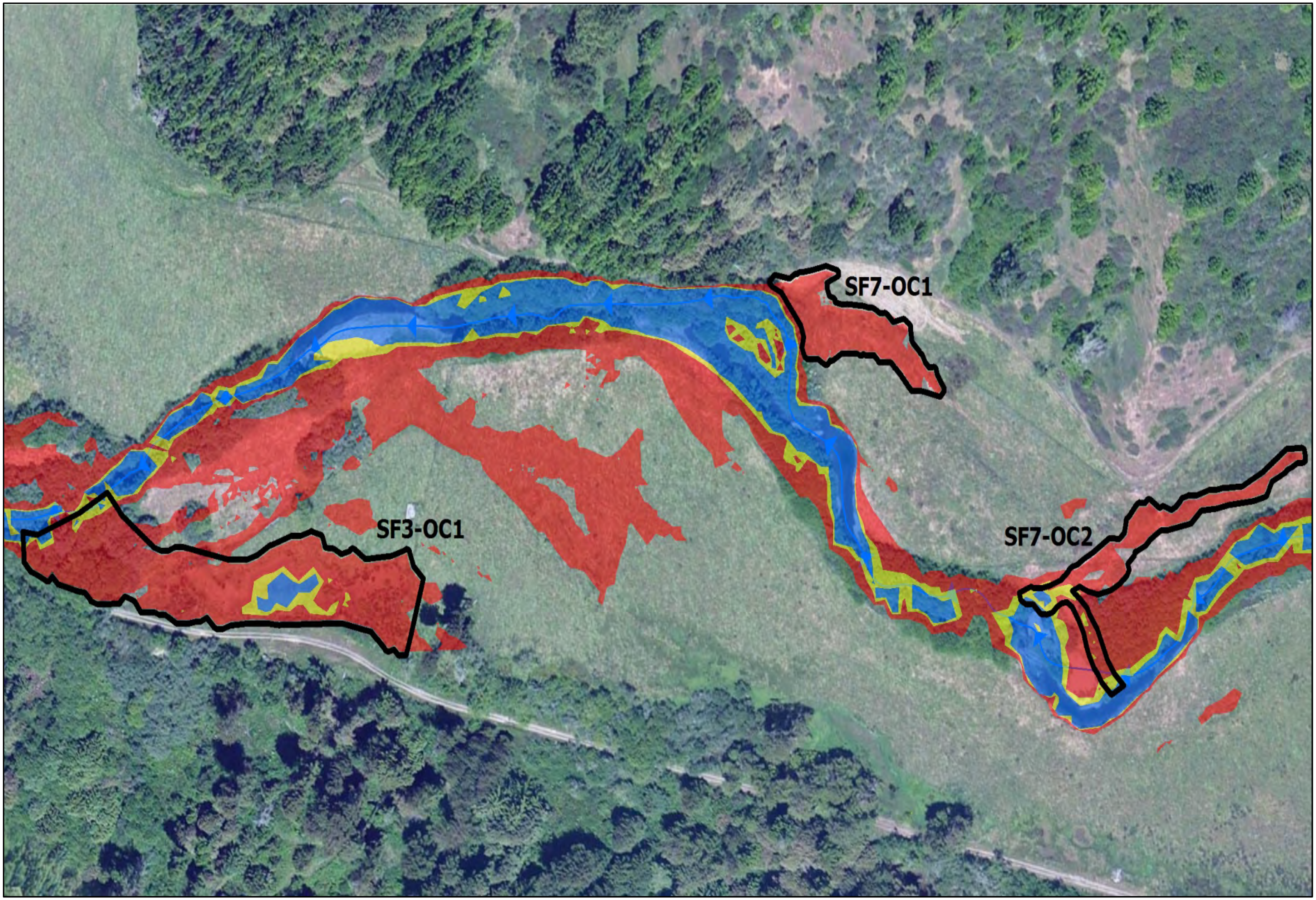




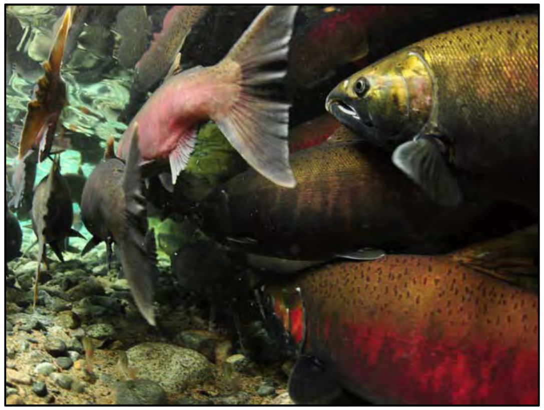
Hypothesis Testing: Virtual Experiments

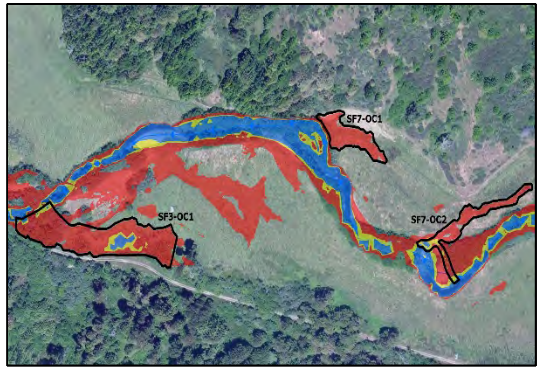


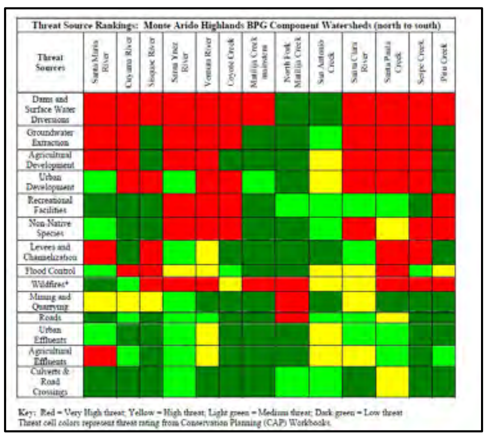
Recovery, Restoration, & Mitigation Planning

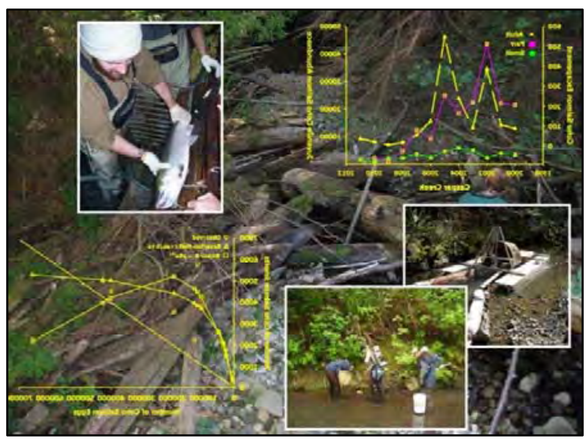


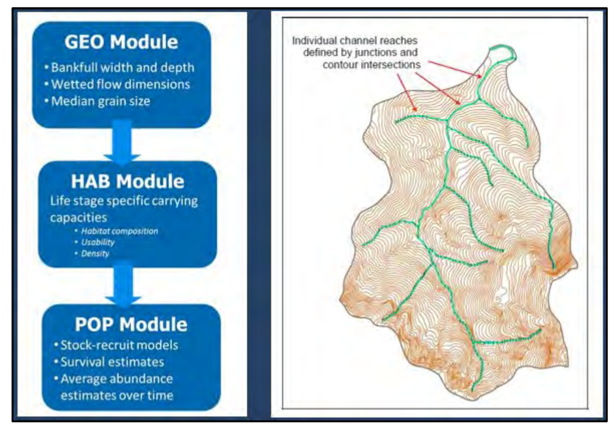
Iterative Synergy: Life-Cycle Monitoring and Population Modeling












Paul Vecsie

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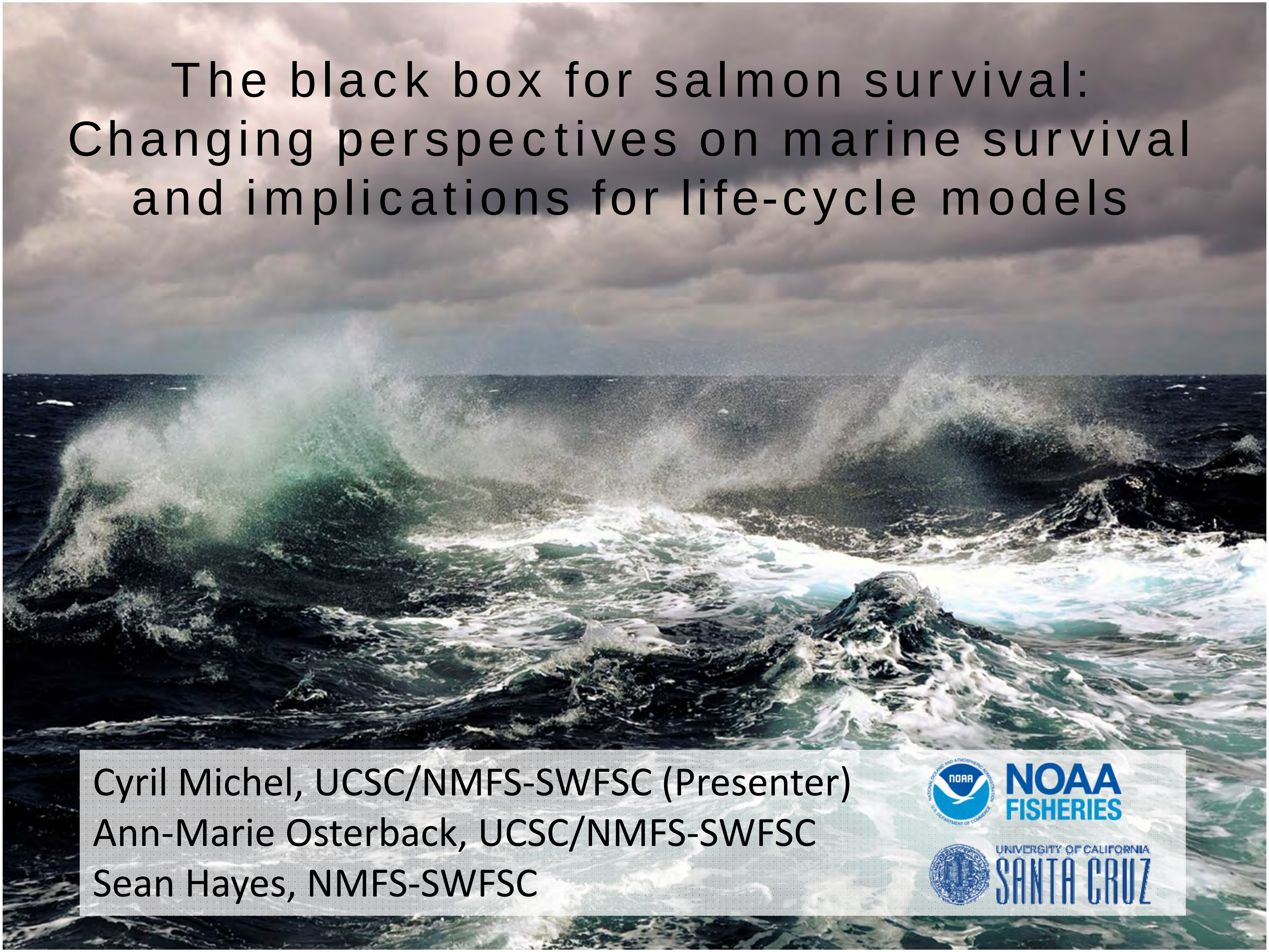


The black box for salmon survival: Changing perspectives on marine survival and implications for life-cycle models

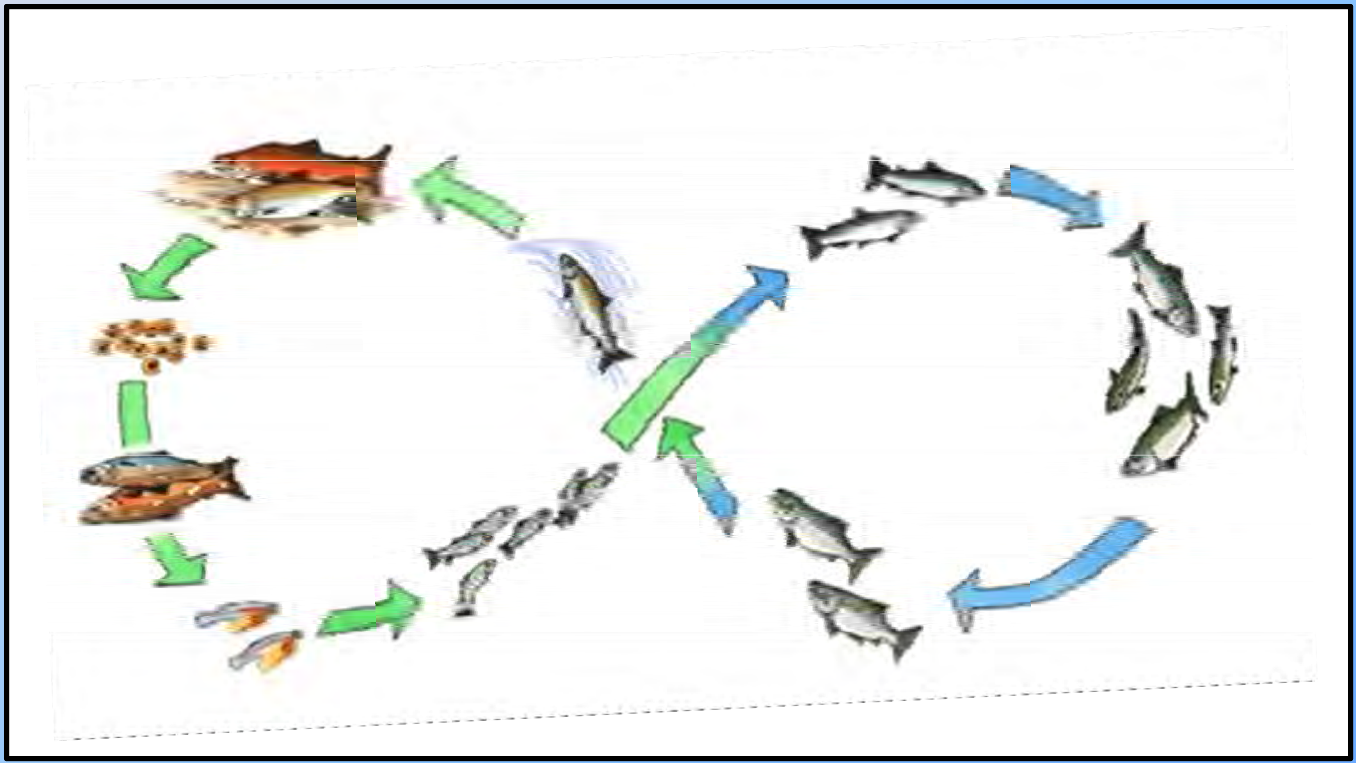
Cyril Michel, UCSC/NMFS-SWFSC (Presenter)
Ann-Marie Osterback, UCSC/NMFS-SWFSC
Sean Hayes, NMFS-SWFSC

DISCLAIMER…

…musings from a freshwater salmon biologist

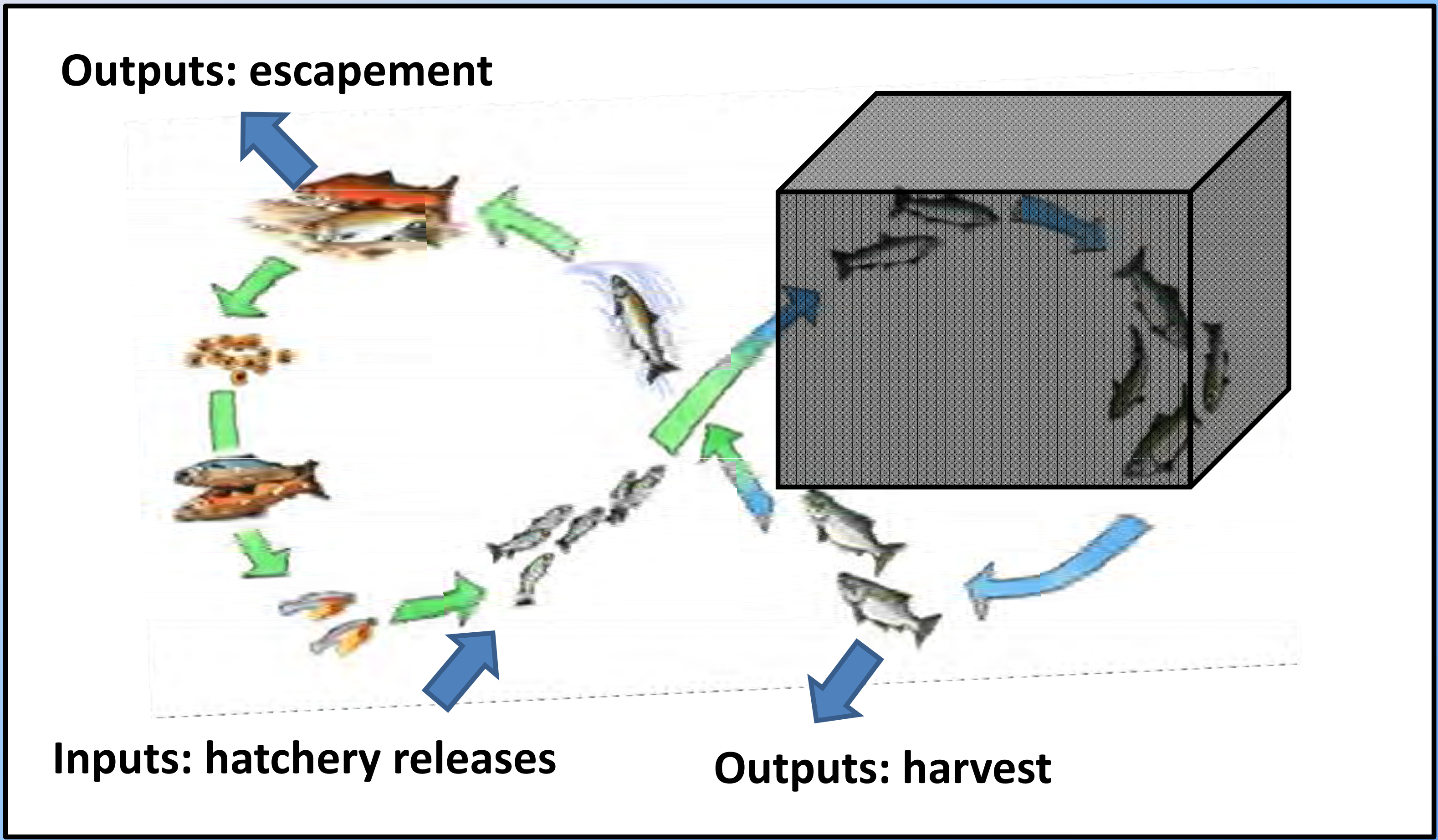
What creates a strong chinook salmon cohort?

Or: what life stages are most vulnerable under varying environmental conditions?



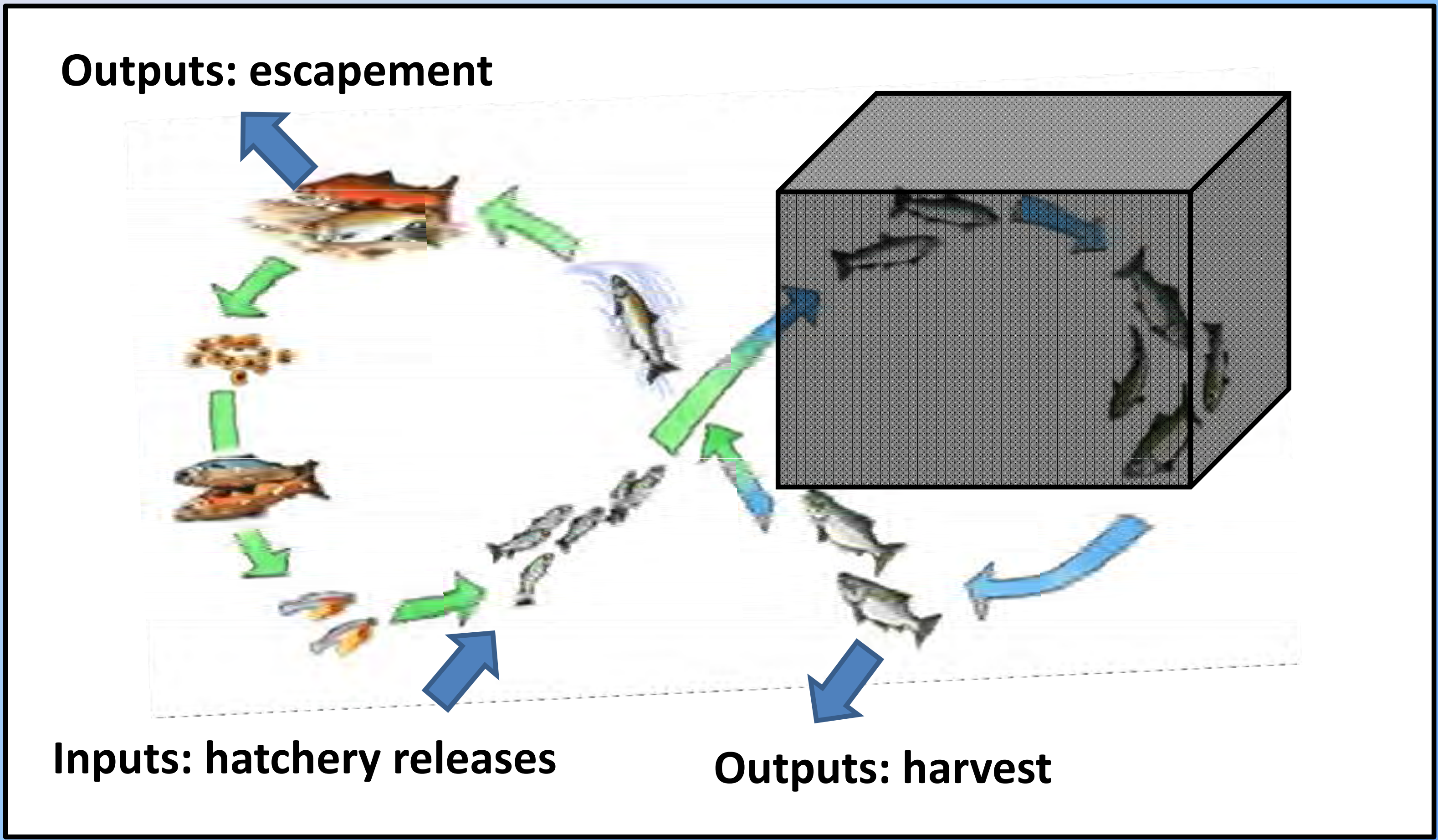
But what about marine survival?

- Little is known about marine survival, including the effect of environmental conditions

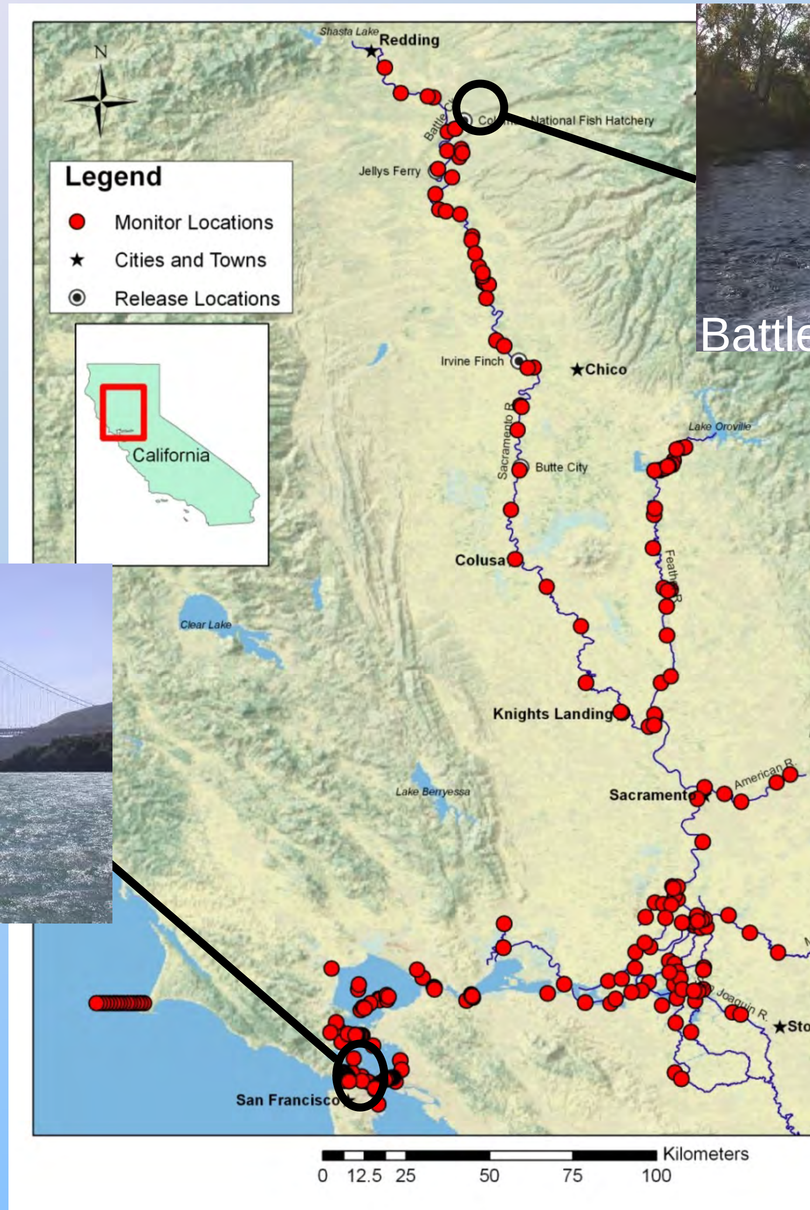


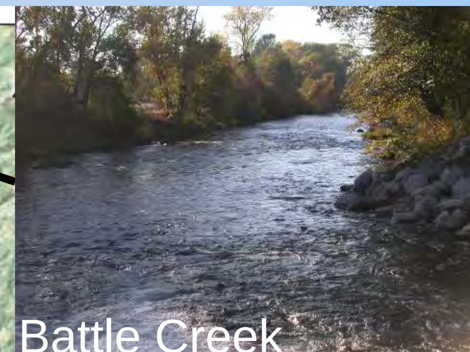
But what about marine survival?

$$\text{Marine Survival} = \frac{Harvest + Escapement}{Hatchery\ Releases}$$

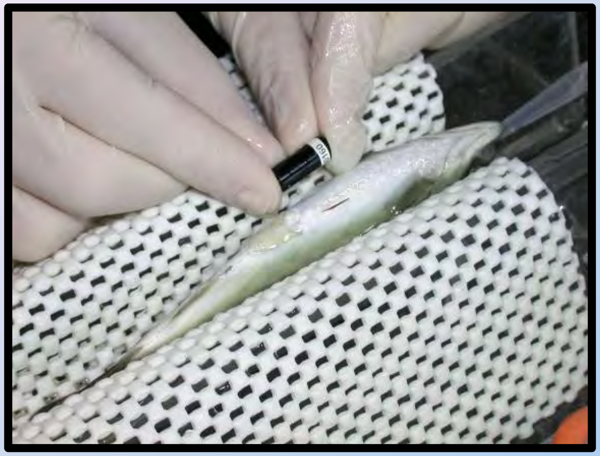


Late-fall run Chinook salmon acoustic tagging project

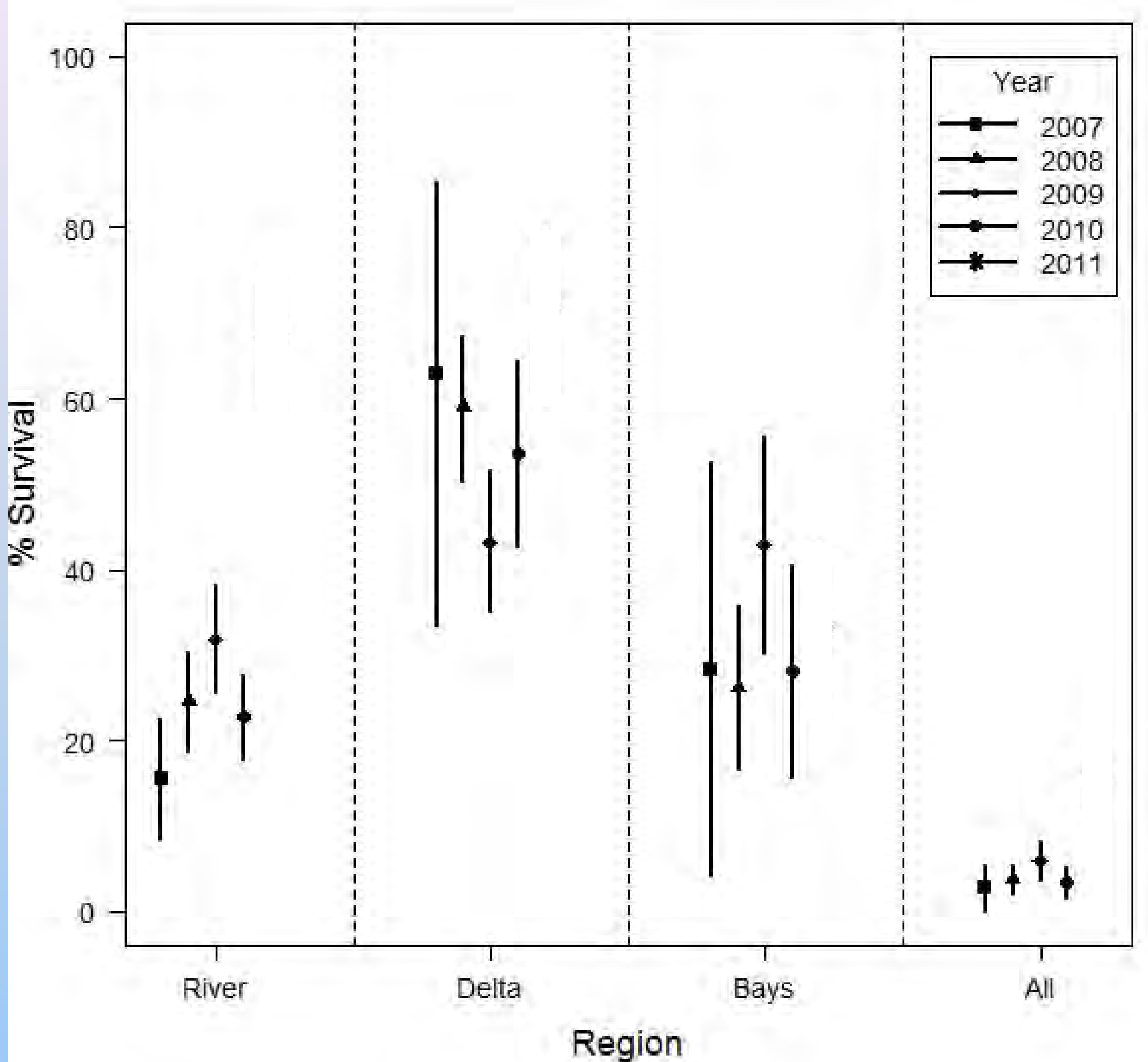




Coleman Hatchery Late-fall yearling Chinook salmon tagging

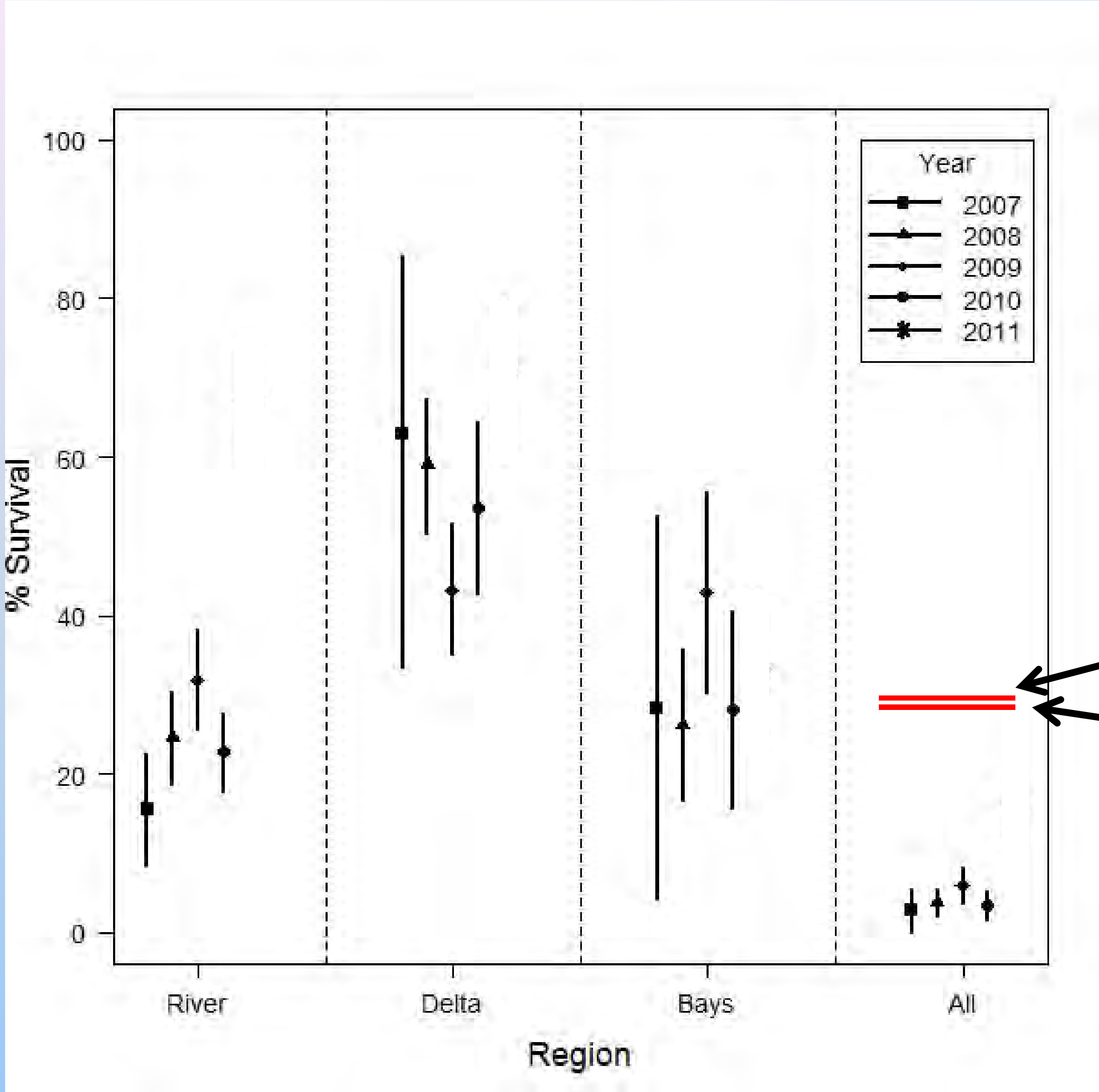


2006/2007	2007/2008	2008/2009	2009/2010	2010/2011
1 release	**2 releases**	**2 releases**	**3 releases**	**4 releases**
Jan	**Dec/Jan**	**Dec/Jan**	**Dec(2)/Jan**	**Dec(2)/Jan(2)**



2007 – 2.8%
2008 – 3.8%
2009 – 5.9%
2010 – 3.4%

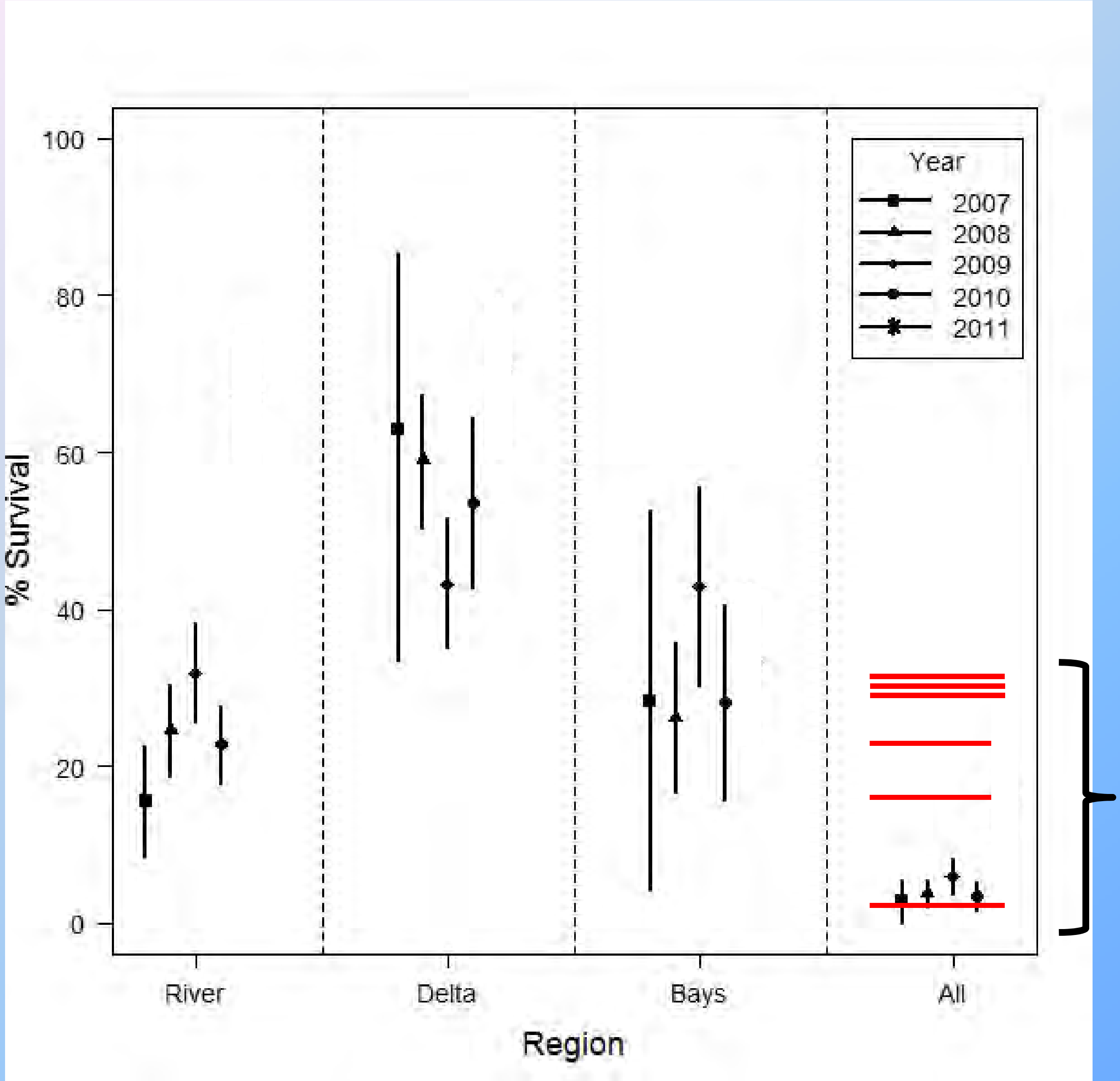
Michel et al. 2015. Chinook salmon outmigration survival in wet and dry years in California's Sacramento River. CJFAS 72:1749-1759.



Yakima River

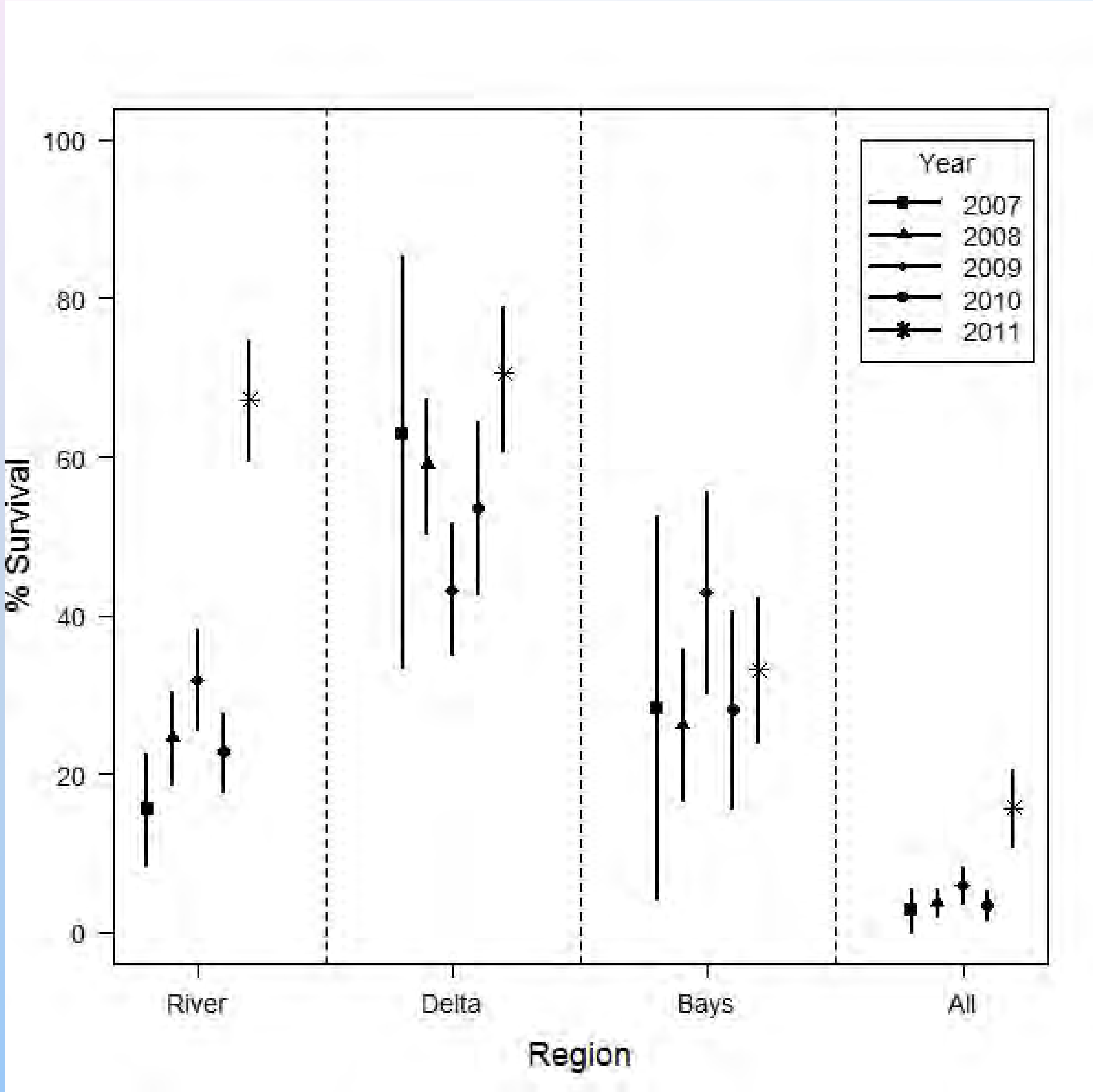
Snake River (tributaries to the Columbia River)

Welch et al. 2008
Rechisky et al. 2009



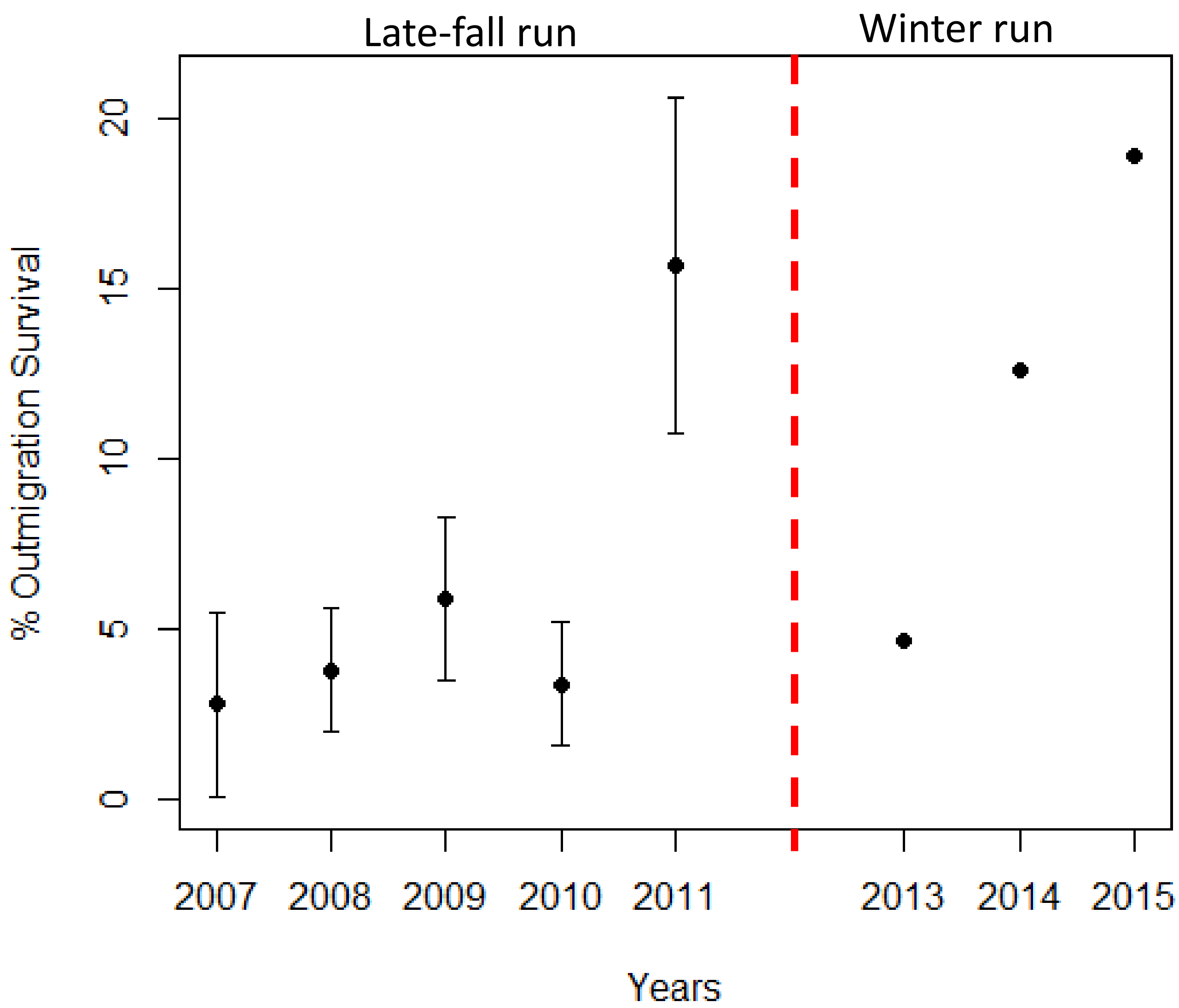
Various Fraser River tributaries

Welch et al. 2008
Rechisky et al. 2009



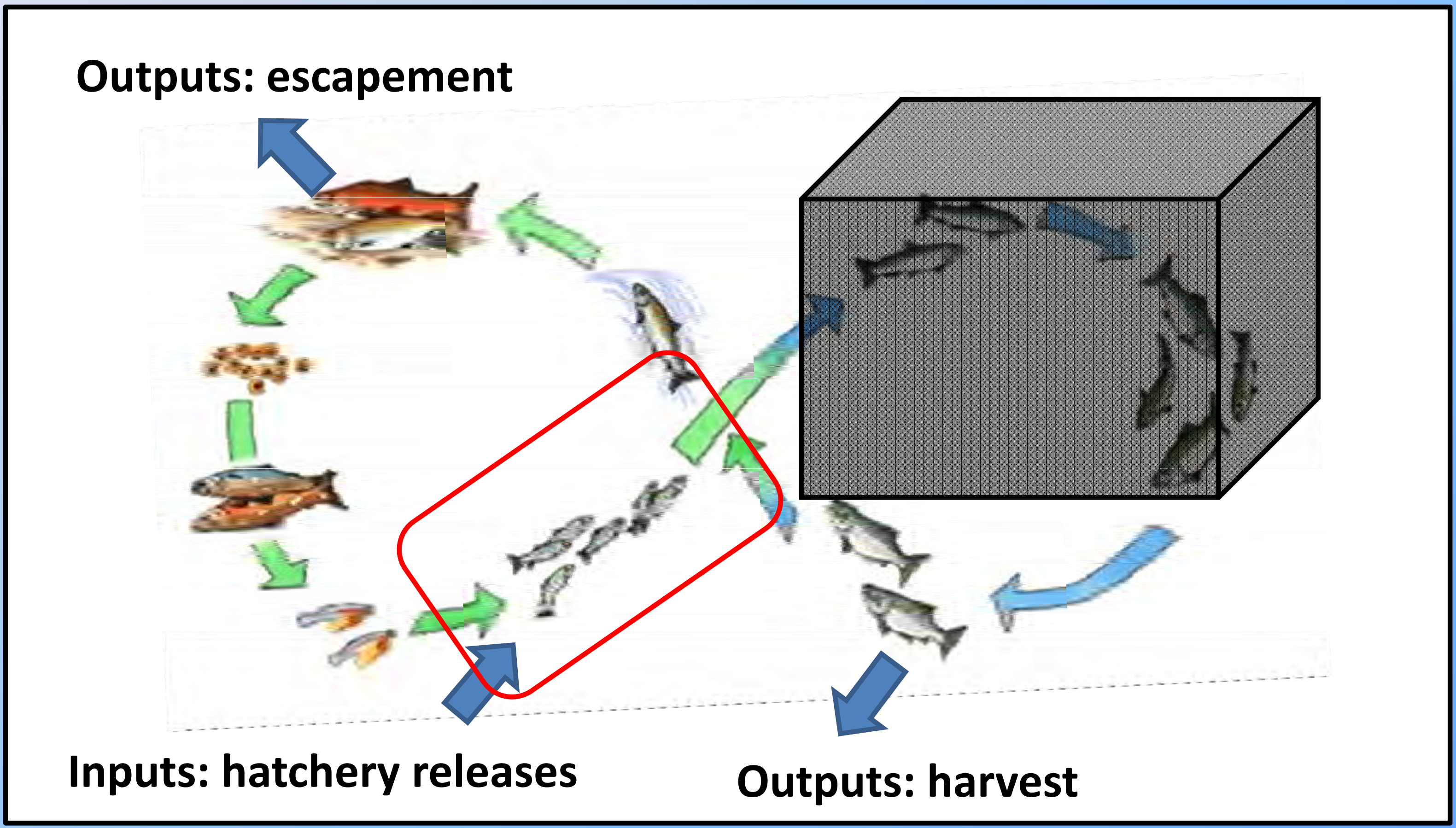
2007 – 2.8%
2008 – 3.8%
2009 – 5.9%
2010 – 3.4%
2011 – 15.7%


28,000
157,000

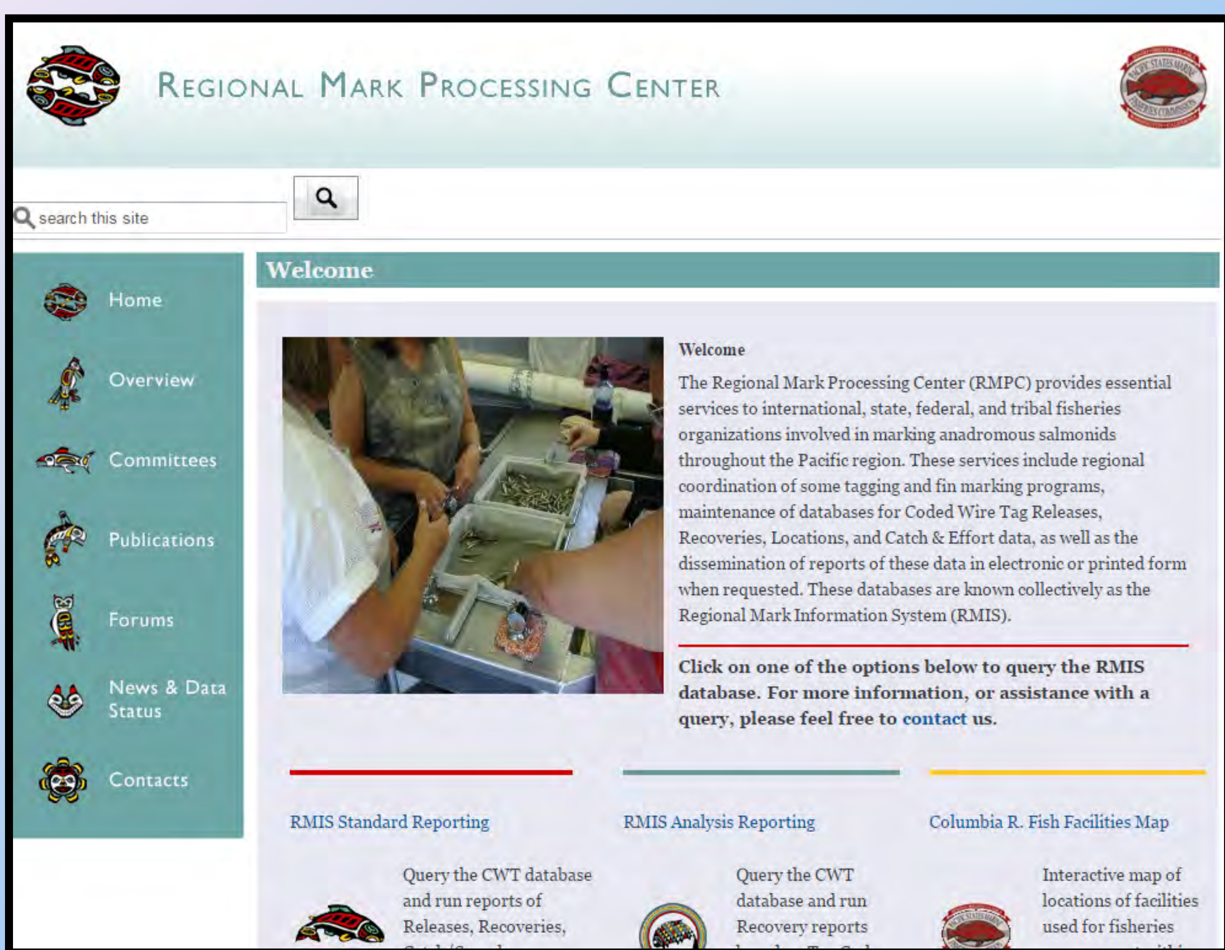


Preliminary Winter run survival estimates from Arnold Ammann, SWFSC

Have studies been over-attributing unexplained mortality to the ocean?

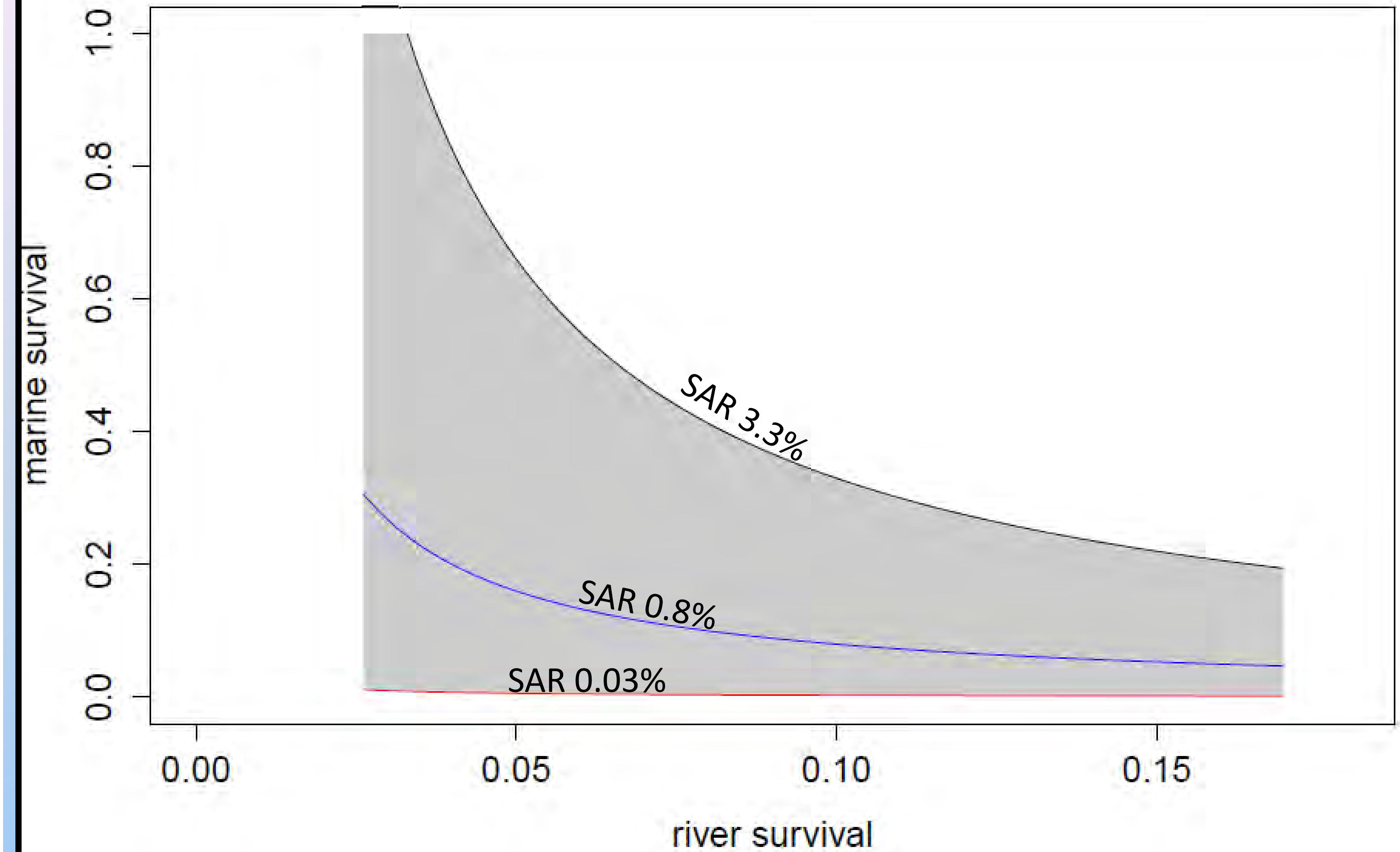


Smolt-to-adult return rate (SAR)

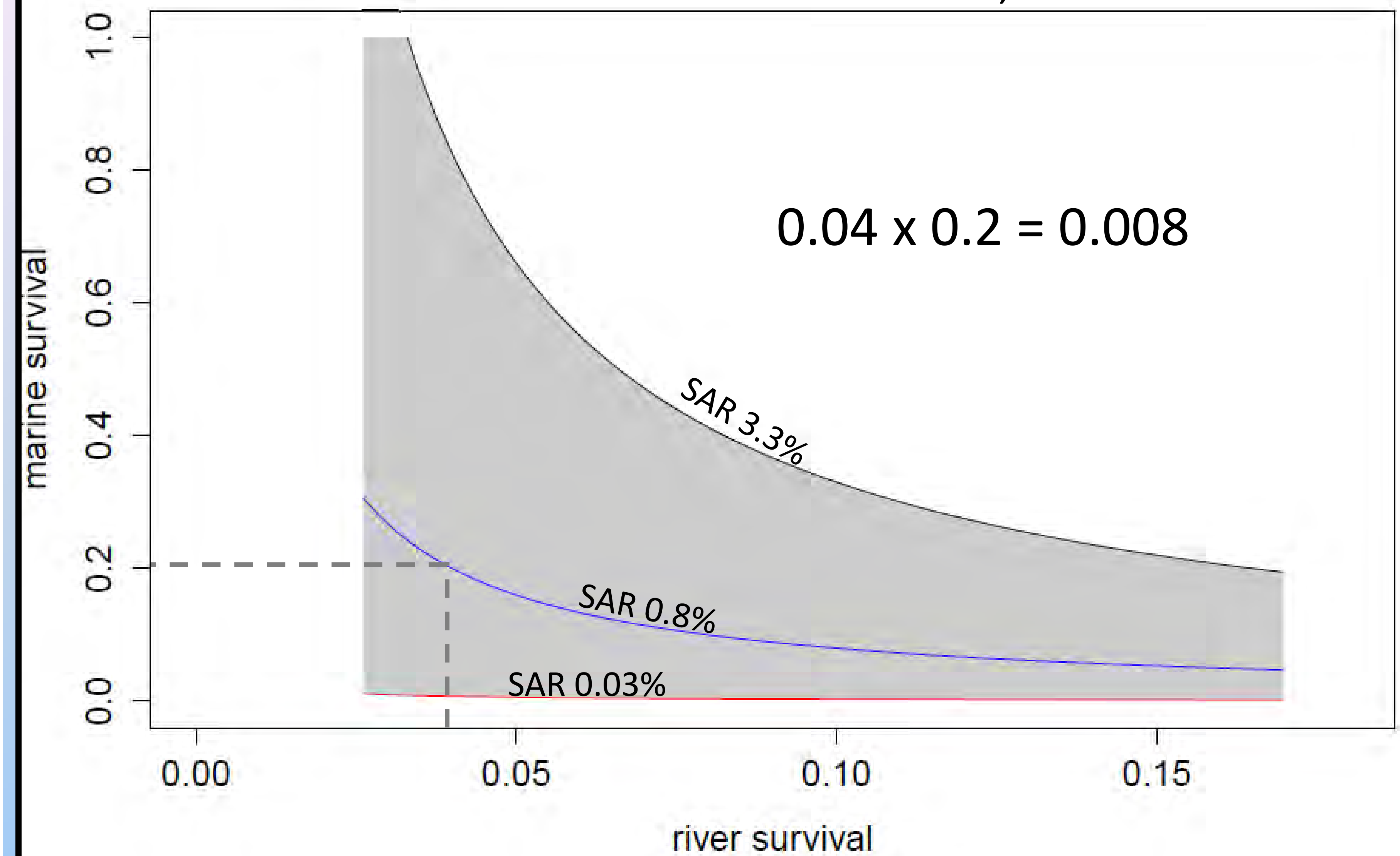


$$\text{SAR} = \frac{Estimated\ contribution\ to\ fishery + Estimated\ escapement}{Total\ smolts\ released}$$

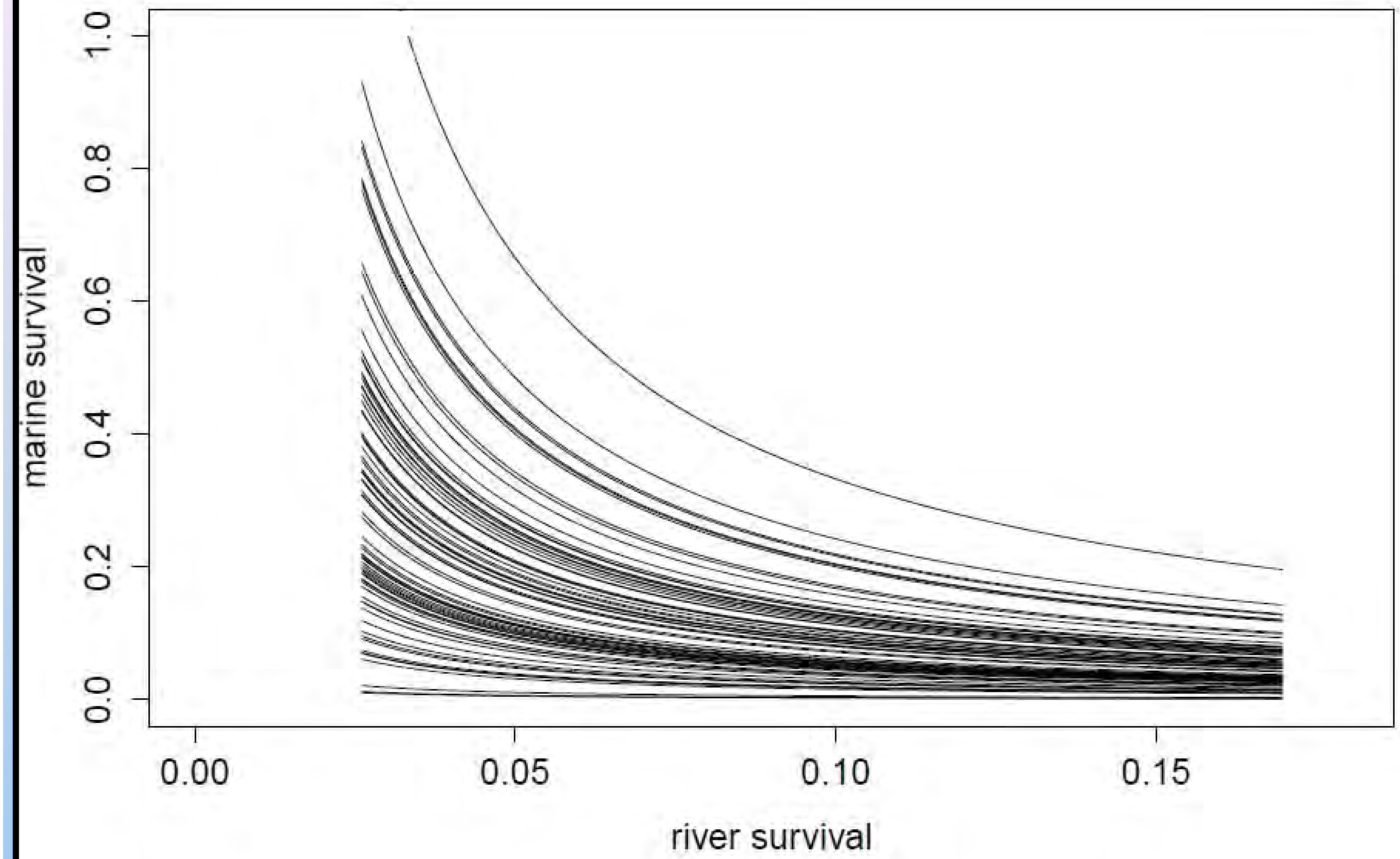
Minimum, maximum, and median per release day SAR values for Coleman late-fall run, 1993-2011



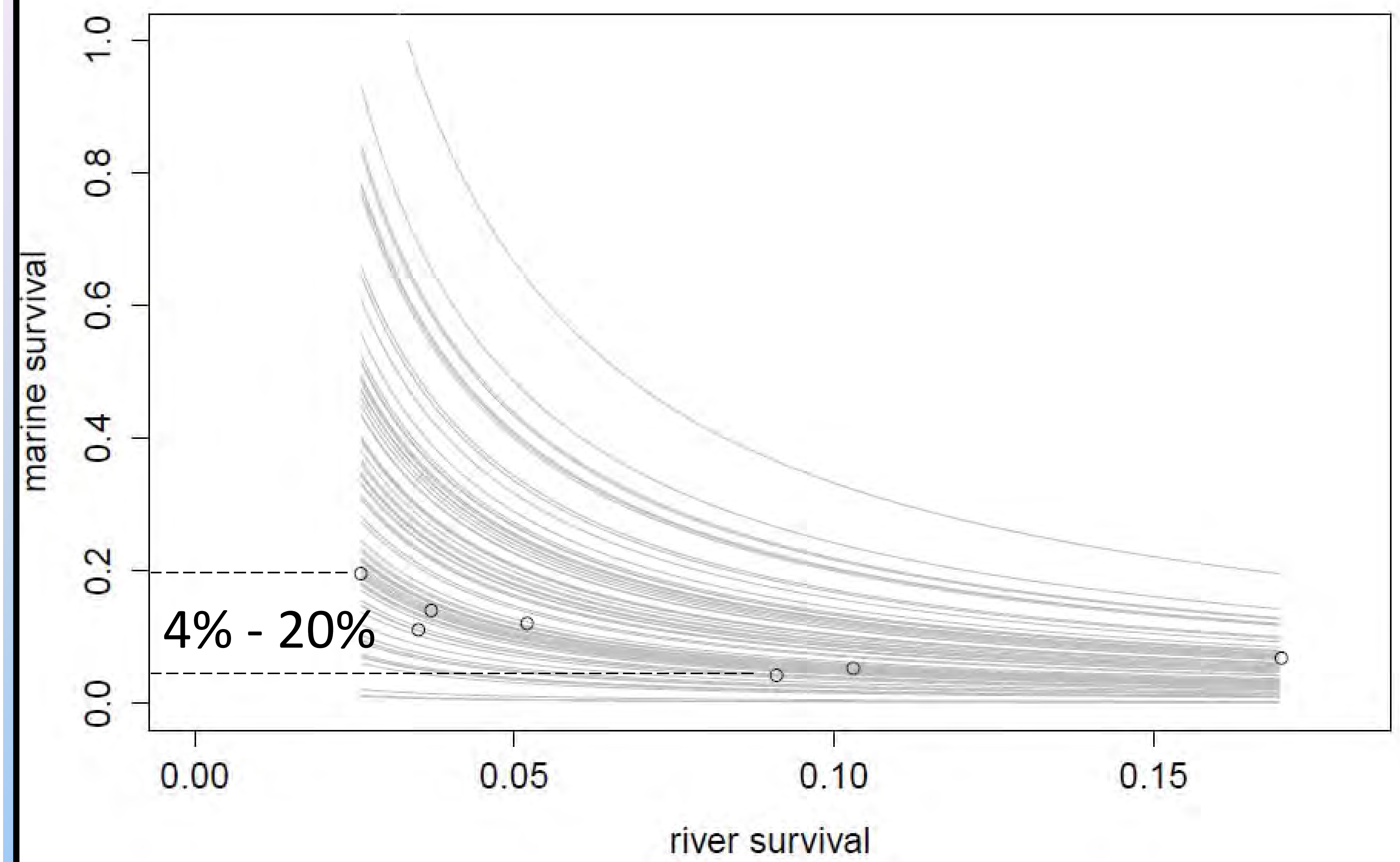
Minimum, maximum, and median per release day SAR values for Coleman late-fall run, 1993-2011



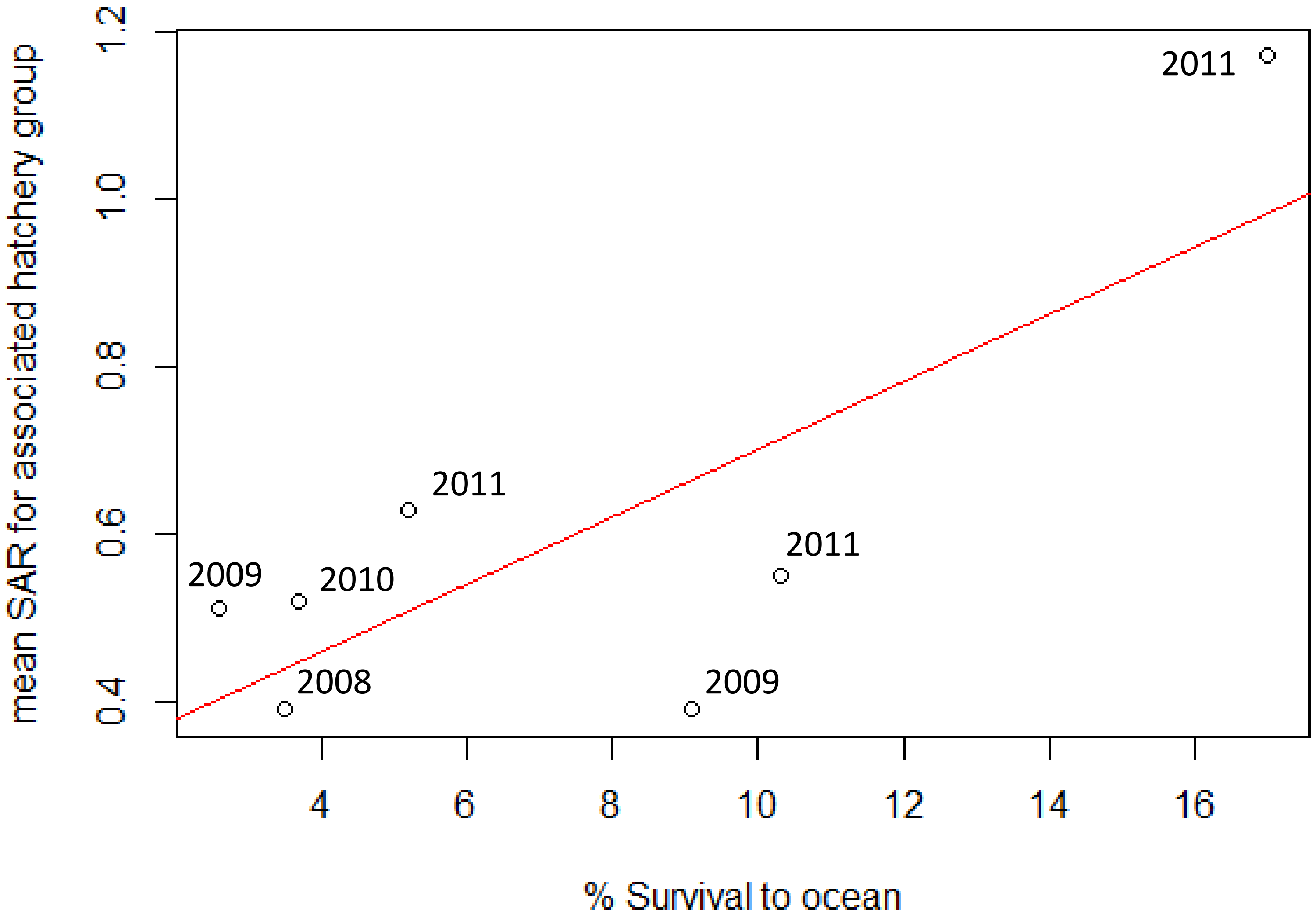
All per release day SAR values for Coleman late-fall run, 1993-2011



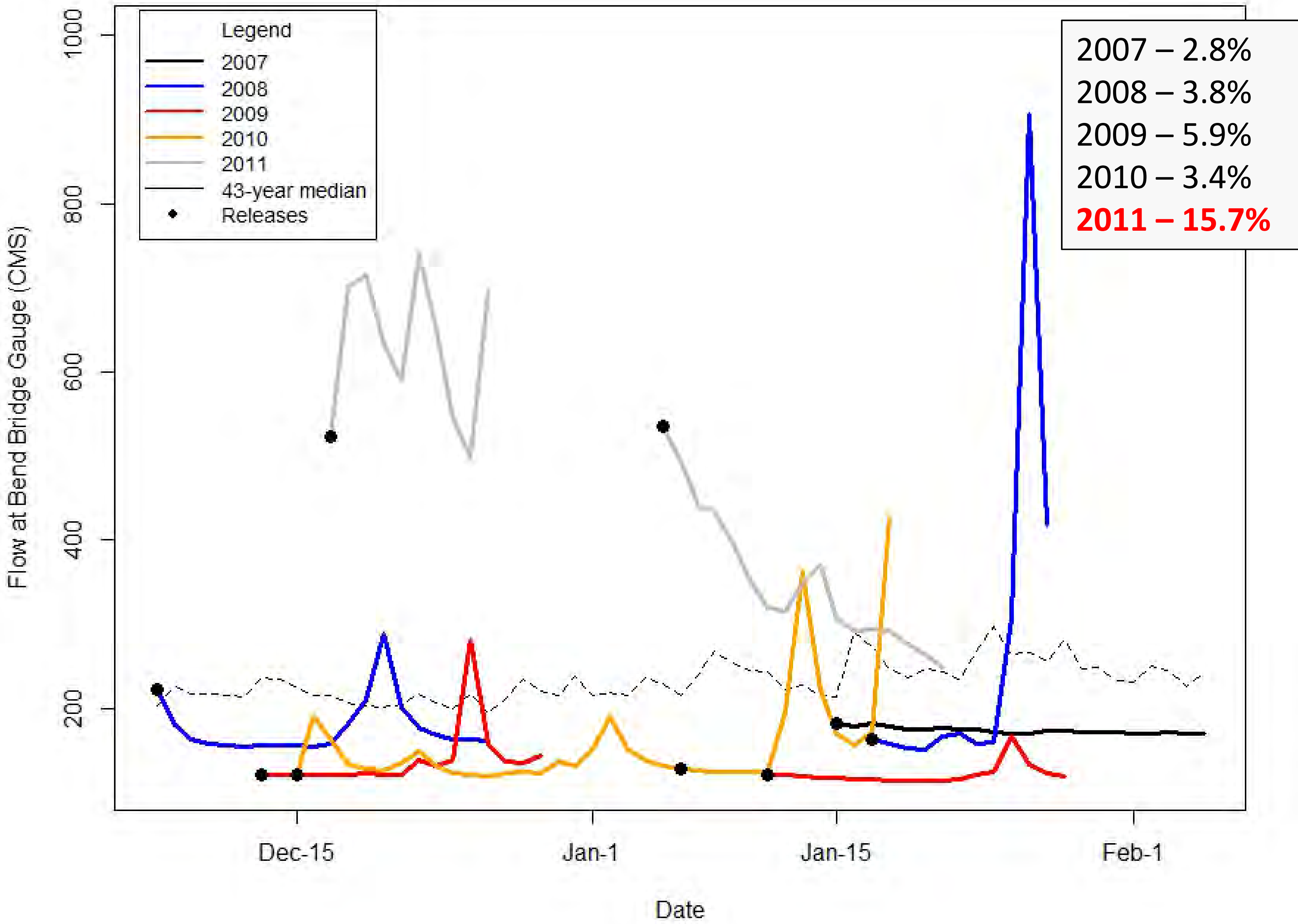
All per release day SAR values for Coleman late-fall run, 1993-2011



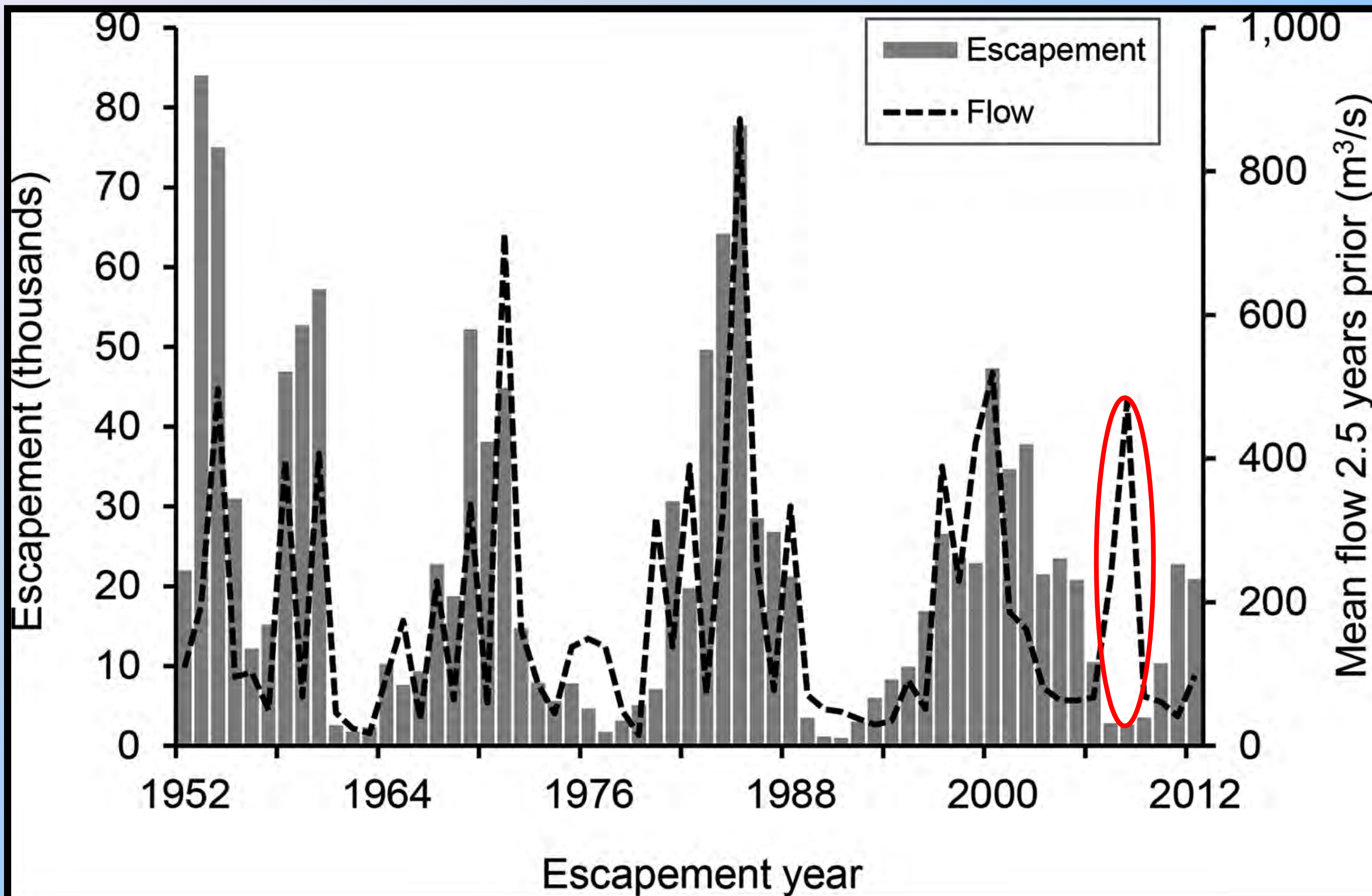
Outmigration survival vs. release group SAR



Flow experienced per tagging group



Does flow determine adult recruitment?



Sturrock et al. 2015. Reconstructing the Migratory Behavior and Long-Term Survivorship of Juvenile Chinook Salmon under Contrasting Hydrologic Regimes. PLoS One **10**:e0122380.

Mid-presentation outline…

What have I (hopefully) communicated:

- Survival during outmigration = LOW
- Survival during outmigration in Sacramento = EVEN LOWER
- Therefore, marine survival = HIGHER?
- Outmigration survival dynamics ~ adult salmon recruitment dynamics
  - ➢ Limited evidence from acoustic tagged cohorts
- Flow ~ outmigration survival = STRONG

What do I hope to now argue:

- A case study using Late-fall run Chinook salmon:
  - ➢ ~~Outmigration survival estimates~~, so instead, does flow ~ adult salmon recruitment?
  - ➢ Remaining unexplained variance attributable to marine conditions?
- Other examples in literature?
- Relevance to life-cycle models

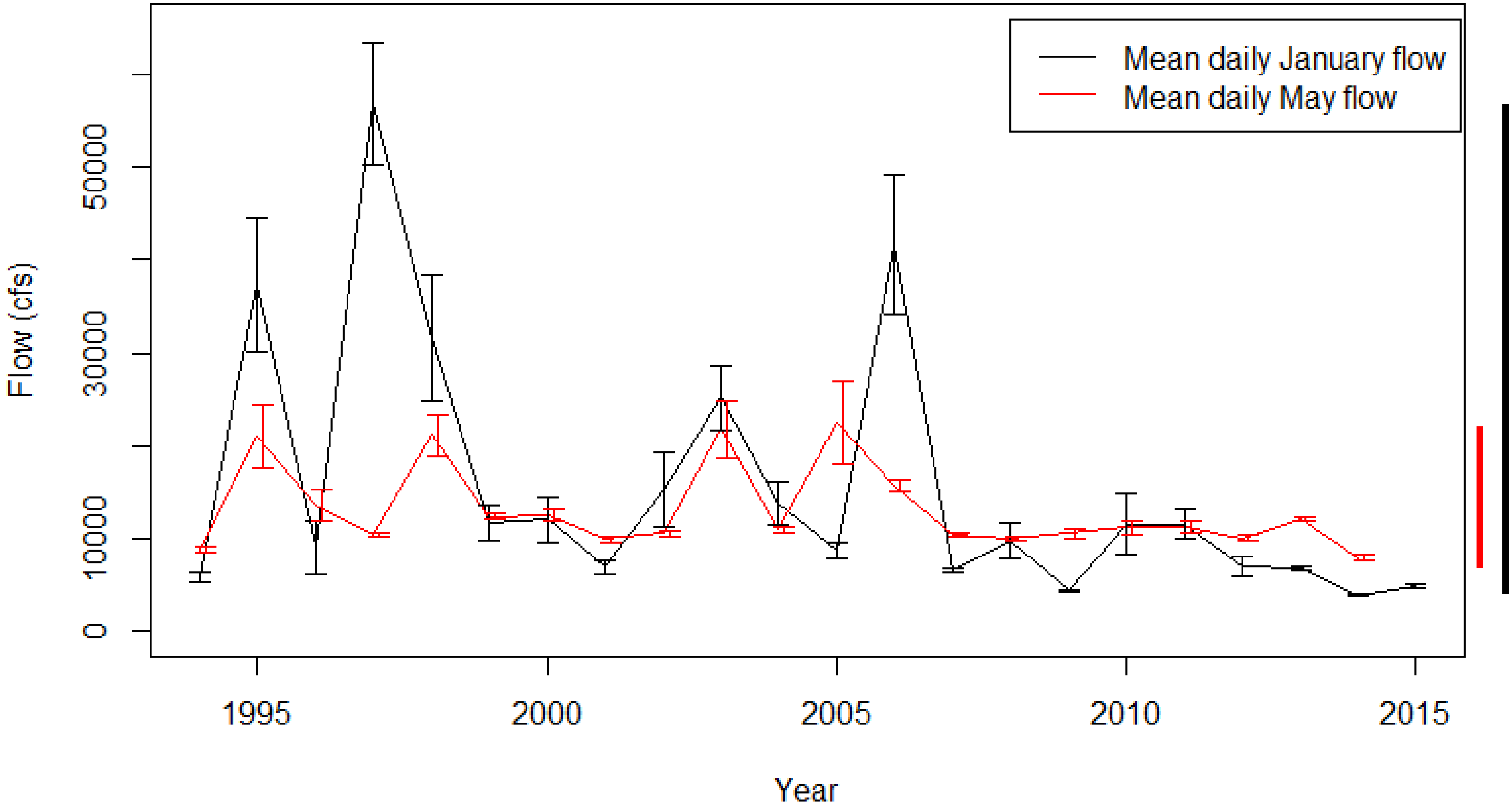
Late-fall run Chinook salmon

Let's keep using hatchery late-fall run Chinook salmon to conceptually explore these next ideas…

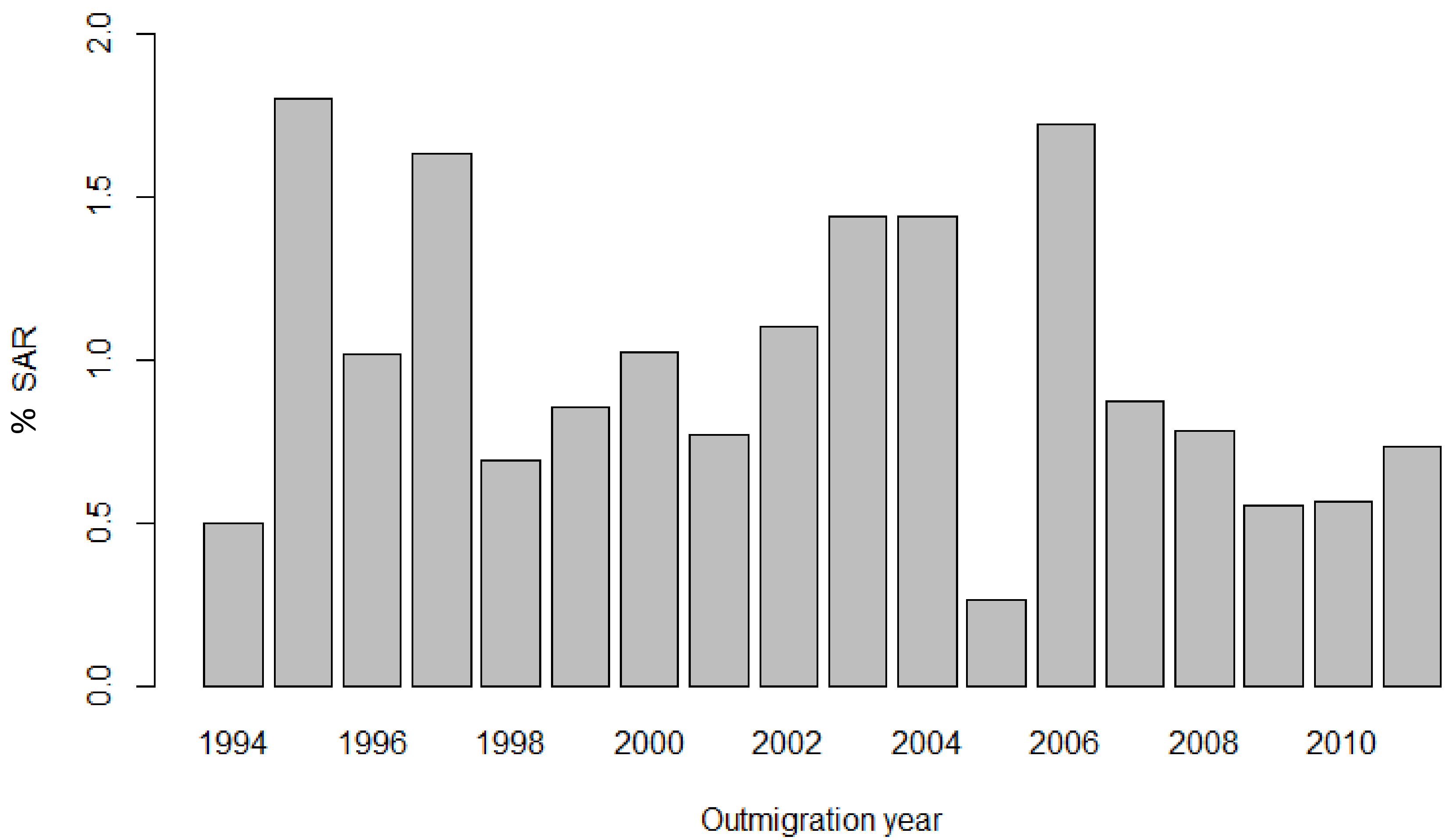
Late-fall are ideal for several reasons:

- Hatchery fish are 100% CWT since 1993 -> release and survival information for all fish
- The majority of the population are hatchery-origin (Palmer-Zwahlen, M., and Kormos, B. 2013)
- The majority of releases were not trucked
  - ➢ Only used on-site releases for this analysis
- On-site released fish have stray rates are near zero (Palmer-Zwahlen, M., and Kormos, B. 2013), and so CWT recovery rates are high
- Outmigrate during December- February.
  - ➢ More variable flows than for fall run
  - ➢ Increase potential for detecting signal of flow vs. SAR

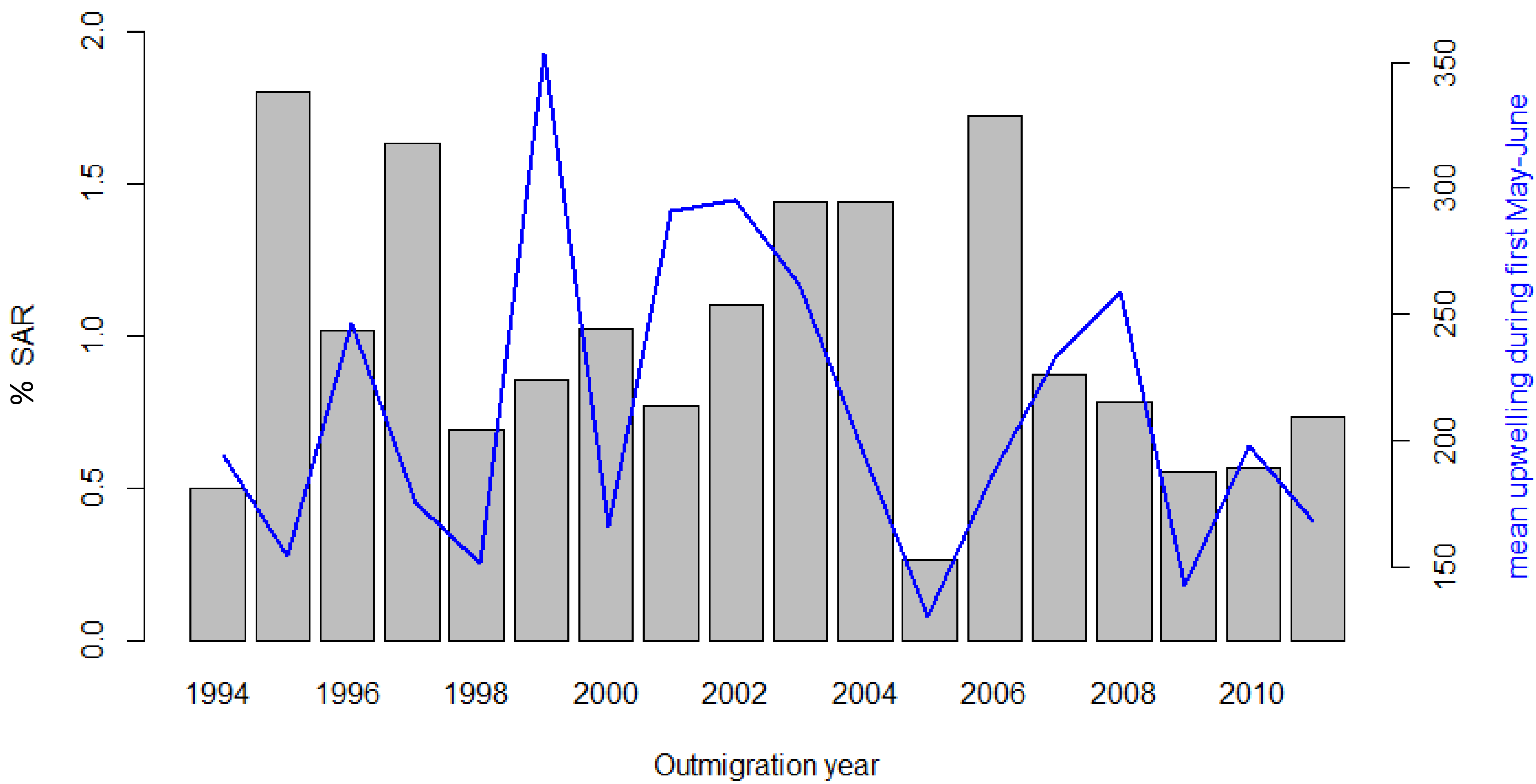
Flow variability during peak late-fall vs. fall run outmigration



Yearly SAR for Coleman Late-fall run Chinook salmon

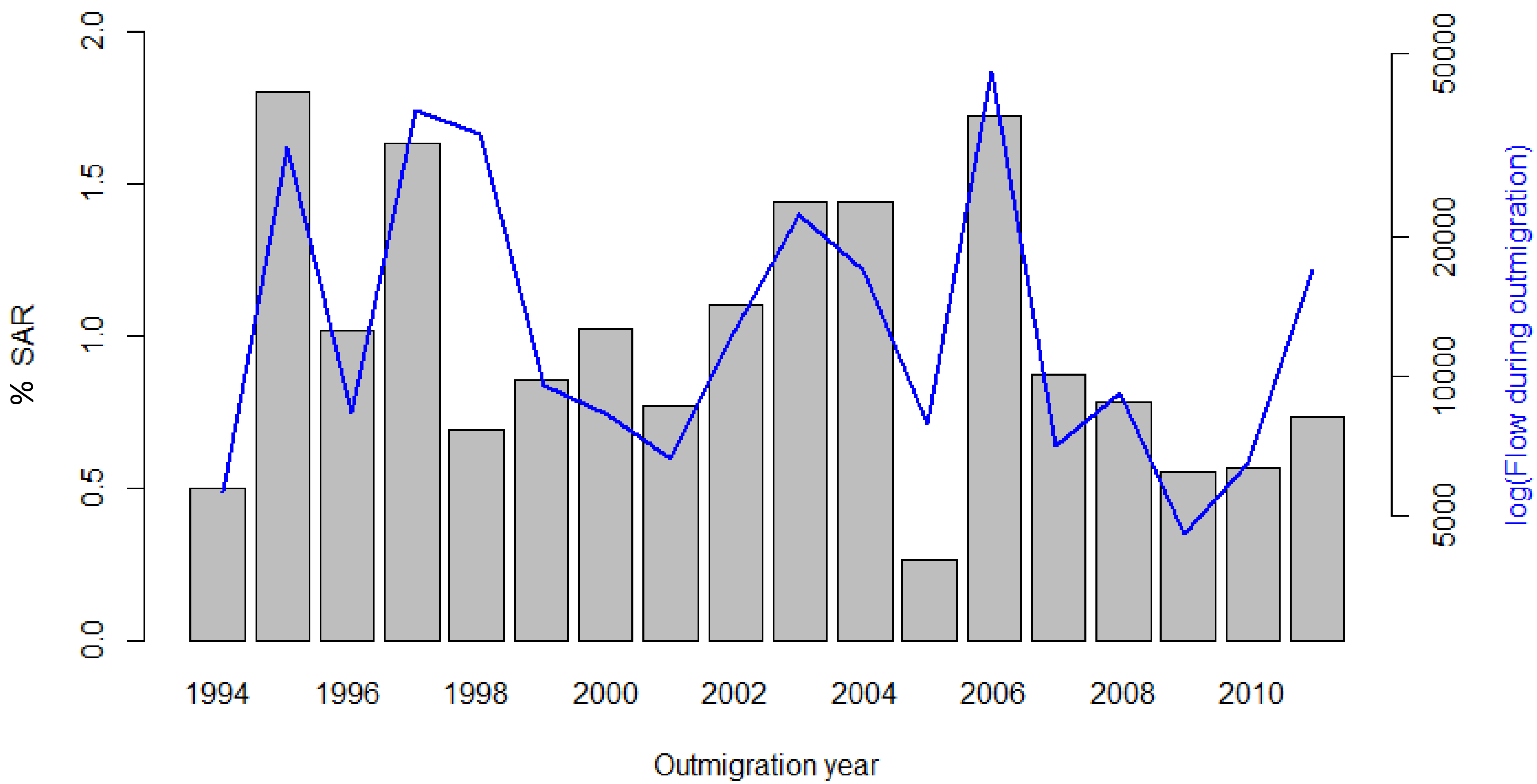


Yearly SAR for Coleman Late-fall run Chinook salmon

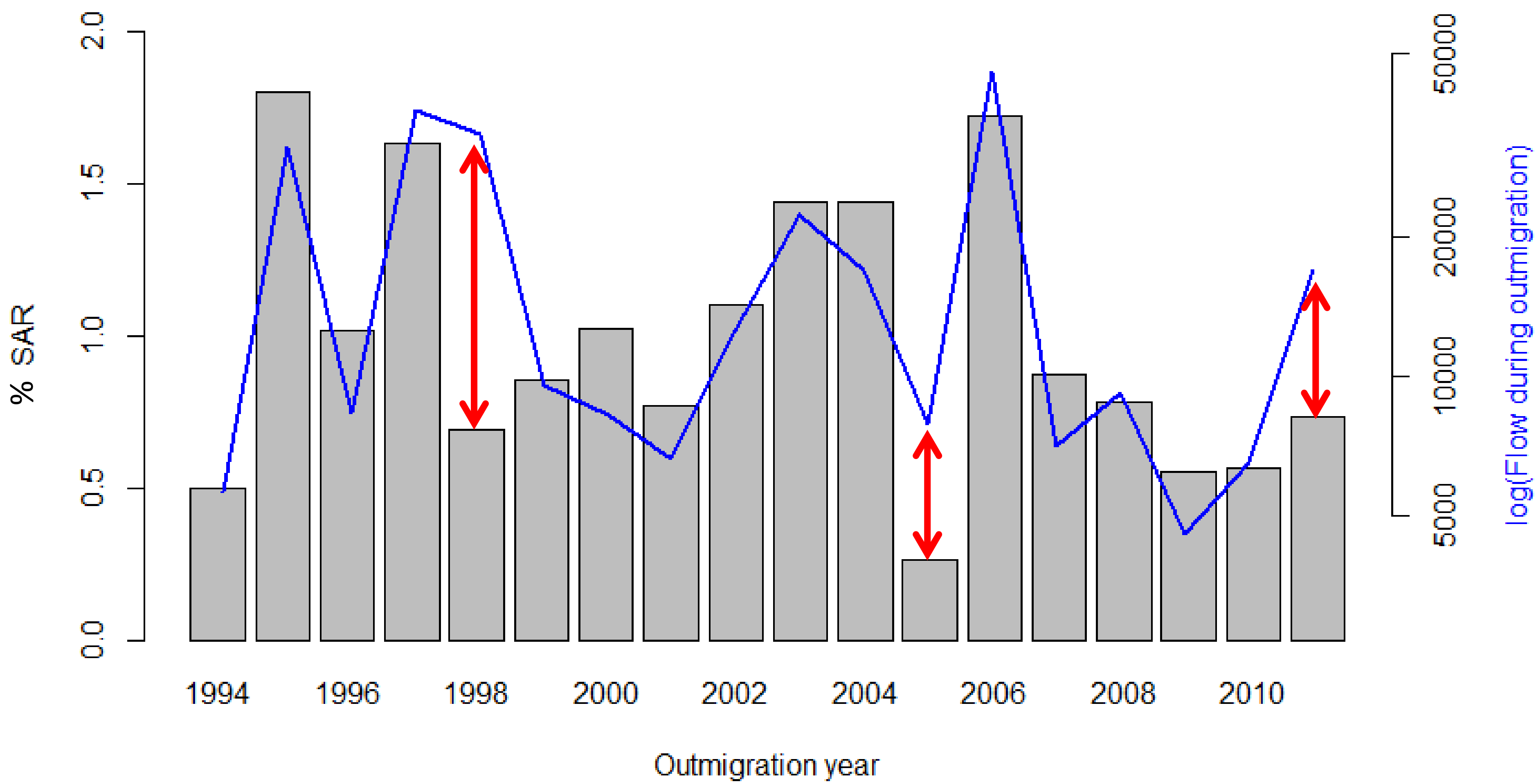


Upwelling units: metric tons/sec/100 m. of coastline
From: Pacific Fisheries Environmental Laboratory

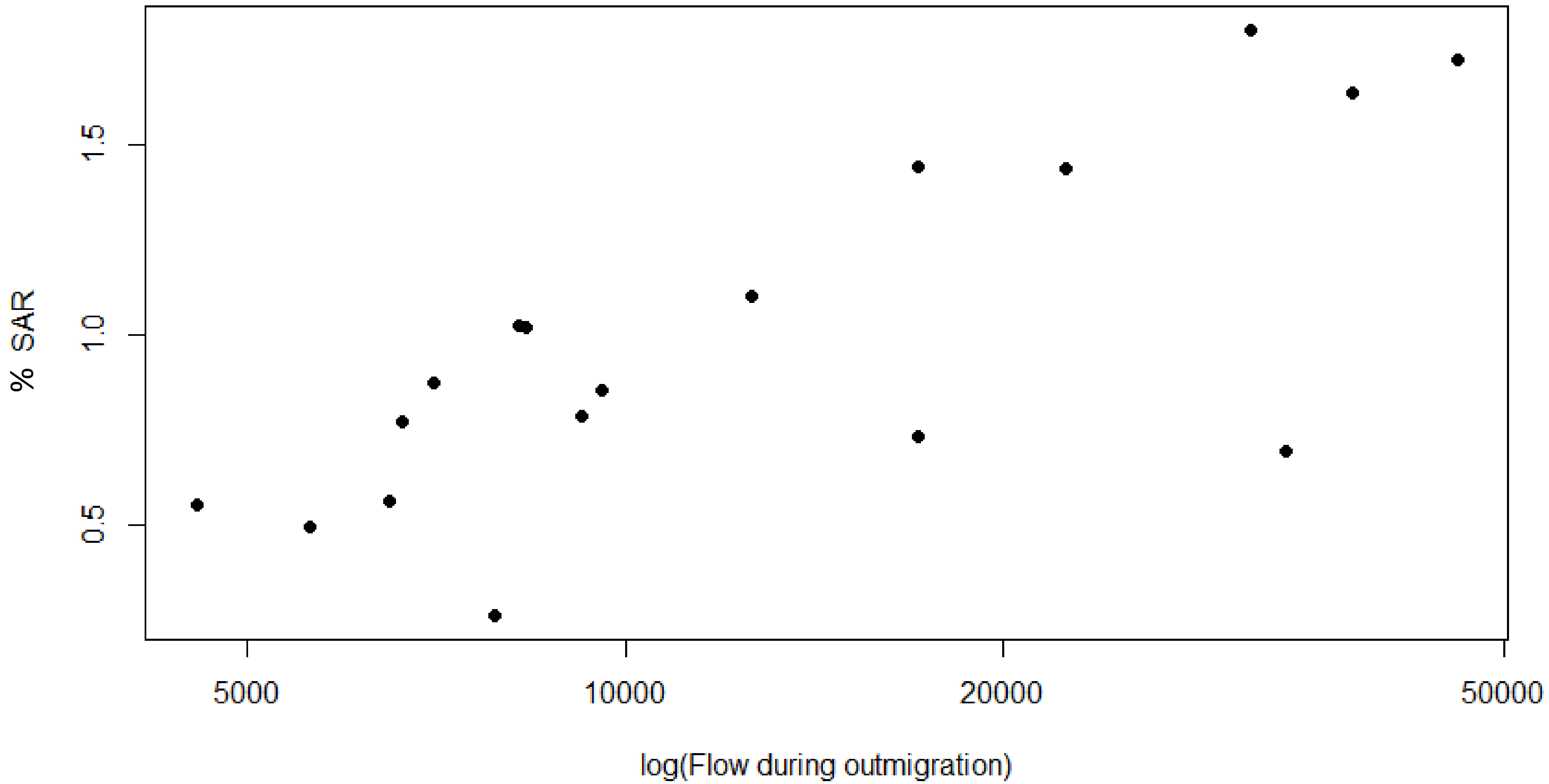
Yearly SAR for Coleman Late-fall run Chinook salmon



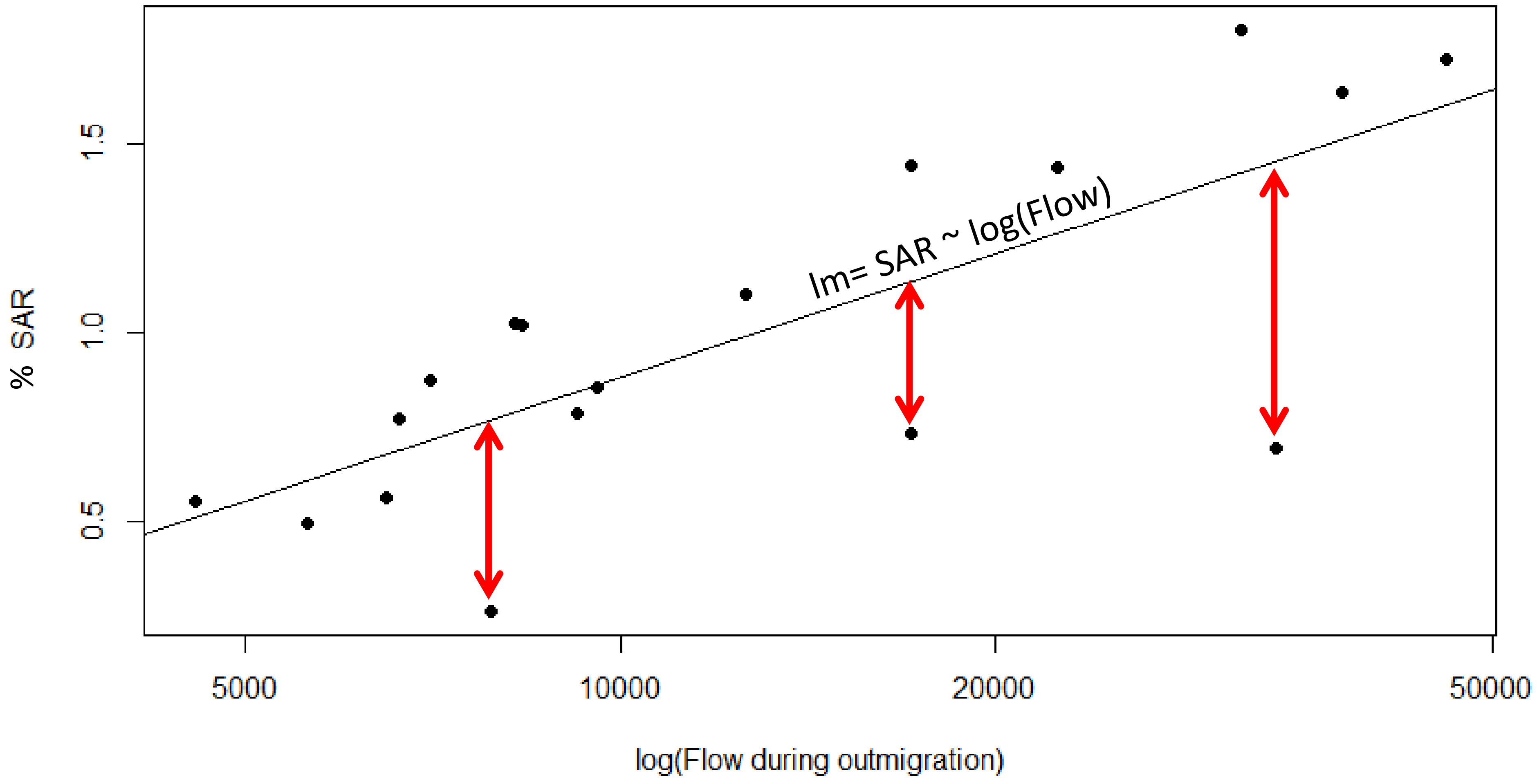
Yearly SAR for Coleman Late-fall run Chinook salmon

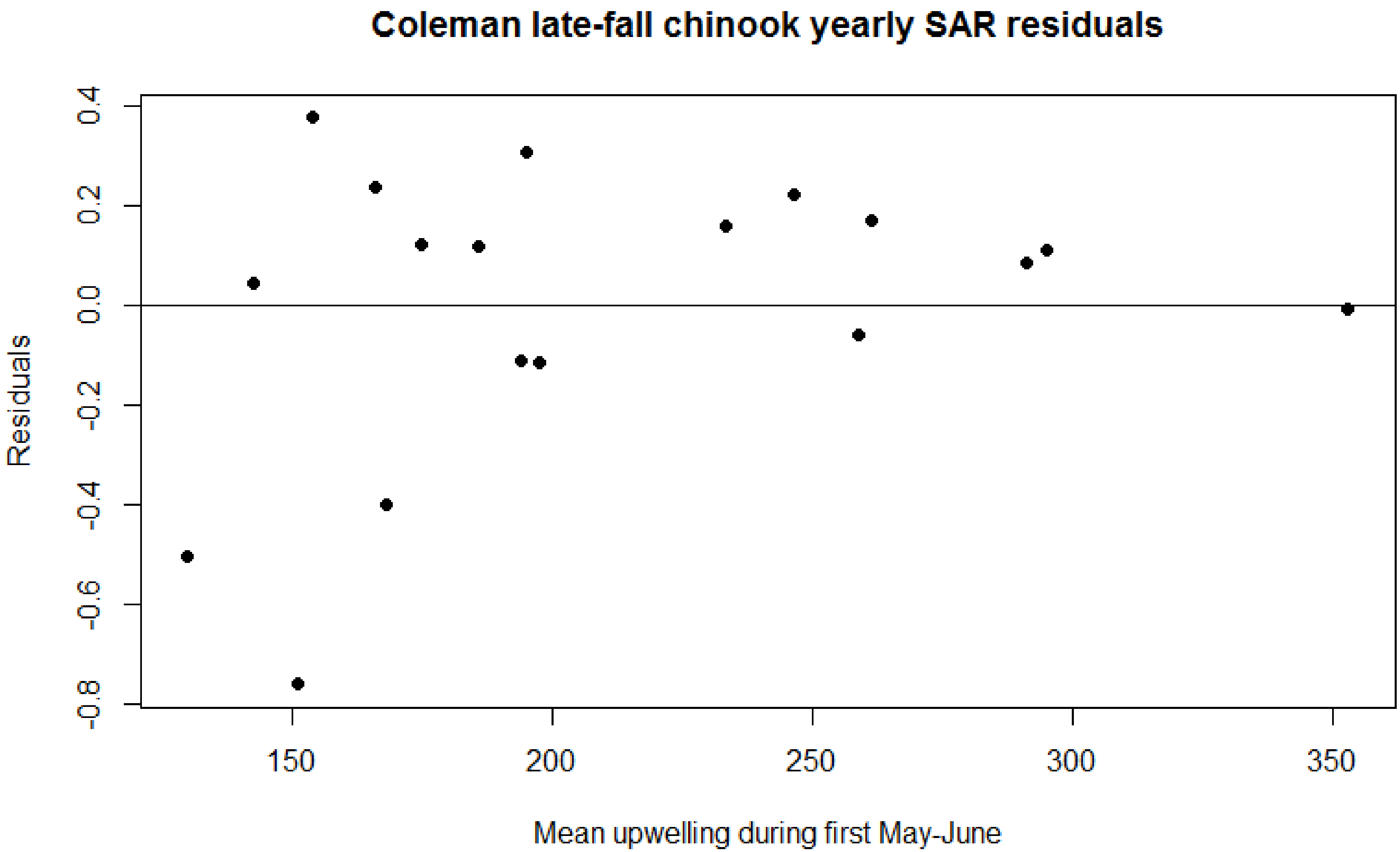


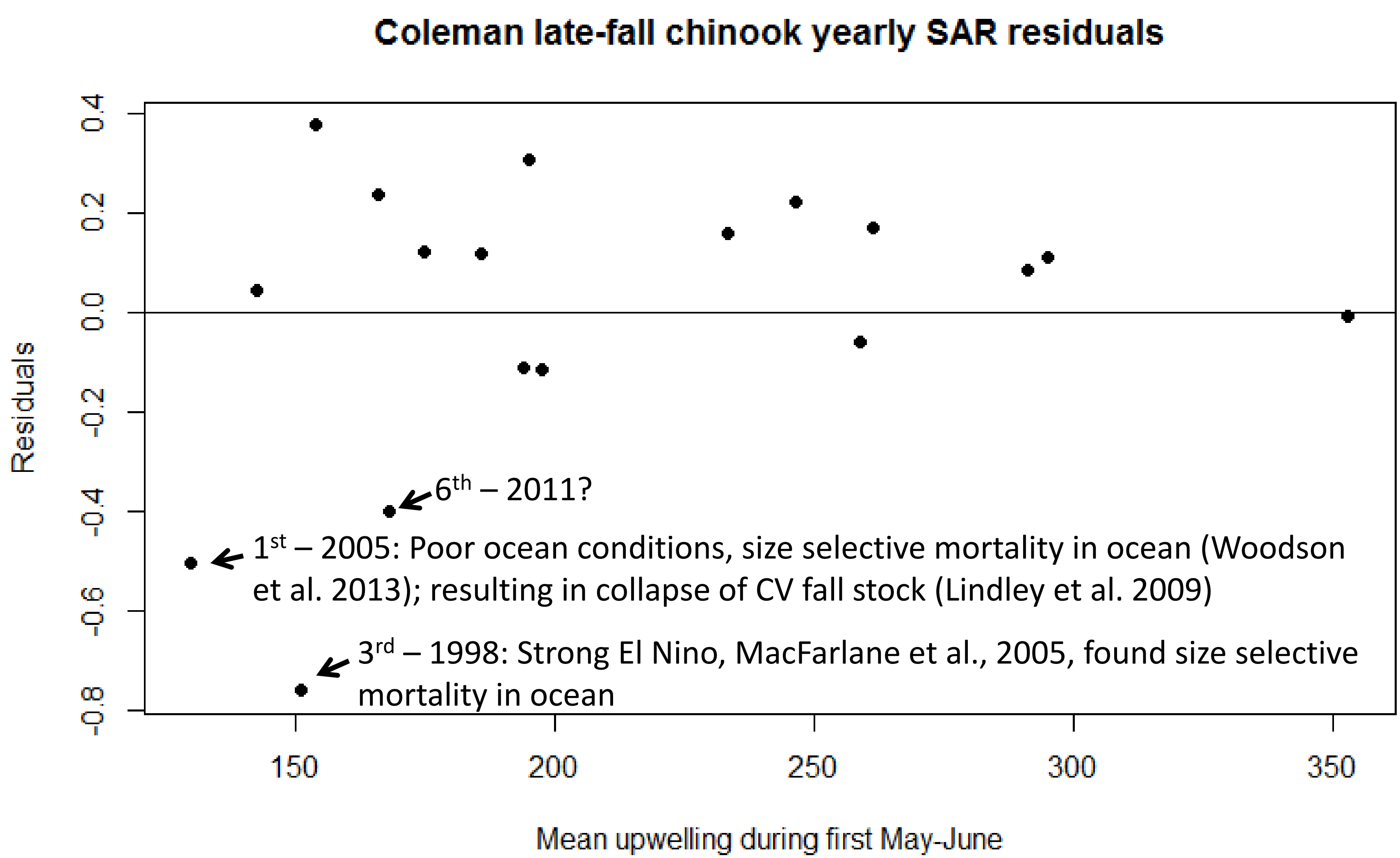
Yearly SAR vs. Flow

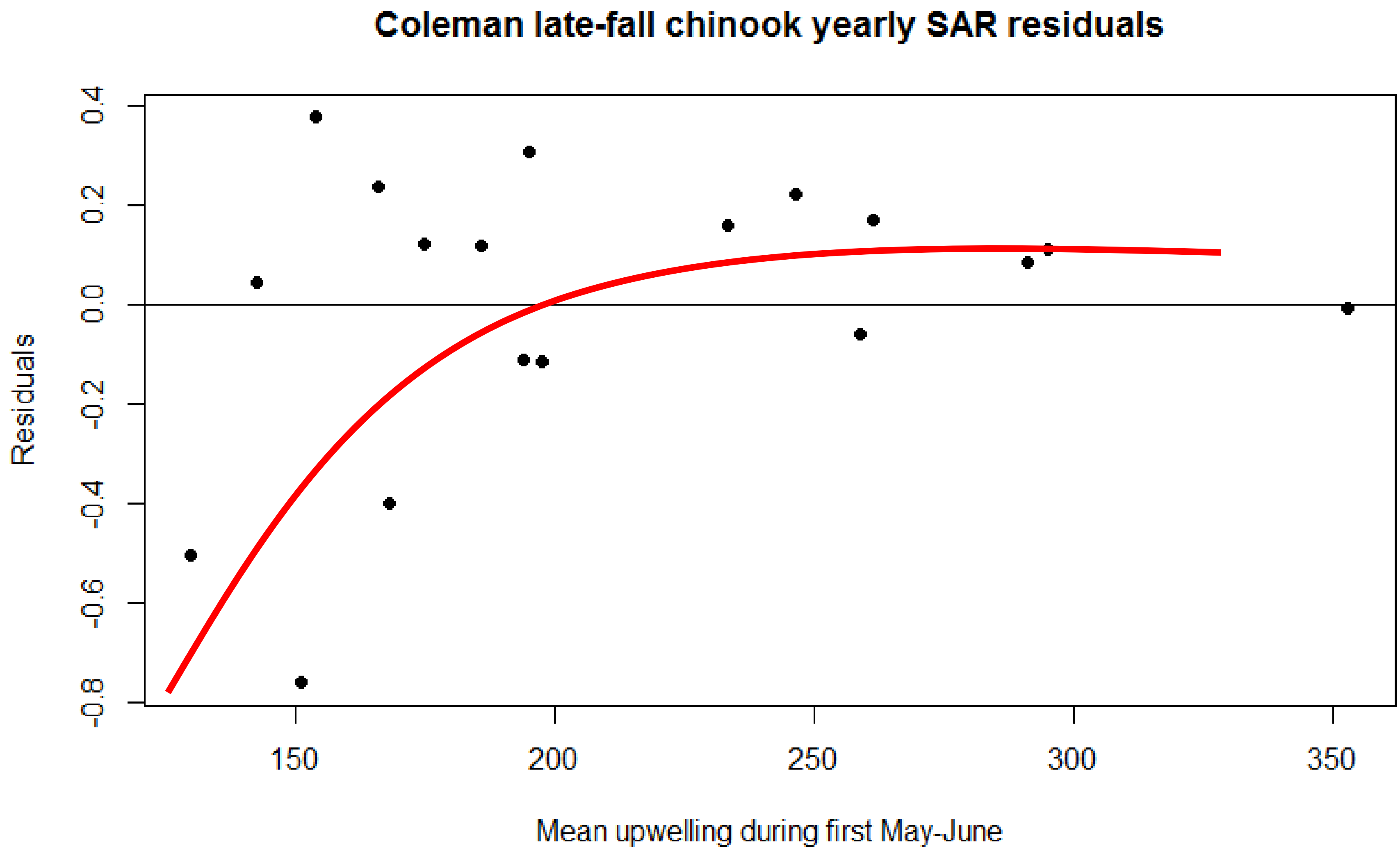


Yearly SAR vs. Flow




Coleman late-fall chinook yearly SAR residuals
Residuals
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
150
200
250
300
350
Mean upwelling during first May-June


Coleman late-fall chinook yearly SAR residuals
Residuals
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
150
200
250
300
350
Mean upwelling during first May-June
6th – 2011?
1st – 2005: Poor ocean conditions, size selective mortality in ocean (Woodson et al. 2013); resulting in collapse of CV fall stock (Lindley et al. 2009)
3rd – 1998: Strong El Nino, MacFarlane et al., 2005, found size selective mortality in ocean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150
200
250
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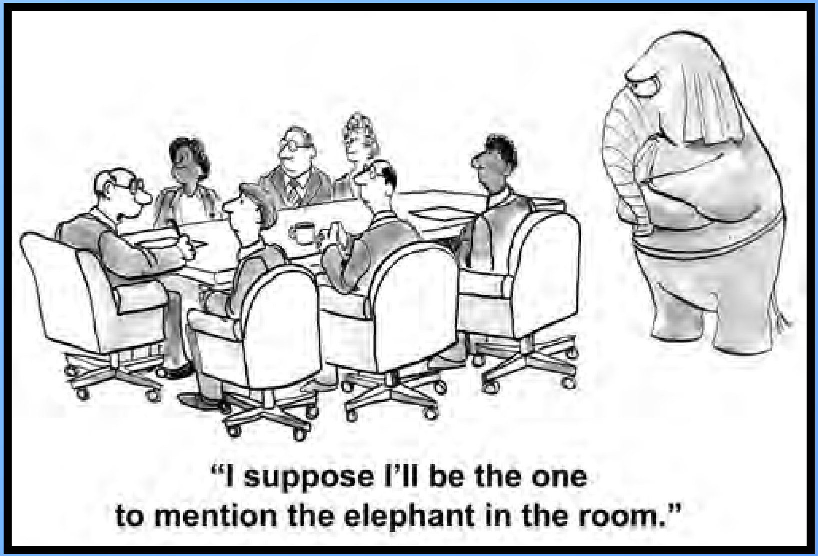
350
Mean upwelling during first May-June

Caveats…

- Late-fall Chinook are yearlings - largest smolts in the Central Valley
  - 90 - 170 mm (Fisher 1994; Snider and Titus 2000)
- Furthermore, hatchery fish are often larger than their wild counterparts



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- Larger smolts could be more less susceptible to poor ocean conditions due to increased fat reserves and increased mobility to forage

"In years of improved ocean productivity and exceptional recruitment, such as 2000 and 2001, selective mortality went undetected, as both large, fast-growing and small, slow growing individuals survived the ocean entry period. **The selective mortality detected in 2005** is similar to cases presented by Holtby et al. (1990), Blom et al. (1994), Saloniemi et al. (2004) and Cross et al. (2008), who observed an **increased benefit of larger size to other juvenile salmonids in low survival years**."

Woodson LE, Wells BK, Weber PK, MacFarlane RB, Whitman GE, Johnson RC. 2013. Size, growth, and origin-dependent mortality of juvenile Chinook salmon *Oncorhynchus tshawytscha* during early ocean residence. MEPS 487:163-175

Caveats…

- Late-fall Chinook are yearlings largest smolts in the Central Valley
  - 90 - 170 mm
- Furthermore, hatchery fish are often larger than their wild counterparts
- Larger smolts could be more less susceptible to poor ocean conditions due to increased fat reserves and increased mobility to forage
- Below-average marine conditions may have strong influence on marine survival of smaller smolts, but perhaps little to no effect in average or above-average years

"**In years of improved ocean productivity and exceptional recruitment, such as 2000 and 2001, selective mortality went undetected**, as both large, fast-growing and small, slow growing individuals survived the ocean entry period. The selective mortality detected in 2005 is similar to cases presented by Holtby et al. (1990), Blom et al. (1994), Saloniemi et al. (2004) and Cross et al. (2008), who observed an increased benefit of larger size to other juvenile salmonids in low survival years."

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Examples from the literature: wild and hatchery steelhead

Marine survival difference between wild and hatchery-reared steelhead trout determined during early downstream migration

Michael C. Melnychuk, Josh Korman, Stephen Hausch, David W. Welch, Don J.F. McCubbing, and Carl J. Walters

Abstract: We observed large survival differences between wild and hatchery-reared steelhead trout (*Oncorhynchus mykiss*) during the juvenile downstream migration immediately after release, which persisted through adult life. Following a railway spill of sodium hydroxide into the Cheakamus River, British Columbia, a short-term conservation hatchery rearing program was implemented for steelhead. We used acoustic telemetry and mark–recapture models to estimate survival of wild and (or) hatchery-reared steelhead during 4 years of the smolt migration, with both groups released in 2008. After adjusting for estimated freshwater residualization, 7%–13% of wild smolts and 30%–40% of hatchery smolts died in the first 3 km of the migration. Estimated survival from release to ocean entry was 71%–84% for wild fish and 26%–40% for hatchery fish and to exit from the Strait of Georgia system was 22%–33% for wild fish and 3.5%–6.7% for hatchery fish. A calculated 2.3-fold survival difference established during the downstream migration was similar to that after the return of adult spawners, as return rates were 8.0% for wild fish and 4.1% for hatchery fish. Contrary to current understanding, a large proportion of salmon mortality in the smolt-to-adult period, commonly termed "marine mortality", may actually occur prior to ocean entry.

Can. J. Fish. Aquat. Sci. **71**: 831–846 (2014) dx.doi.org/10.1139/cjfas-2013-0165

Examples from the literature: wild sockeye salmon

Abstract

"[…] cumulative survival to the ocean ranged 3-10% among years. […] Current fisheries models for forecasting the number of adult sockeye returning to spawn have been inaccurate in recent years and generally do not incorporate juvenile or smolt survival information. Our results highlight significant potential for early migration conditions to influence adult recruitment."

Clark TD, Furey NB, Rechisky EL, Gale MK, Jeffries KM, Porter AD, Casselman MT, Lotto AG, Patterson DA, Cooke SJ, Farrell AP, Welch DW, Hinch SG. 2016 Tracking wild sockeye salmon smolts to the ocean reveals distinct regions of nocturnal movement and high mortality. Ecological Applications, DOI: 10.1890/15-0632.

What does this have to do with life-cycle models?

- Recognize the potential shortcomings of literature that does not parse out outmigration vs. marine survival when parameterizing our models
- Consider that the importance of marine survival dynamics may be overshadowed by outmigration survival dynamics during average or above-average marine conditions
- We should revisit attempts at modeling the relationship between environmental indicators and marine survival after parsing out outmigration survival when possible
- Life-cycle models may be the only way to truly elucidate marine survival dynamics because it does inherently consider outmigration survival in the model structure

Potential Management Implications

- Further evidence that high flows during outmigration are beneficial to survival and, ultimately, adult recruitment

- Evidence that outmigration tagging studies can also be critical for understanding other life stages -> value added

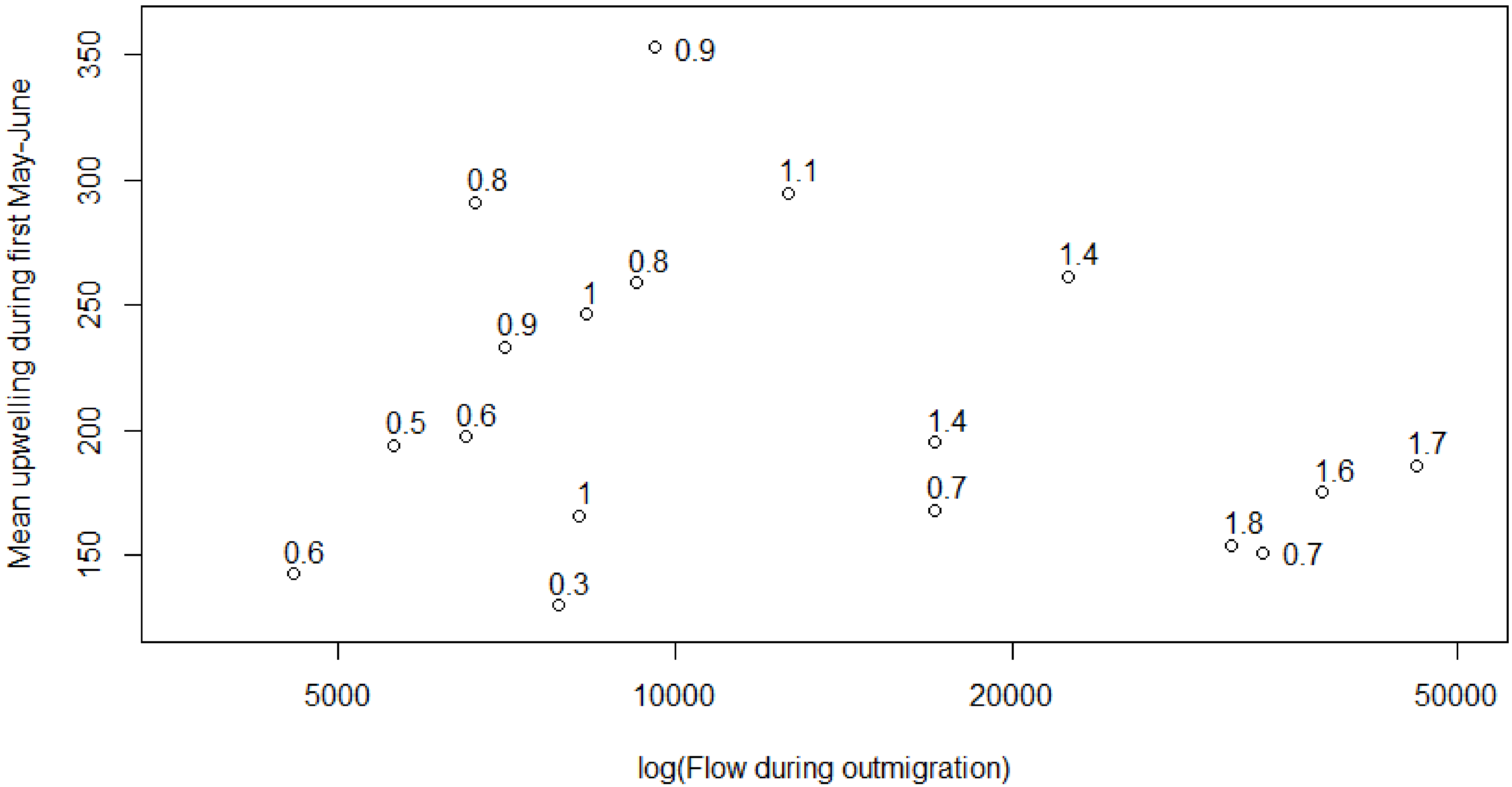
- Even with ideal outmigration conditions, poor marine survival can lead to stock collapse
  - ➢ We only have the luxury of mitigation in freshwater
  - ➢ Manage one system with both in mind

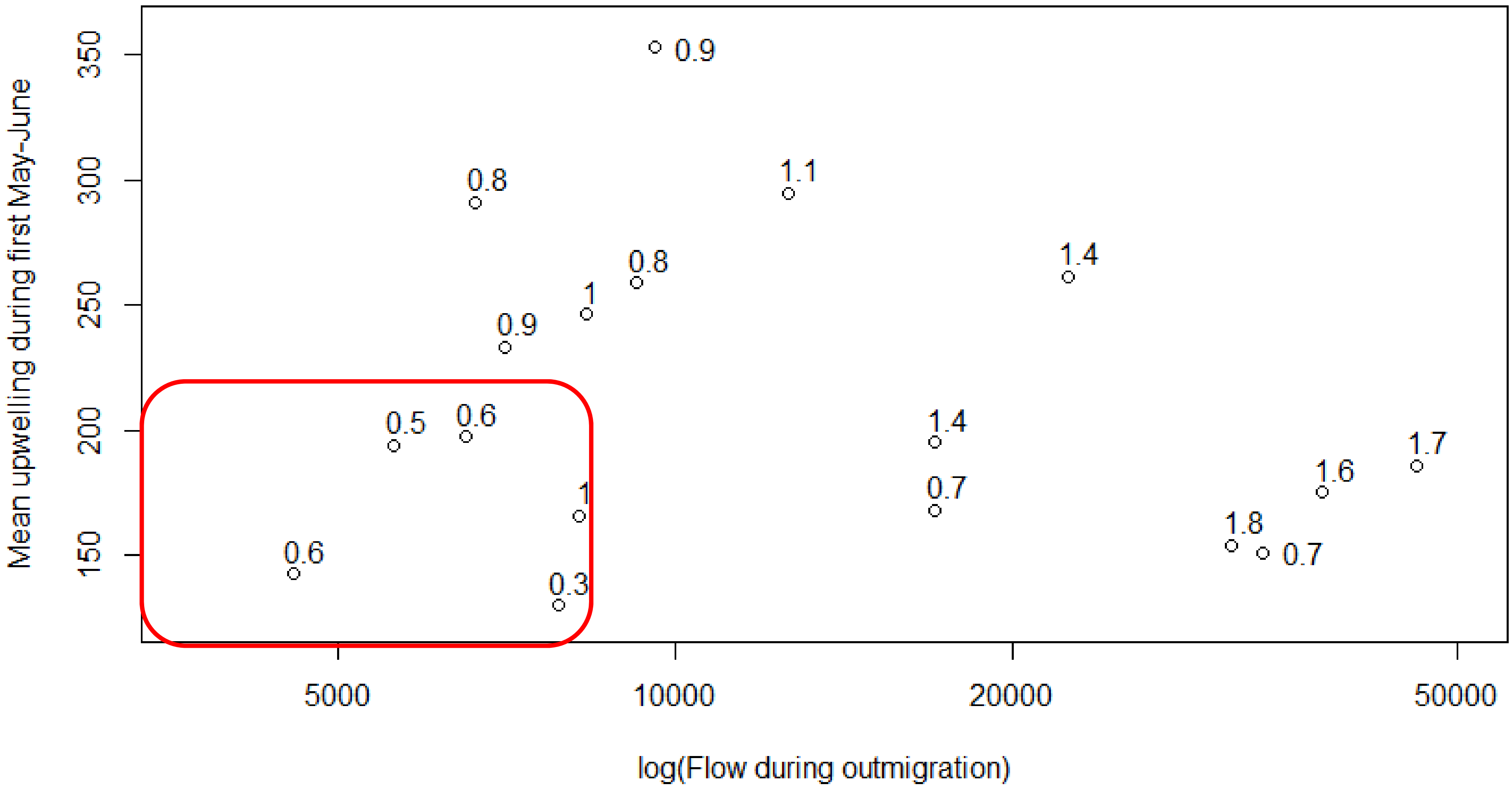
Next steps…

- What about other populations? Winter run?

- Use measurements of meaningful marine survival indicators
  - ➢ e.g. krill abundance

- Potential for simplistic environment-based forecast model?


Mean upwelling during first May-June
350
300
250
200
150
0.9
0.8
1.1
0.8
1.4
1
0.9
0.5
0.6
1.4
1.7
1.6
1
0.7
1.8
0.6
0.7
0.3
5000
10000
20000
50000
log(Flow during outmigration)


Mean upwelling during first May-June
350
300
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20000
50000
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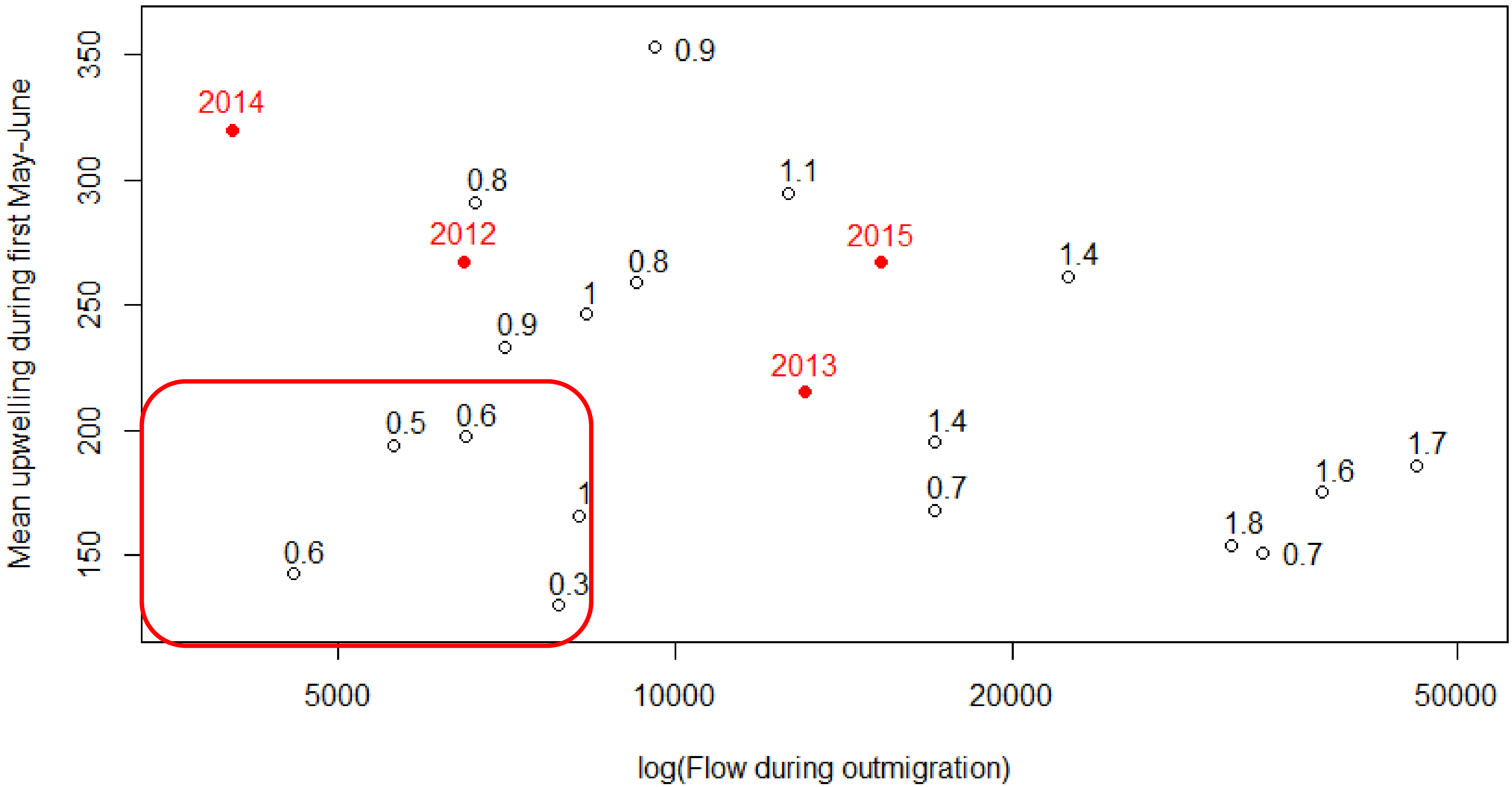
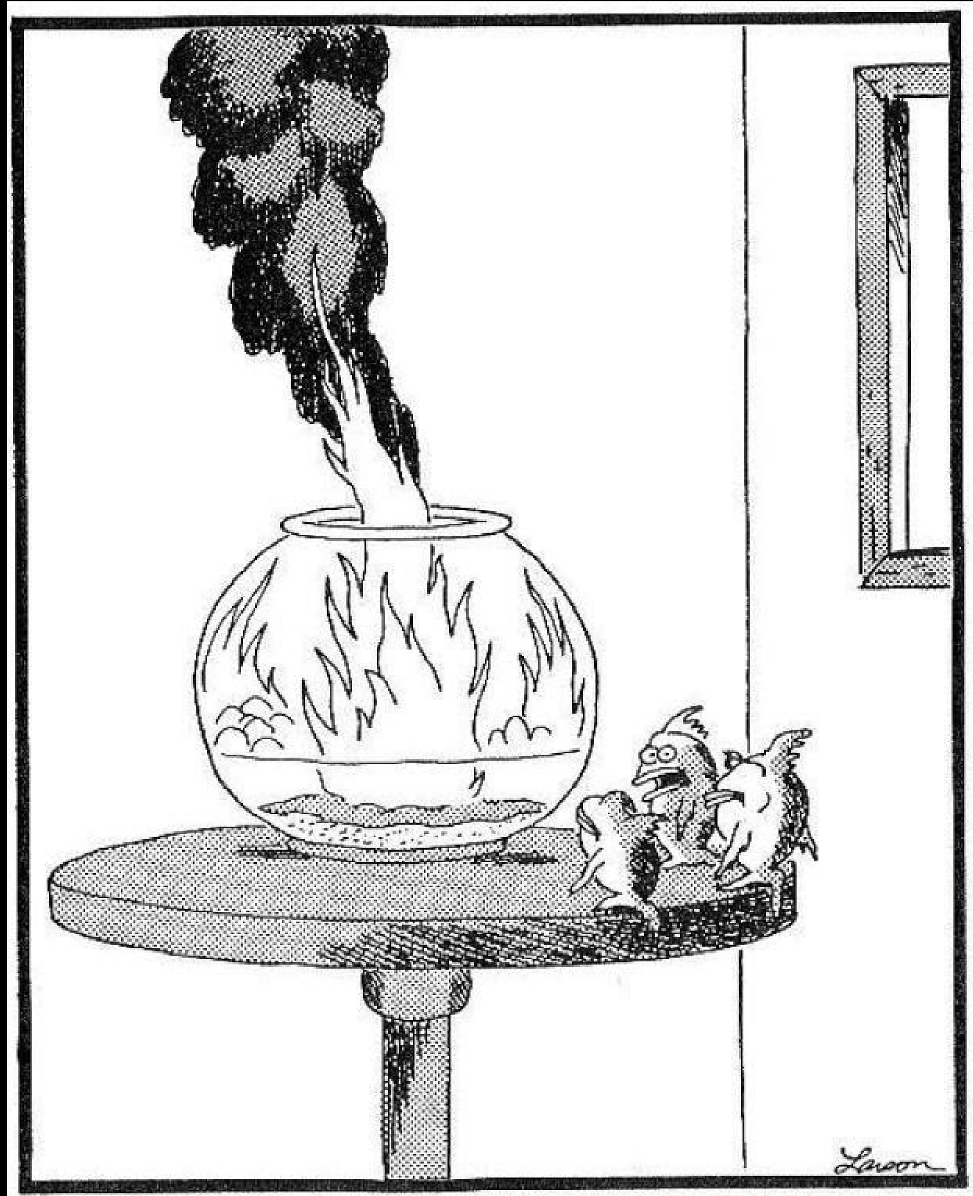
0.9
0.8
1.1
0.8
1.4
1
0.9
0.5
0.6
1.4
1
0.7
1.7
1.6
0.6
1.8
0.7
0.3



Mean upwelling during first May-June
log(Flow during outmigration)
350
300
250
200
150
5000
10000
20000
50000
2014
2012
2015
2013
0.9
0.8
1.1
1.4
0.8
1
0.9
0.5
0.6
1.4
0.7
1.7
1.6
1.8
0.7
1
0.6
0.3

Thank you.
Questions, comments, fiery critiques?



"Well, thank God we all made it out in time. ...'Course, now we're equally screwed."

What does that mean for marine survival?

Using methods from Bradford (1995)* review on salmon mortality rates:

$$M \text{ (instantaneous mortality)} = -\log_e(\text{Survival})$$

$$M_{\text{total at 60\% harvest}} = M_{\text{egg-to-smolt}} + M_{\text{smolt-to-adult}}$$

$$M_{\text{smolt-to-adult}} = M_{\text{total at 60\% harvest}} - M_{\text{egg-to-smolt}}$$

$$(M_{\text{marine}} + M_{\text{outmigration}}) = M_{\text{total at 60\% harvest}} - M_{\text{egg-to-smolt}}$$

2007 = 0.028
2008 = 0.038
2009 = 0.059
2010 = 0.034
Mean = 0.039
$M = -\log_e(0.039)$
$M_{\text{outmigration}} = 3.24$

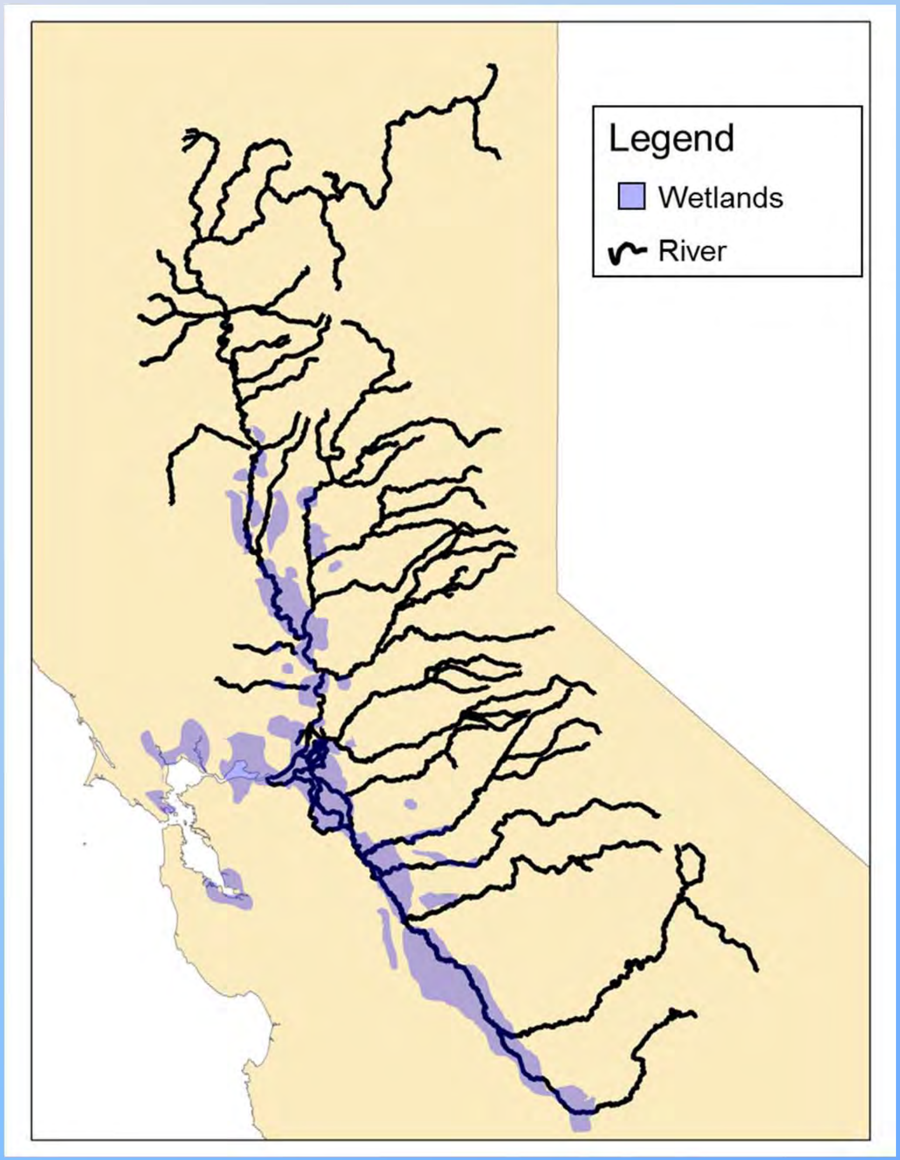
Table 2. Details of chinook egg–smolt mortality data used in the analysis.

Stream	Type	N	Migrant	Fec	M_{tot}	Mean M_f	Est. M_m
Cowichan R., B.C.[a]	Dam	1	Fry, 0+	4500	6.80	2.39	4.41
Fall Ck., Calif.	Nat	4	Fry, 0+	3800	6.63	2.13±0.34	4.50
John Day R., Oreg.	Nat	5	1+	4000	6.68	2.94±0.16	3.74
Lehmi R., Idaho[b]	Nat	9	Fry, 0+, 1+	4500	6.80	1.21±0.11	5.59
Qualicum R., B.C.	Flow	14	Fry, 0+	5400	6.98	2.79±0.32	4.19
Tucannon R., Wash.	Nat	4	1+	4000	6.68	2.01±0.21	4.67
Warm Springs R., Oreg.[b]	Nat	15	0+, 1+	3300	6.49	2.97±0.12	3.52
Yakima R., Wash.[c]	Dam	6	1+	4500	6.80	2.72±0.10	4.08
Yakima R.,Wash.[d]	Dam	8	1+	4500	6.80	3.03±0.25	3.77

$$M_{\text{marine}} = 6.76 - 2.56 - 3.24 = 0.96 \; \mathbf{(0.38\ survival)}$$

*Bradford, MJ 1995. Comparative review of Pacific salmon survival rates. CJFAS 52:1327-1338.

During average or above average marine conditions, perhaps the ocean is a sanctuary to freshwater perils



During average or above average marine conditions, perhaps the ocean is a sanctuary to freshwater perils

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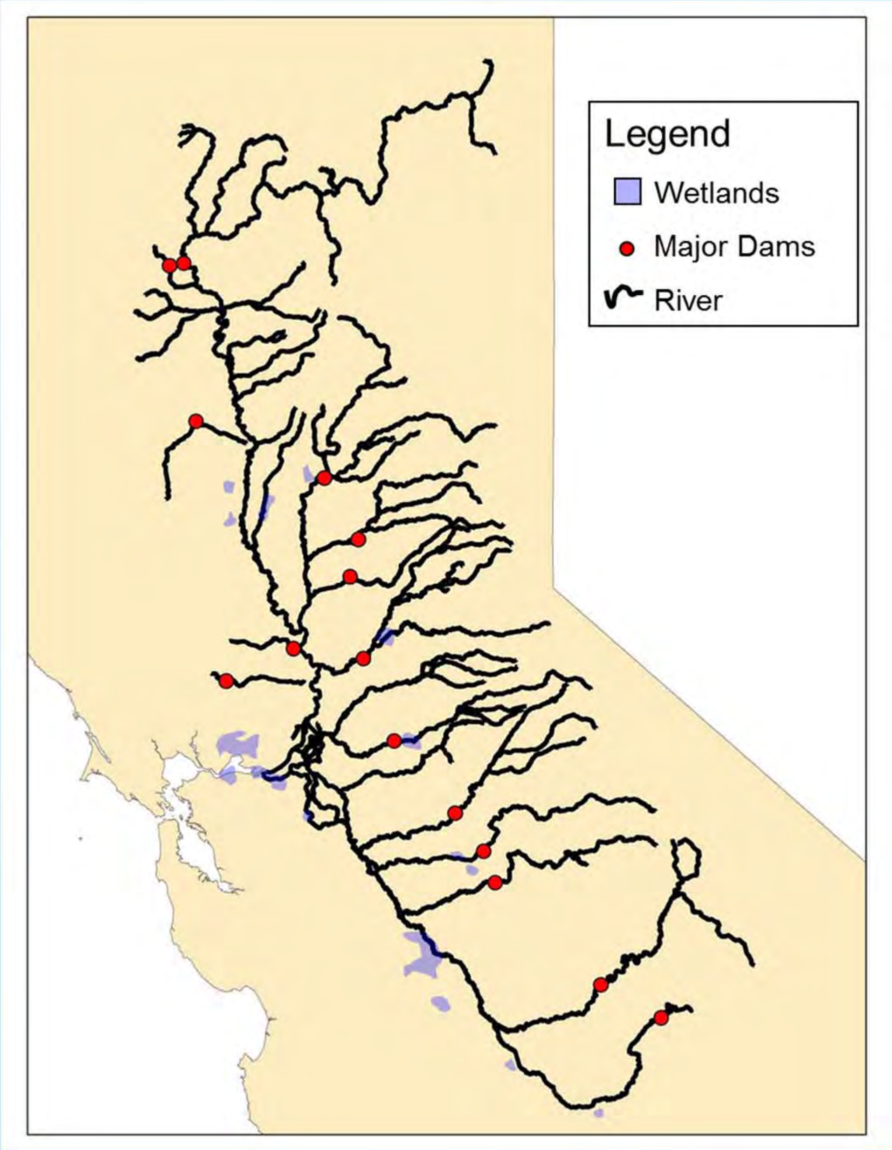

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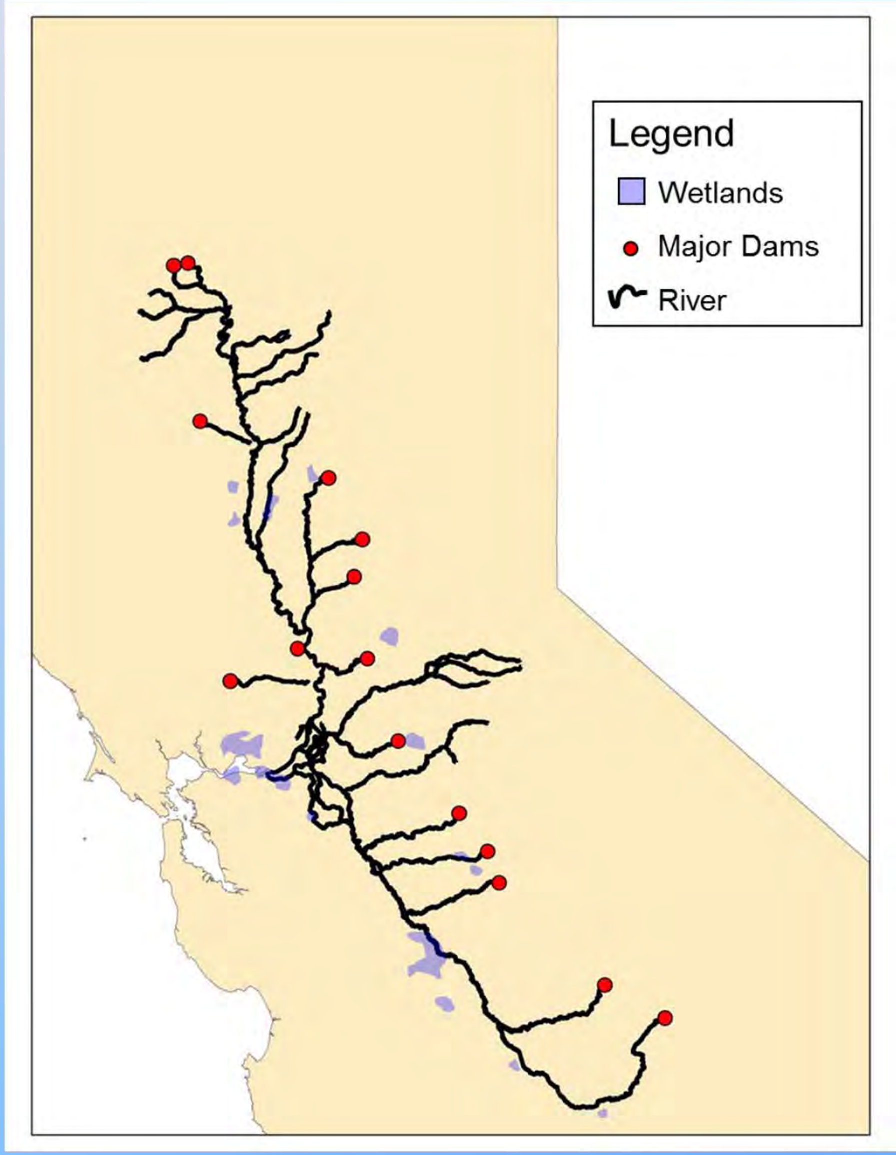

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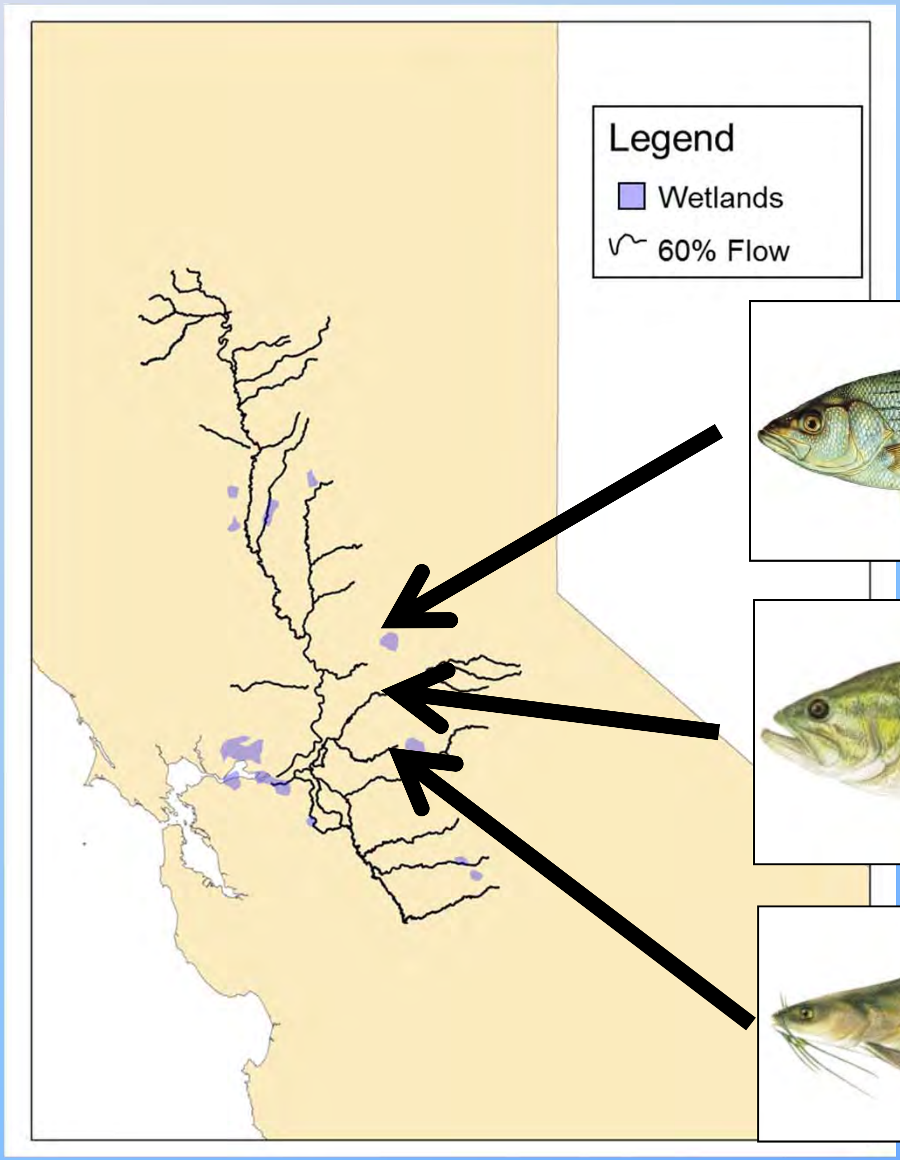
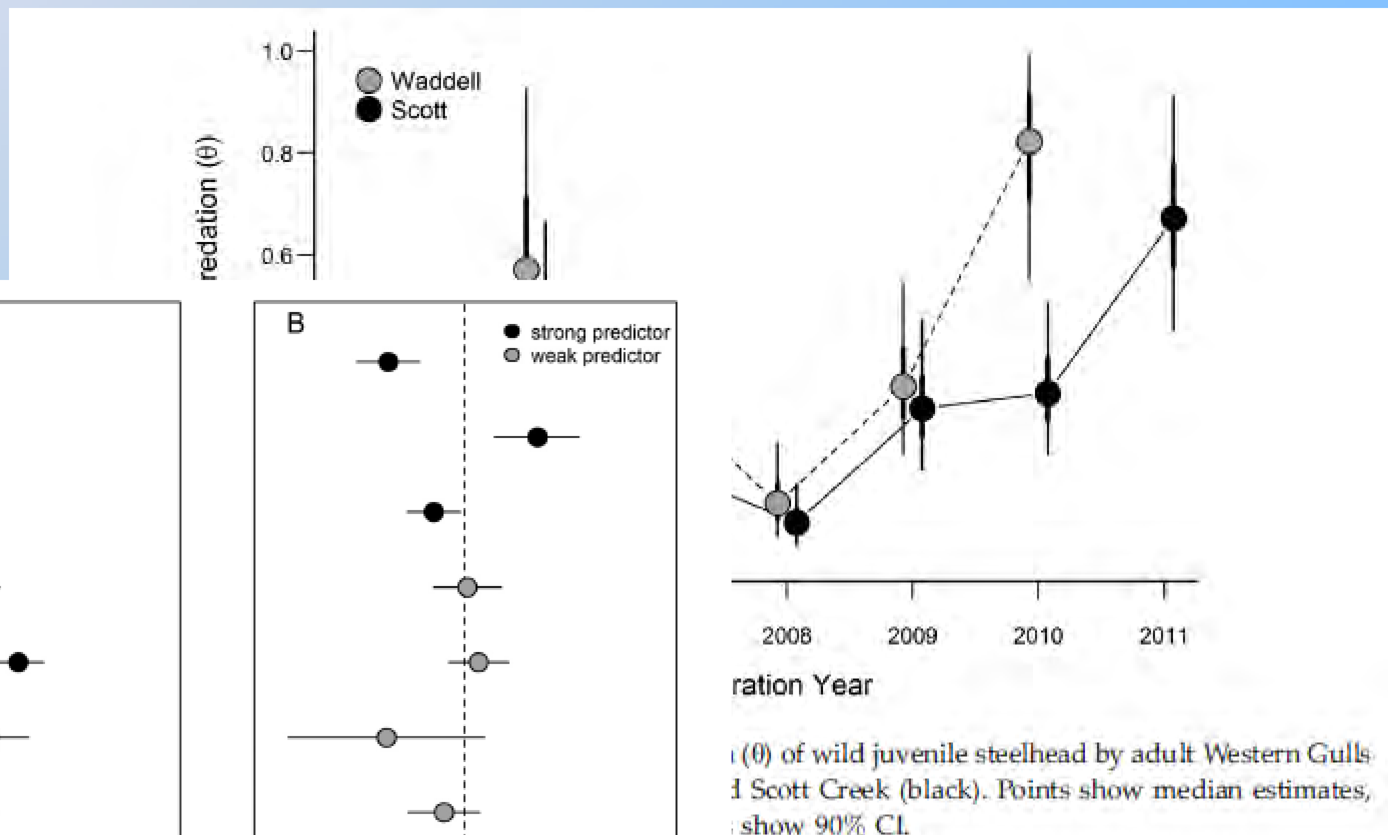
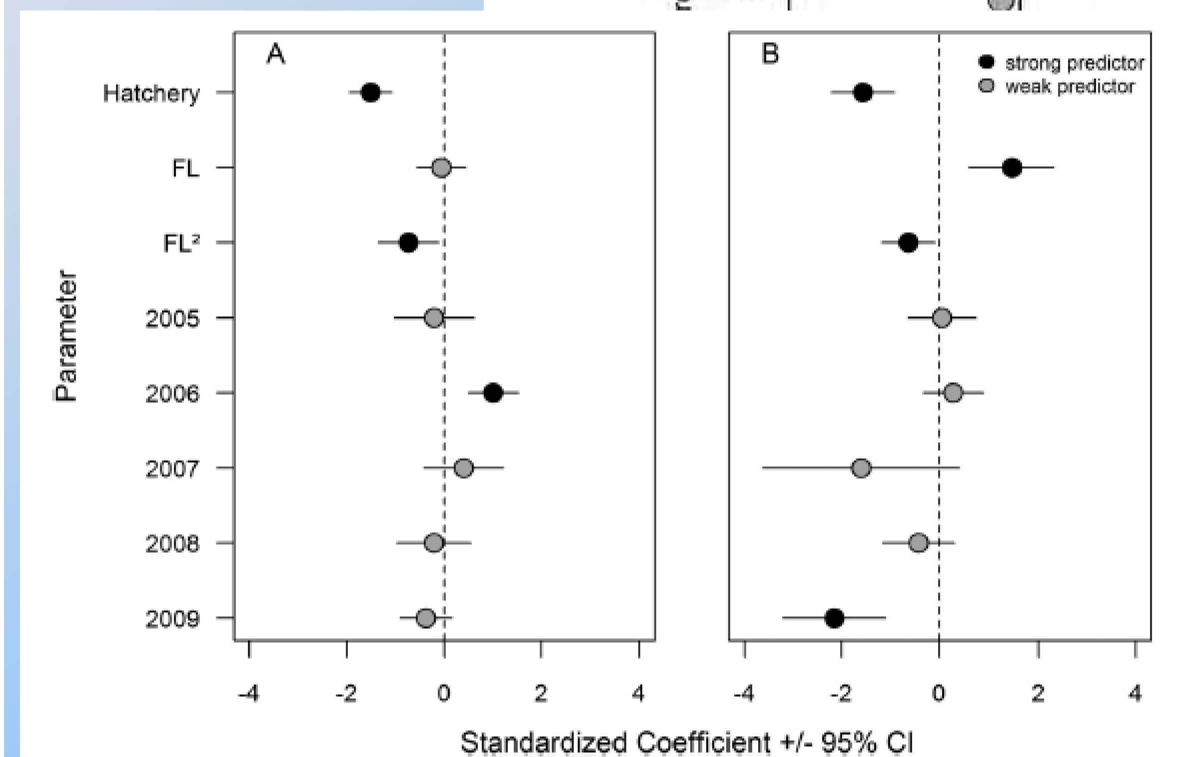


If outmigration survival is lower than expected, have studies been over-attributing unexplained mortality to the ocean?





Incorporating life-history diversity into estimates of Skagit River Chinook salmon production

Corey Phillis (MWD, NWFSC), Correigh Greene (NWFSC),
Joseph Anderson (WDFW),
Eric Beamer, Casey Ruff (Skagit River System Cooperative)

Acknowledgements

- NFWF
- Department of Ecology, IMW
- Trout Unlimited
- Long Live the Kings Salish Sea Marine Survival Project
- Lots of field workers and field hours
- Kim Jones, Kara Anlauf-Dunn

Proximate & Ultimate Goals of restoration should align

Life-Cycle Models can identify restoration actions with the greatest Benefit to Ultimate Goals

Life-history diversity is good, but often not adequately measured

Goal of Restoration

Proximate Goals:

Increase or Improve the qualities of habitat X

Goal of Restoration

Proximate Goals:

Increase or Improve the qualities of habitat X

Photo credit: FISHBIO

Goal of Restoration

Proximate Goals:

Increase or Improve the qualities of habitat X

Goal of Restoration

Ultimate Goals:

Benefit the population or ESU

Goal of Restoration

Ultimate Goals:

Benefit the population or ESU (and in turn us)

Measuring Success of Restoration

Proximate Goals:

Increase or Improve the qualities of habitat X

- How many acres of habitat restored?
- Did rearing capacity increase?
- Did survival in the habitat improve?

Measuring Success of Restoration

Ultimate Goals:

Benefit the population or ESU

- Viability Status (e.g. McElhany et al., 2000)
  - Abundance
  - Population Growth Rate
  - Spatial Structure
  - Diversity (between and within populations)

Measuring Success of Restoration

Ultimate Goals:

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  - Abundance
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  - Spatial Structure
  - **Diversity** (between and **within populations**)

Success Measures Should Align

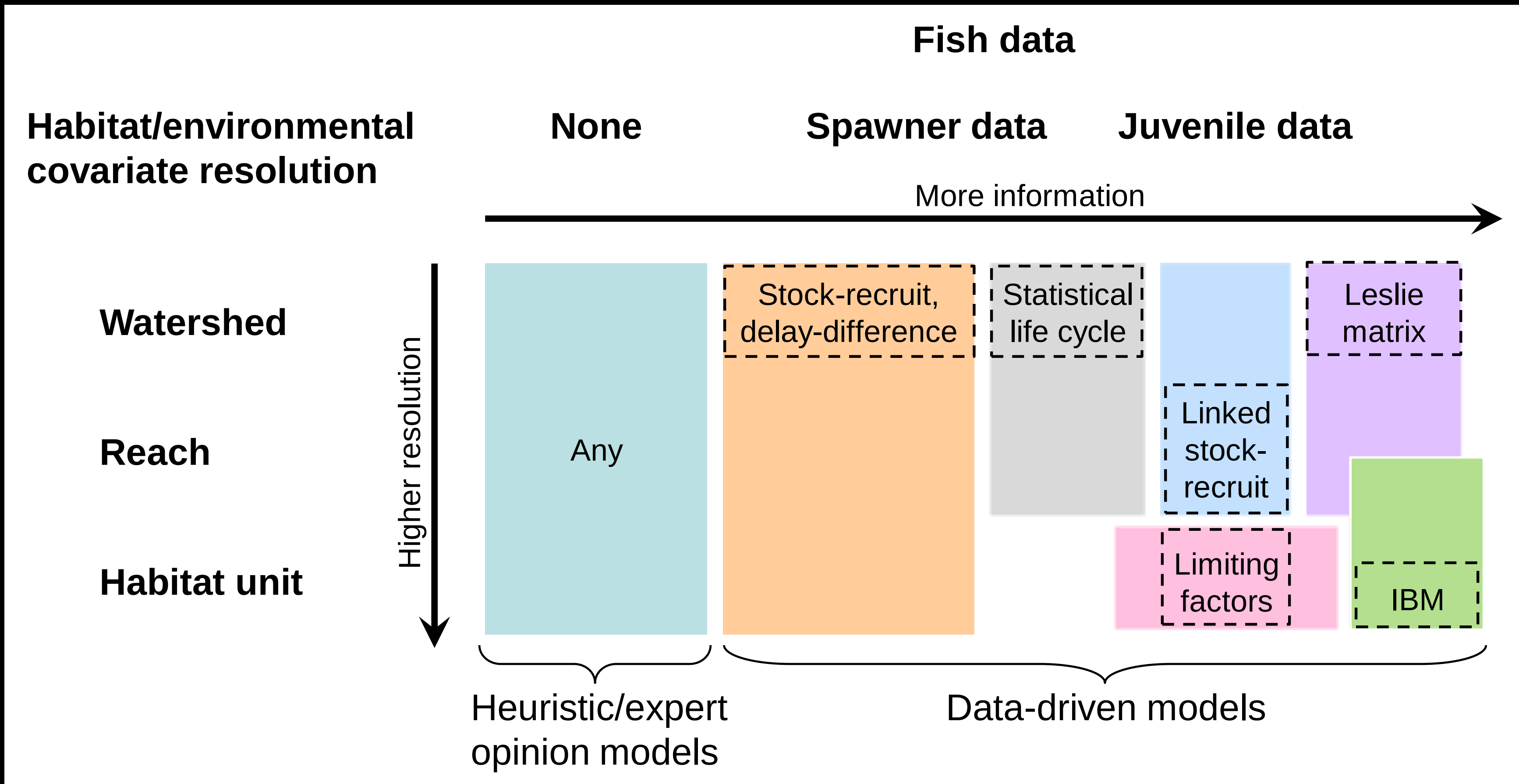
Proximate Goals

- How many acres of habitat restored?
- Did rearing capacity increase?
- Did survival in the habitat improve?

Ultimate Goals

- Abundance
- Population Growth Rate
- Spatial Structure
- Diversity (between and within populations)

Models as Restoration Tools



Knudsen et al. *submitted*

Life History Diversity is Rarely a Target for Management or Restoration

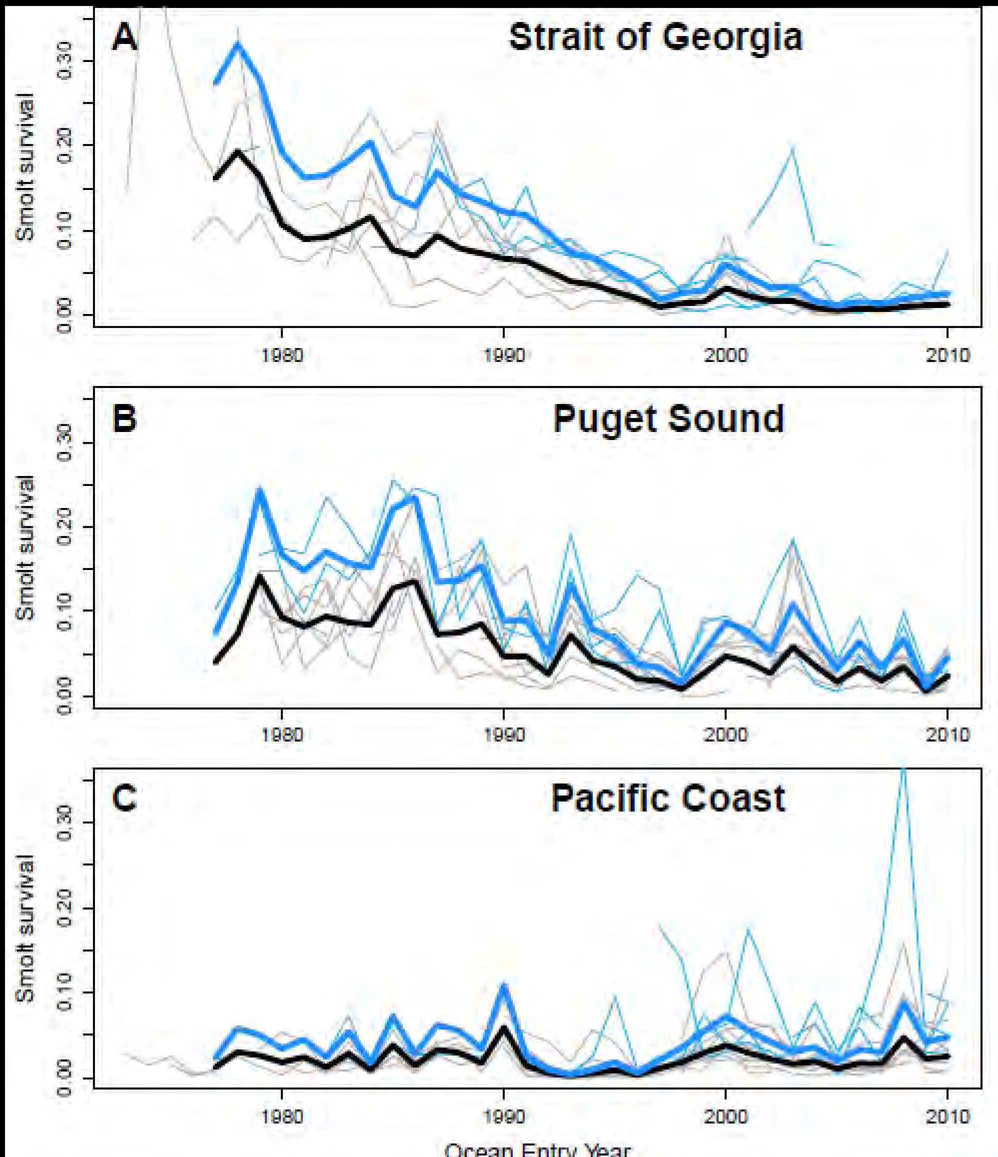
Life history diversity: increasingly recognized as important for resilient populations (e.g., Greene et al. 2010)

BUT, not a focus for management
Examples:

- Coho salmon- focused on freshwater yearlings
- Chinook salmon – in Puget Sound the focus is on estuary residents

Backdrop: Declining marine survival in the Salish Sea

Coho salmon



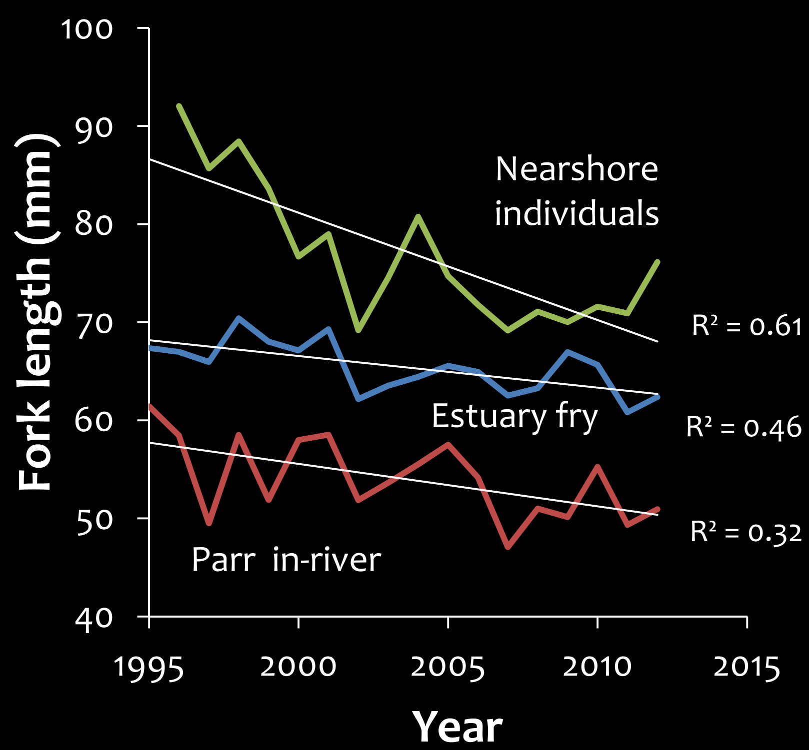
Possible connections between changes in LHD and low marine survival in the Salish Sea

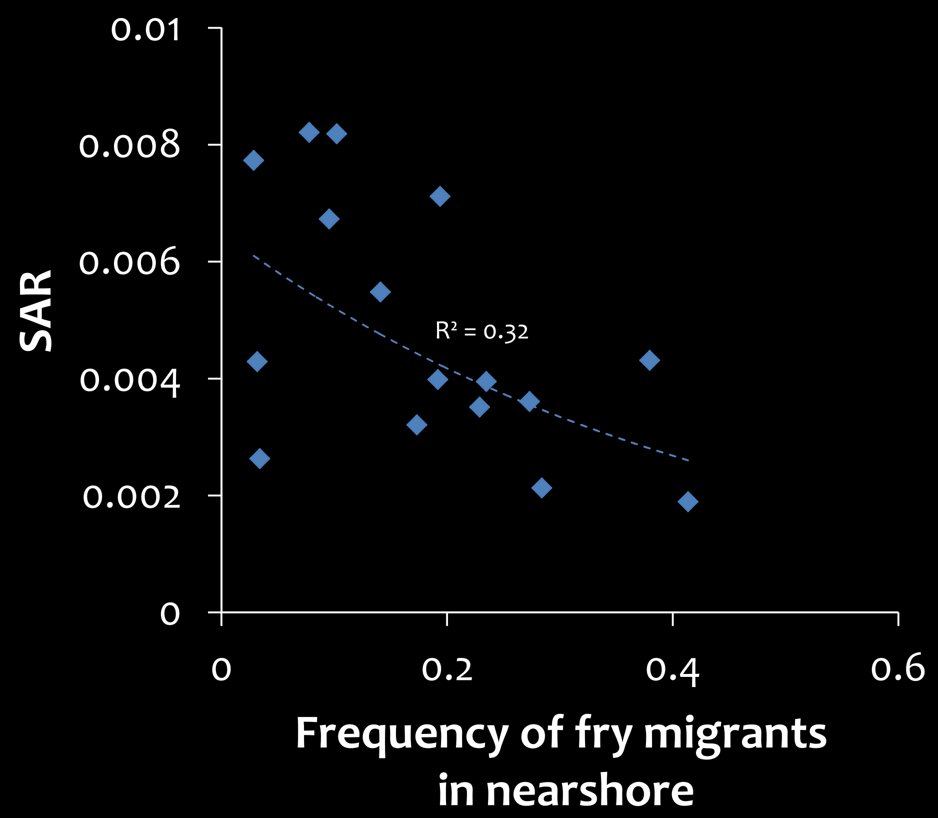
1) Linkages between changes in FW habitat and marine survival

2) Changes in frequencies of key life history types

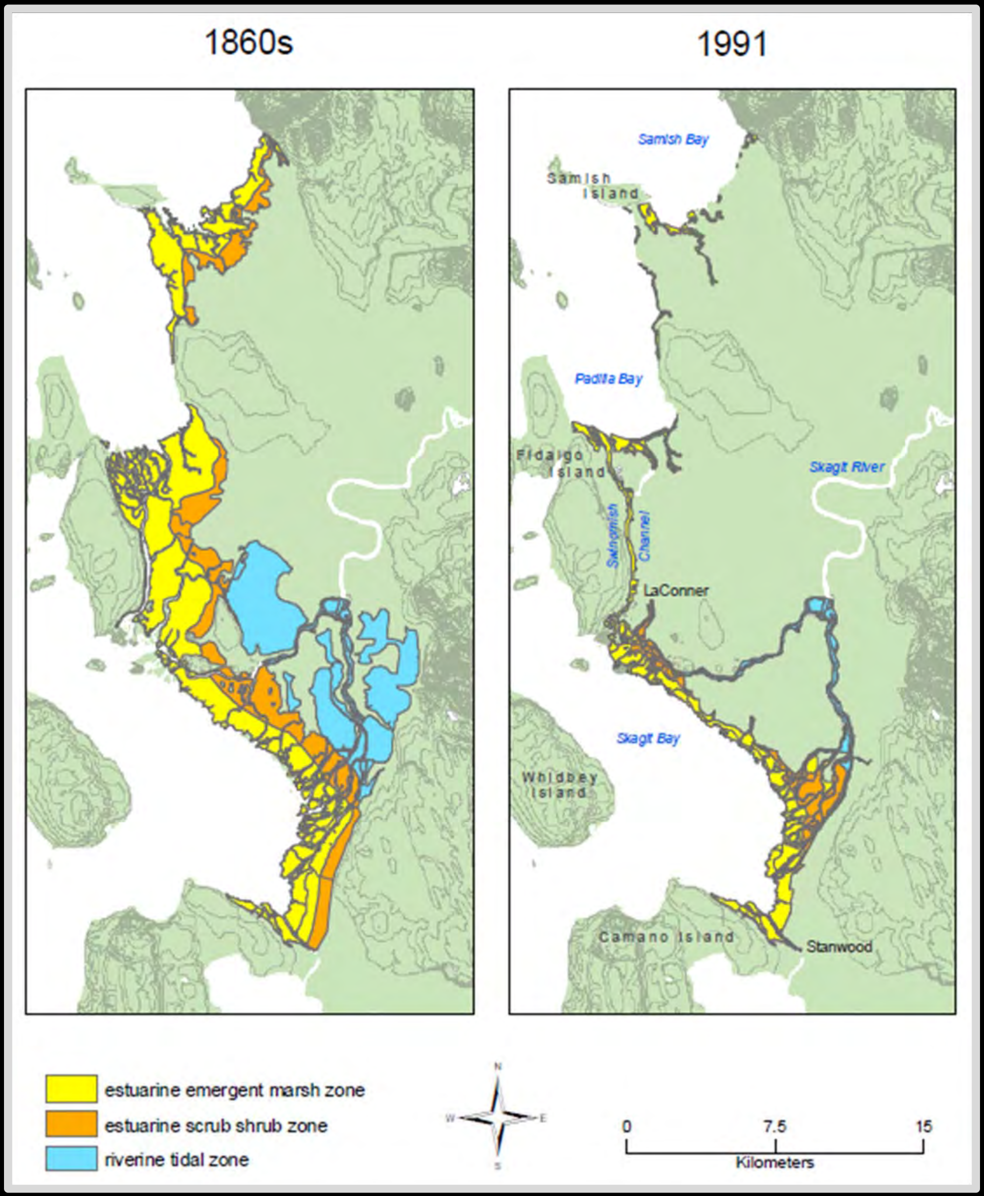
Zimmerman et al. *submitted*

Link between freshwater and marine life stages





Changes in frequencies of key life history types



Loss of habitat will affect some life histories more than others

Key Questions

1) How does habitat limitation structure life history diversity?

2) What are the consequences of juvenile life history variation on marine survival and adult abundance?

Goal

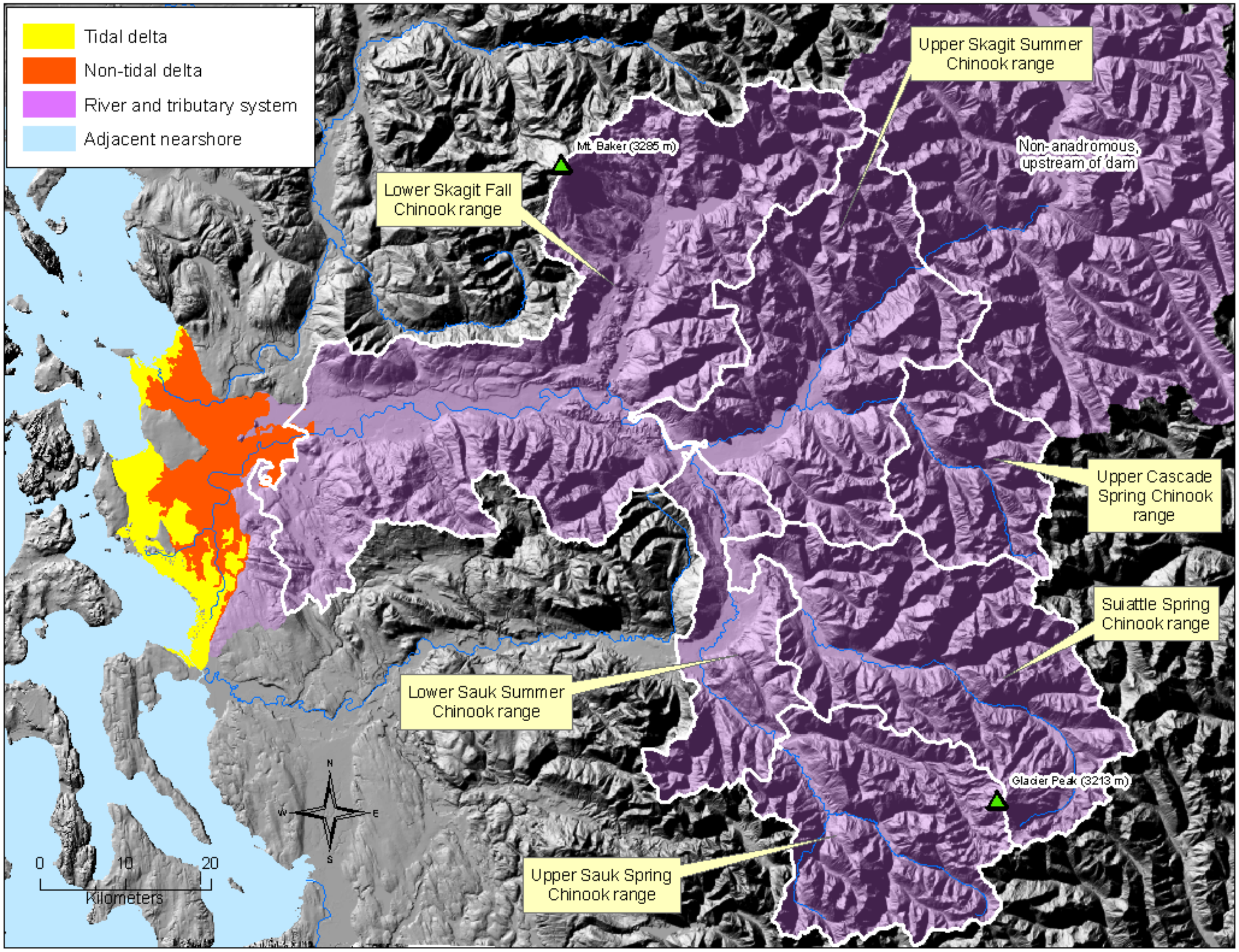
Develop a model to describe:

1. How various habitat features influence carrying capacity and out-migrants

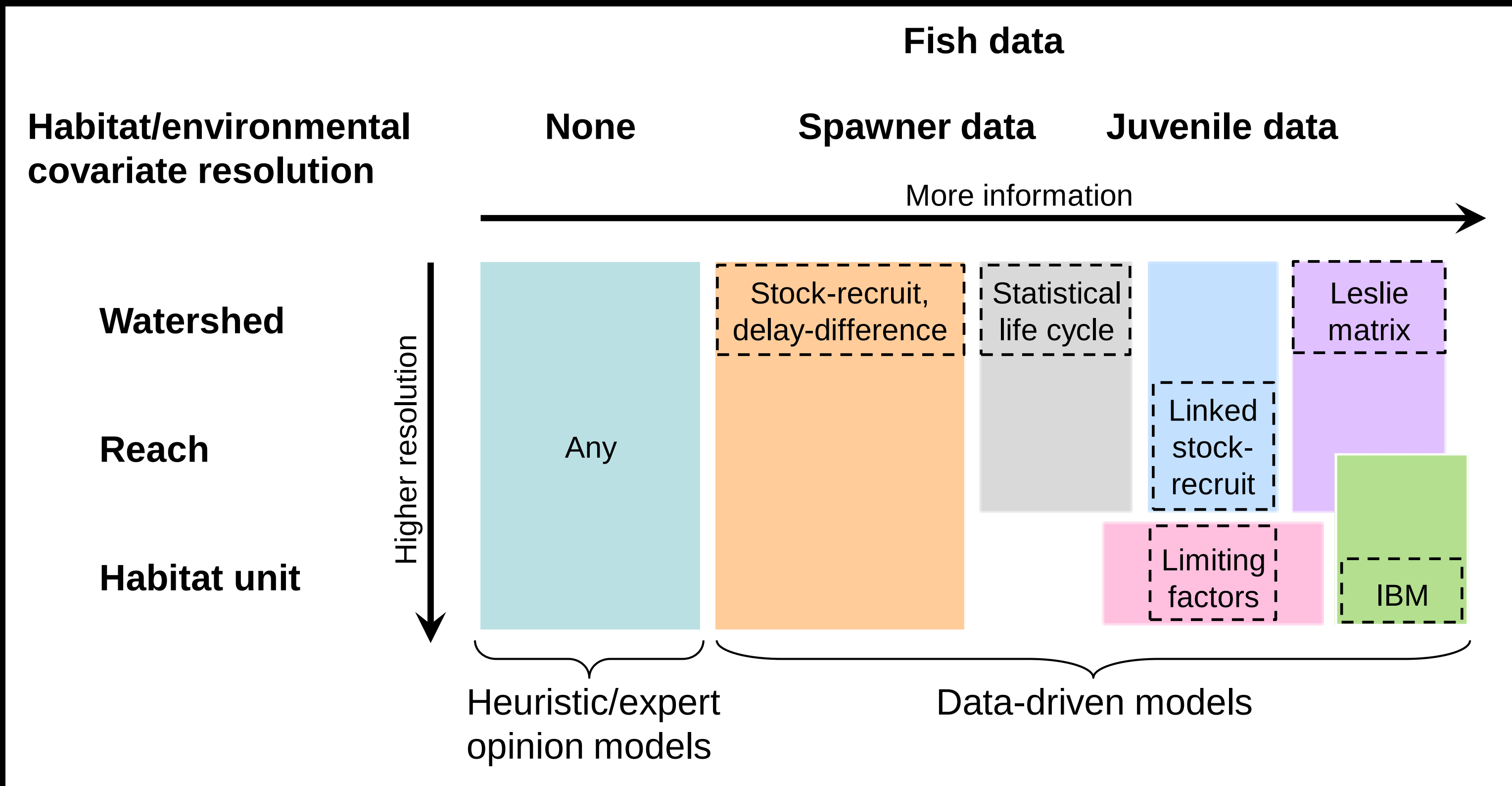
2. How life history variation of out-migrants responds to these habitat factors

3. What are the consequences for adult return rates

The Skagit River watershed

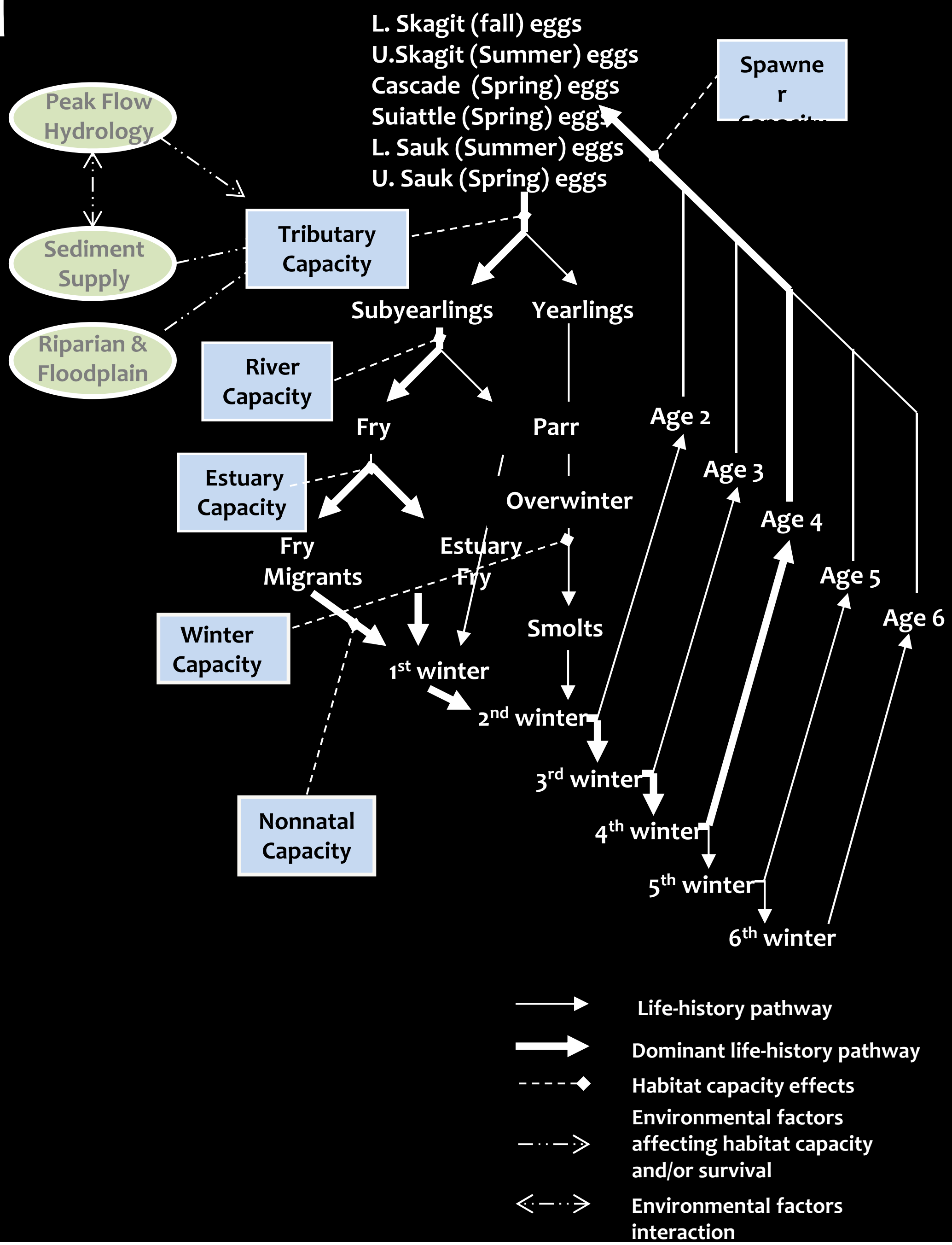


Balancing complexity with data availability

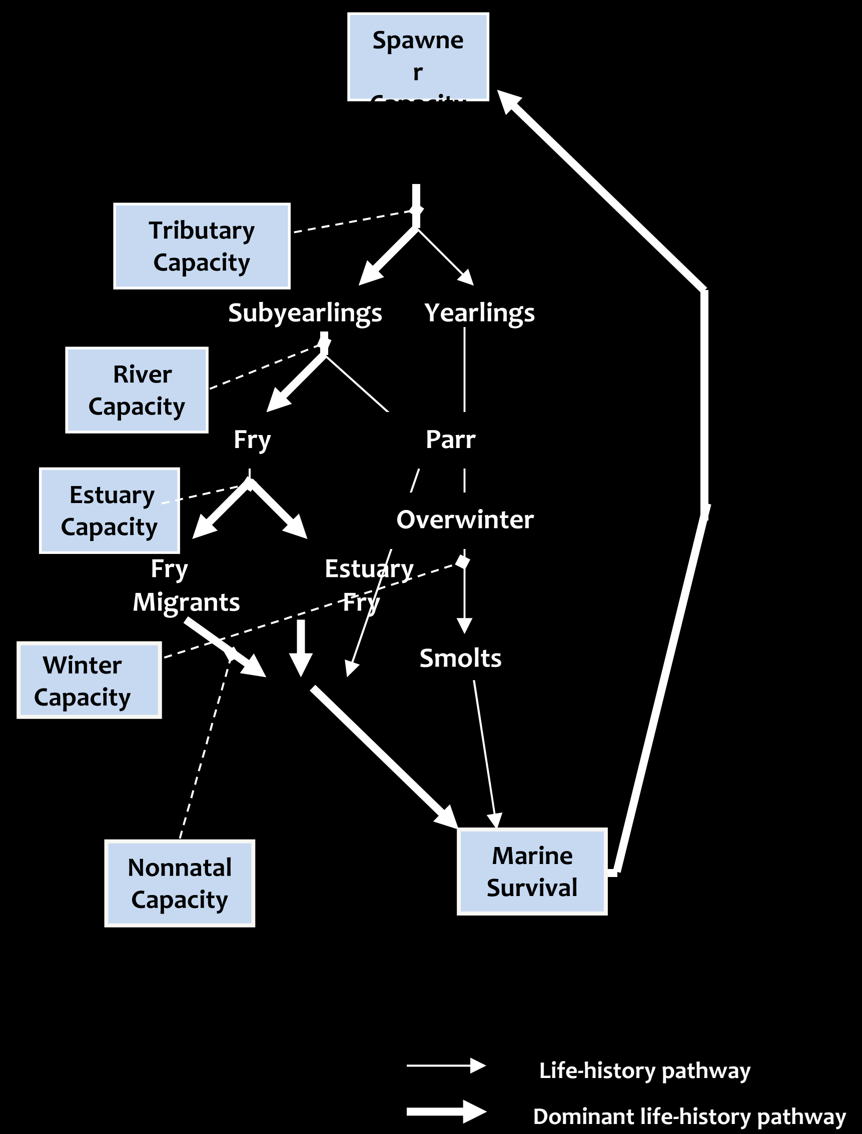


Knudsen et al. *submitted*

Chinook Conceptual Model



Chinook "Data Available" Model

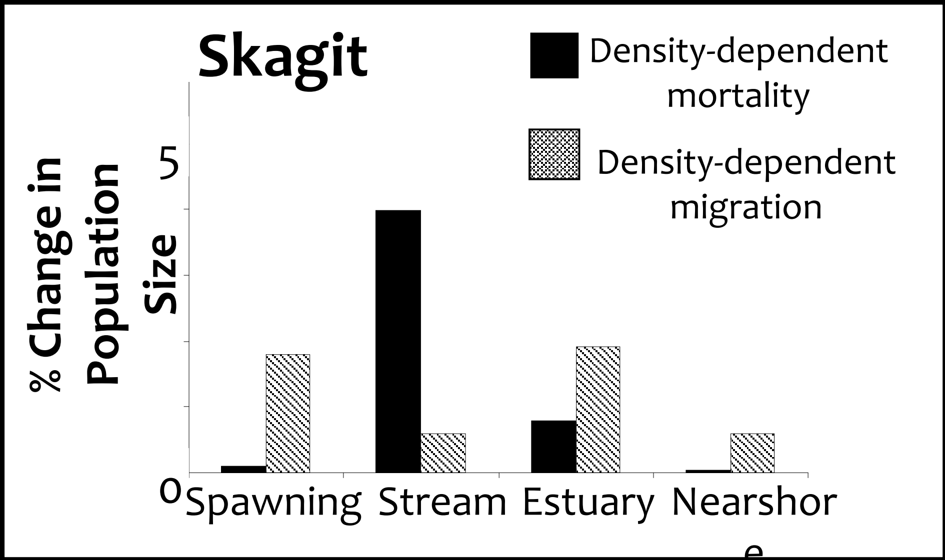


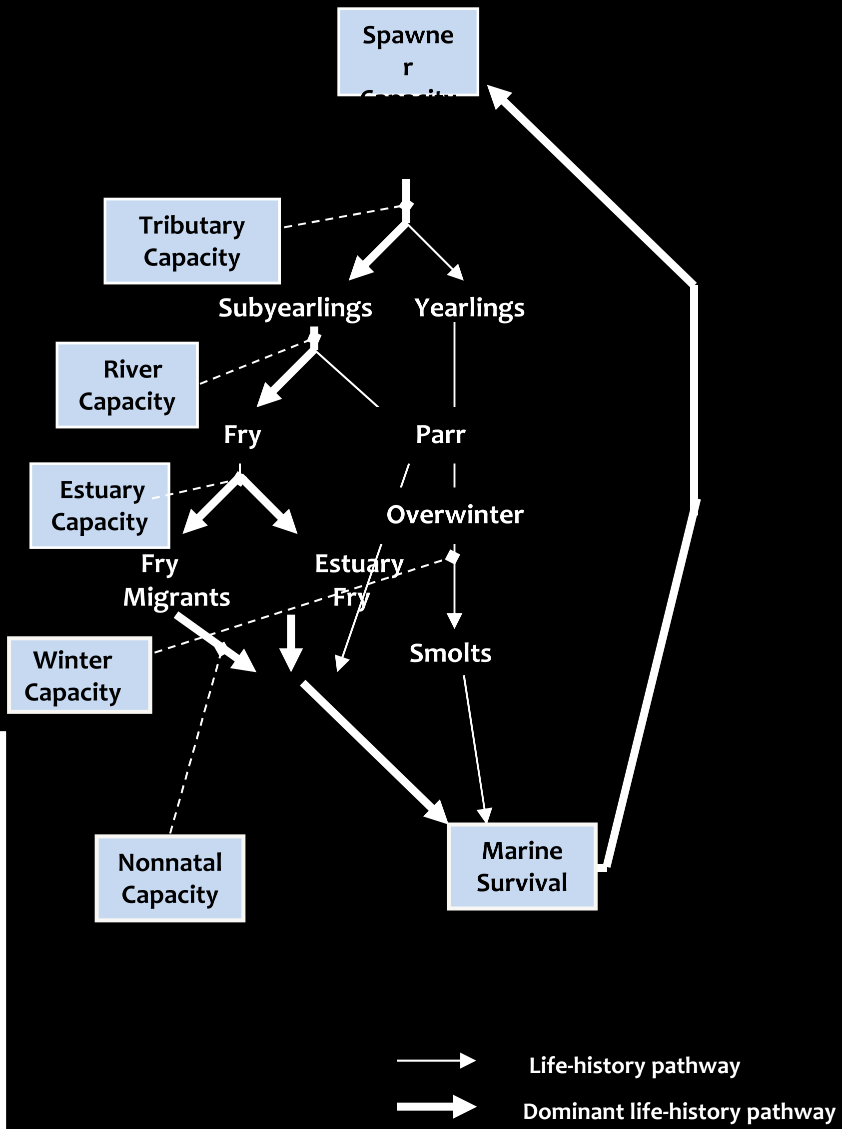
Previous Skagit salmon models:

Skagit Chinook Recovery Plan (2005)
- Informal Limiting Factors Analysis

Beechie et. al (1994)
- Limiting Factors Analysis (coho)

Greene & Beechie (2004)
- Life Cycle Model





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Skagit Chinook Recovery Plan (2005)

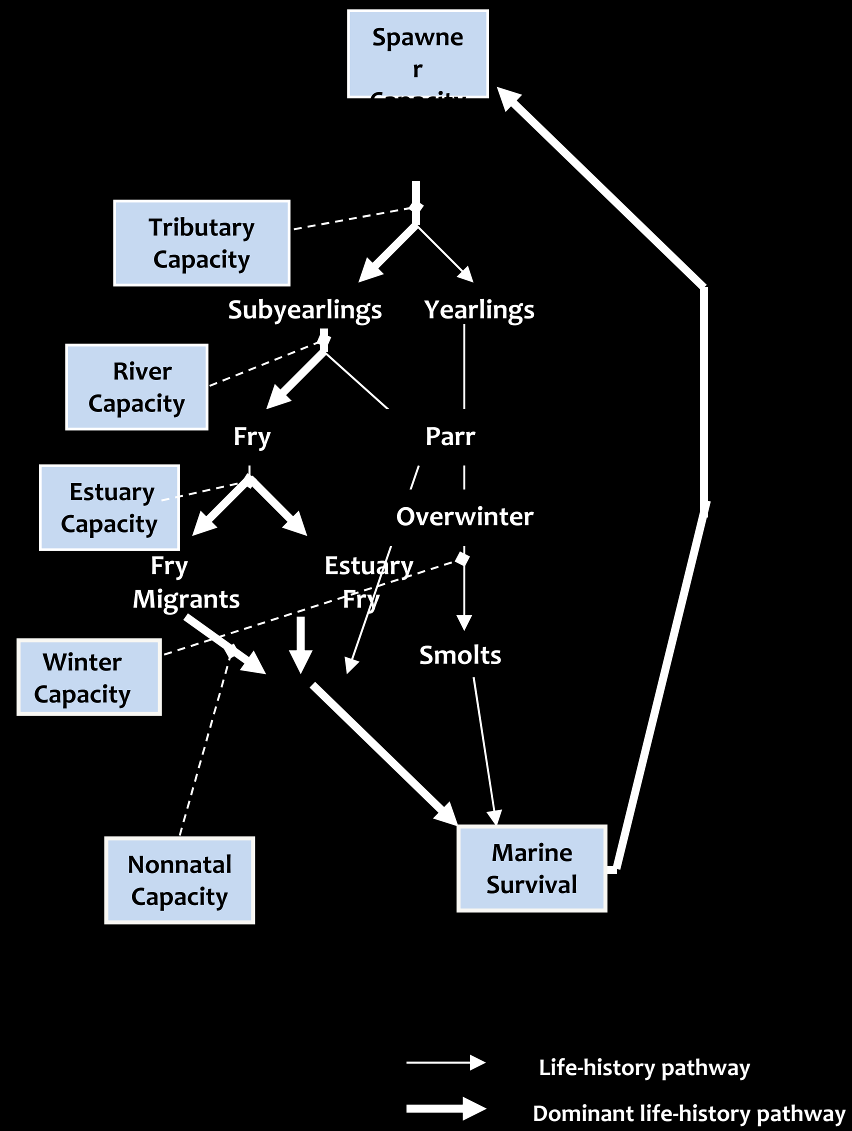
- Informal Limiting Factors Analysis

Beechie et. al (1994)

- Limiting Factors Analysis (coho)

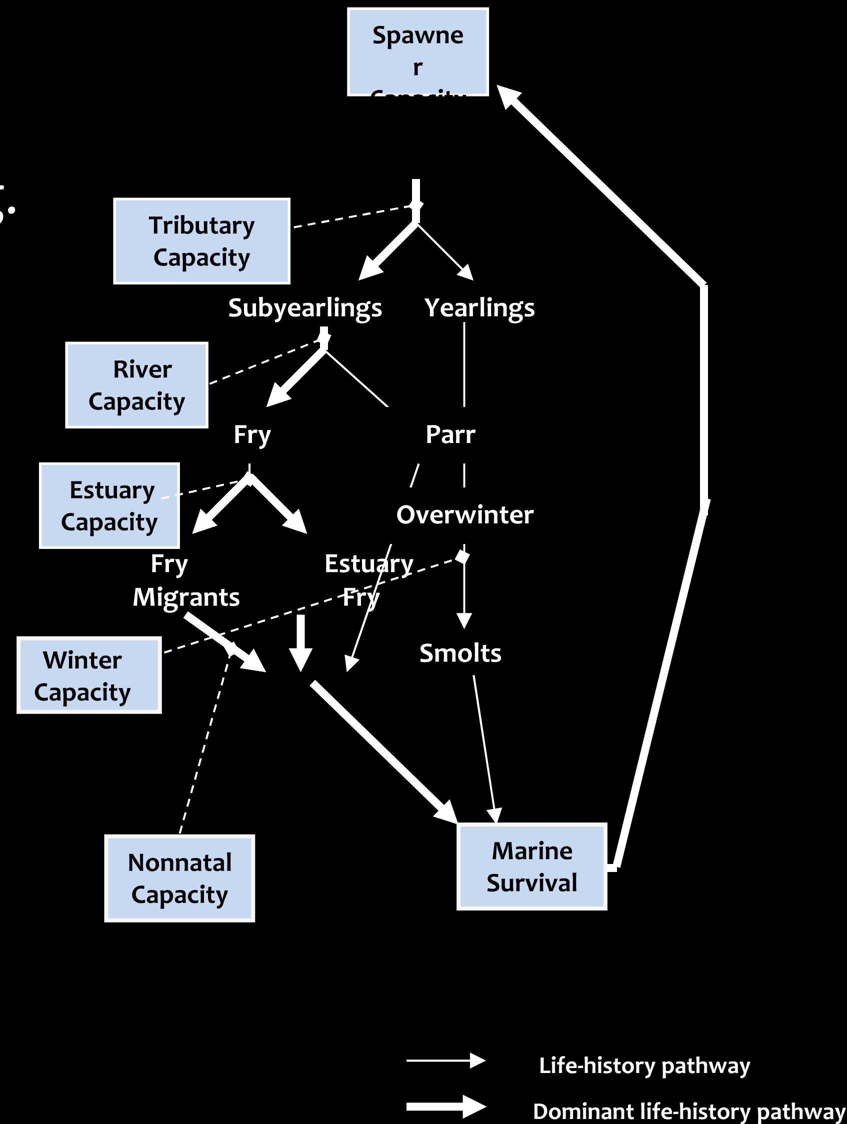
Greene & Beechie (2004)

- Life Cycle Model with Density-Dependent Migration



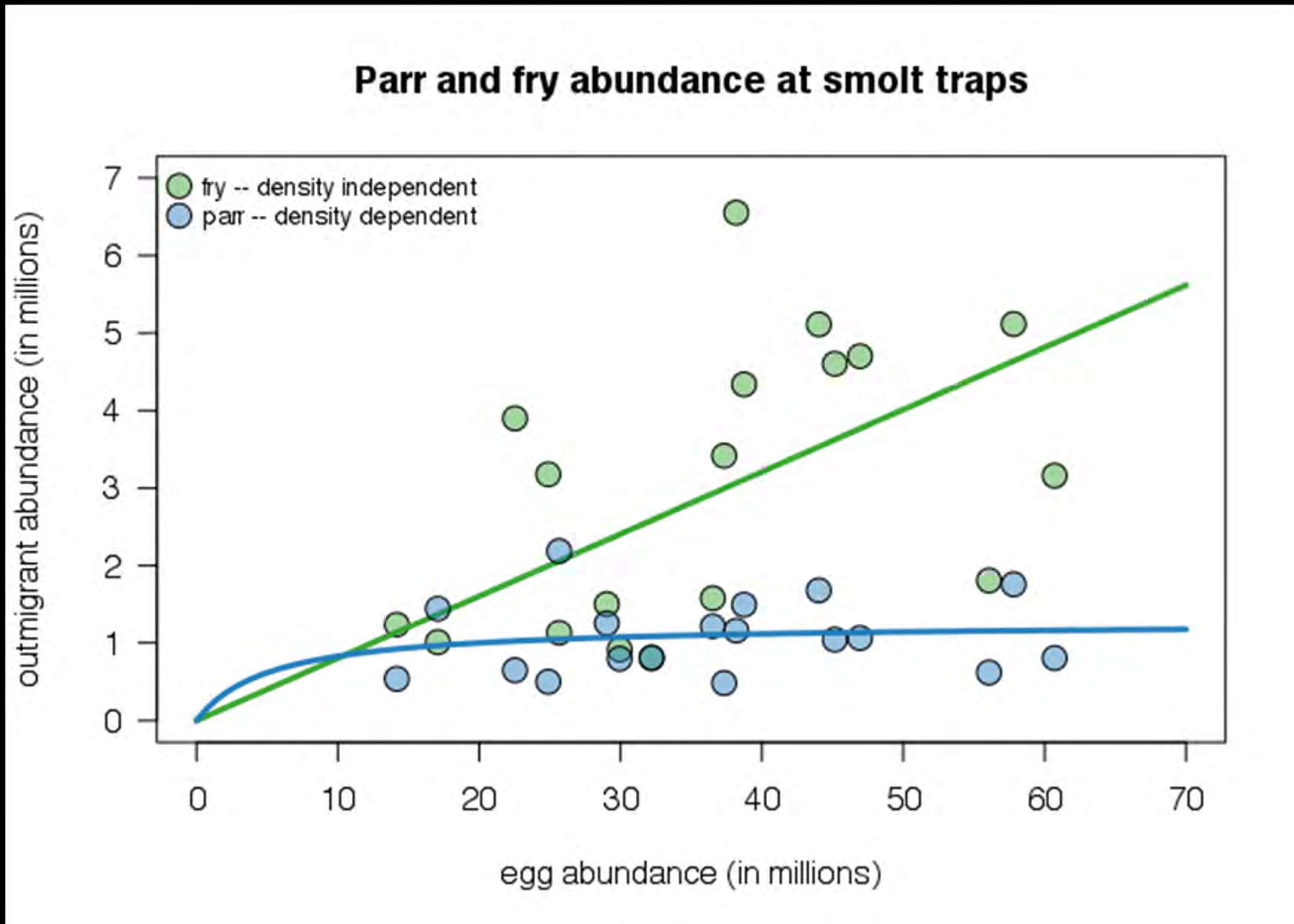
What's new?

Better understanding of habitat use (e.g. non-natal sites like "pocket estuaries")

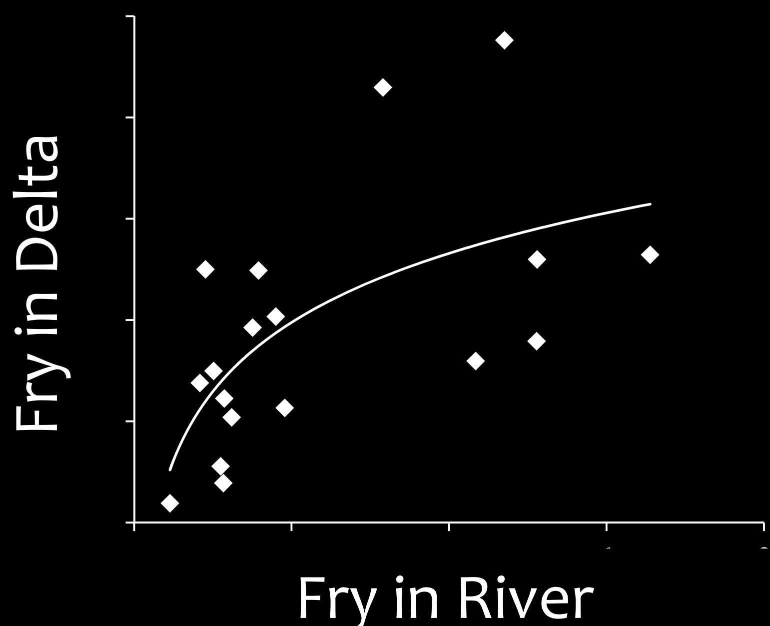


More and better data (e.g. strong evidence for density dependent migration)

Density-dependent migration:
Parr vs. Fry



Density-dependent migration:
Delta Fry vs. Migrant Fry



Density-dependent migration:
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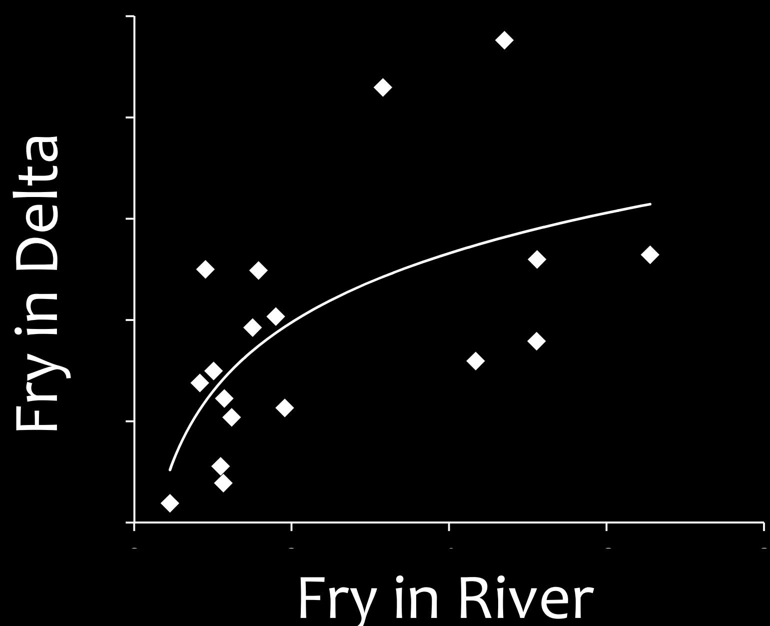
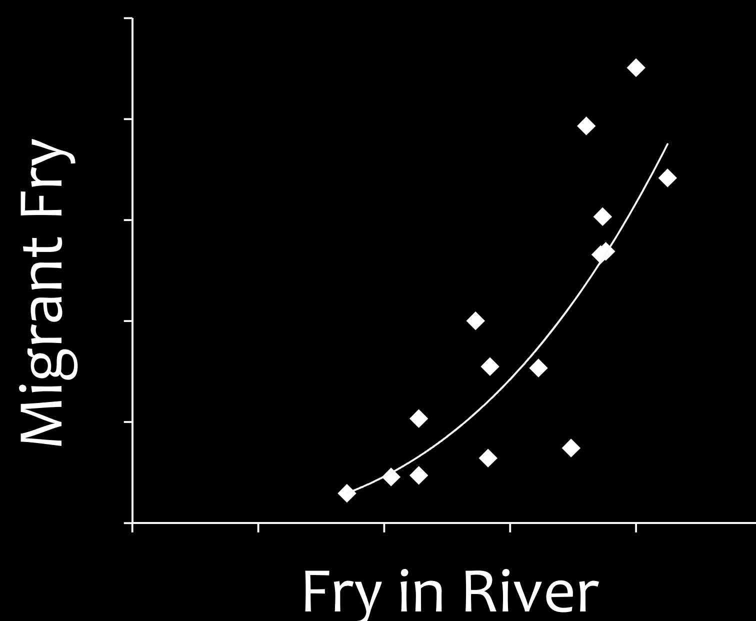


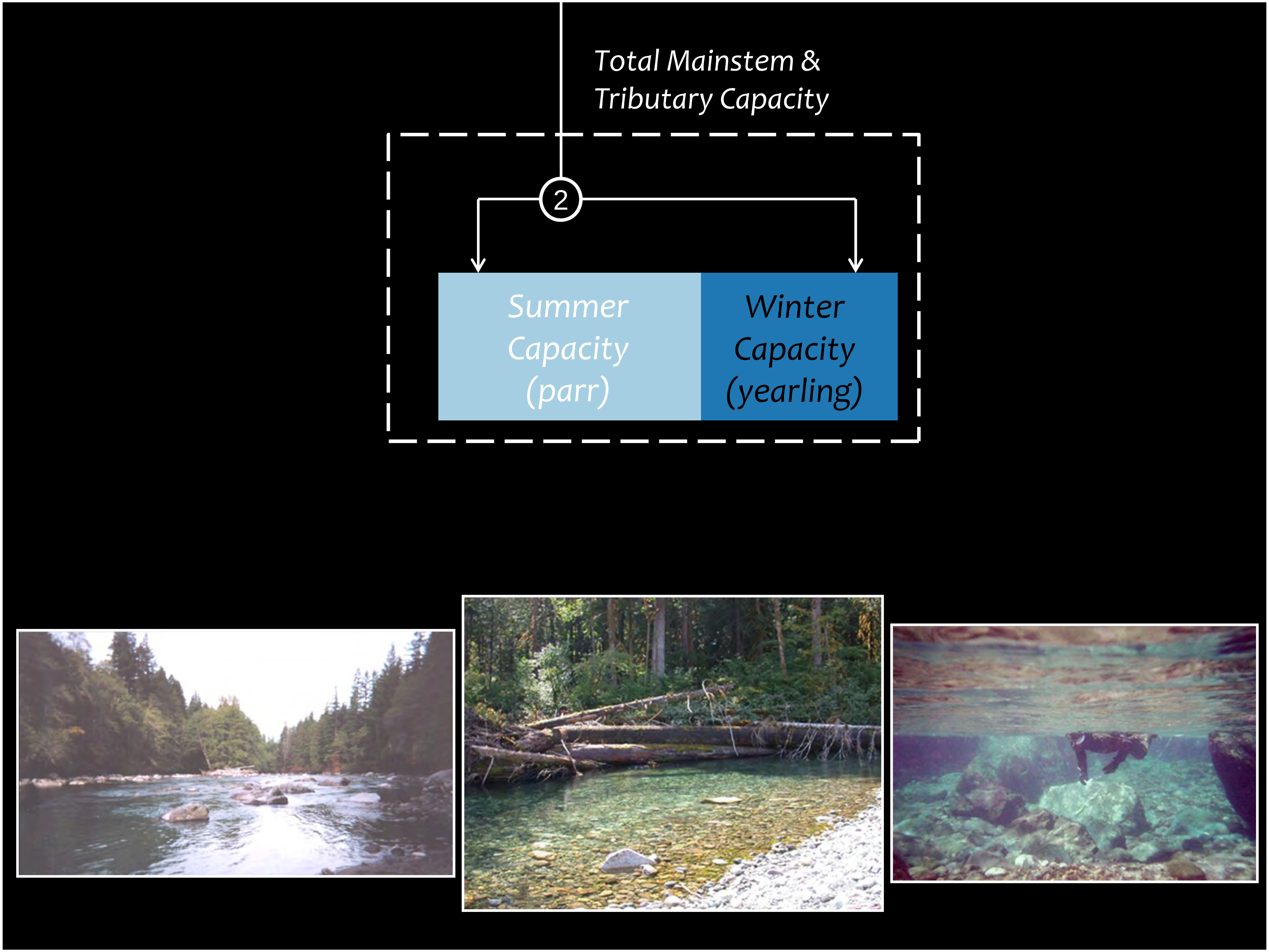


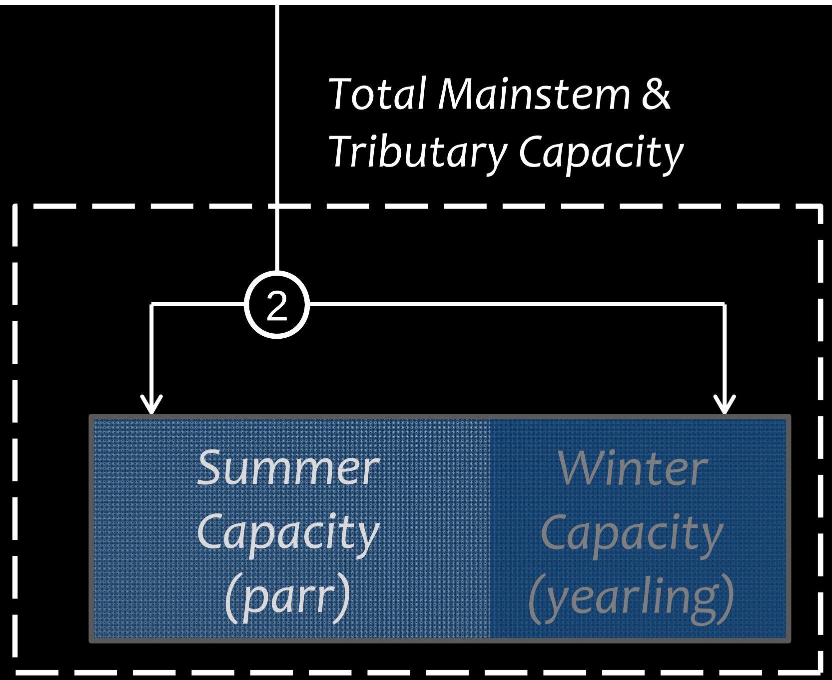
A Limiting Factors Analysis Modified for Multiple Life History Types

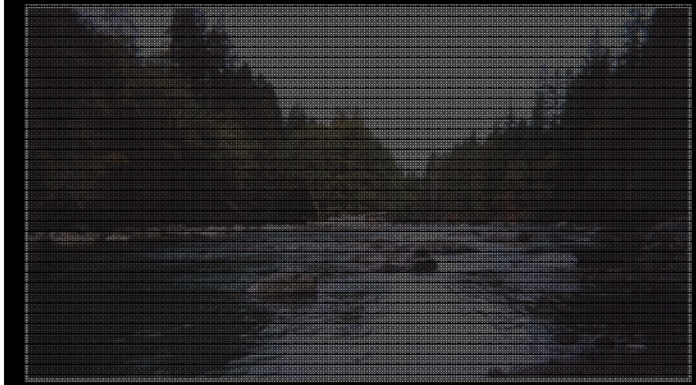
Spawners

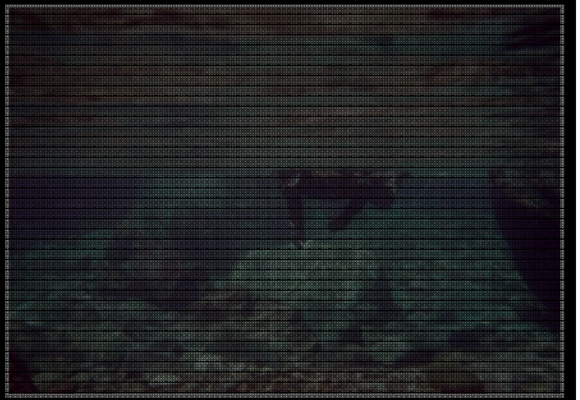
→ Eggs

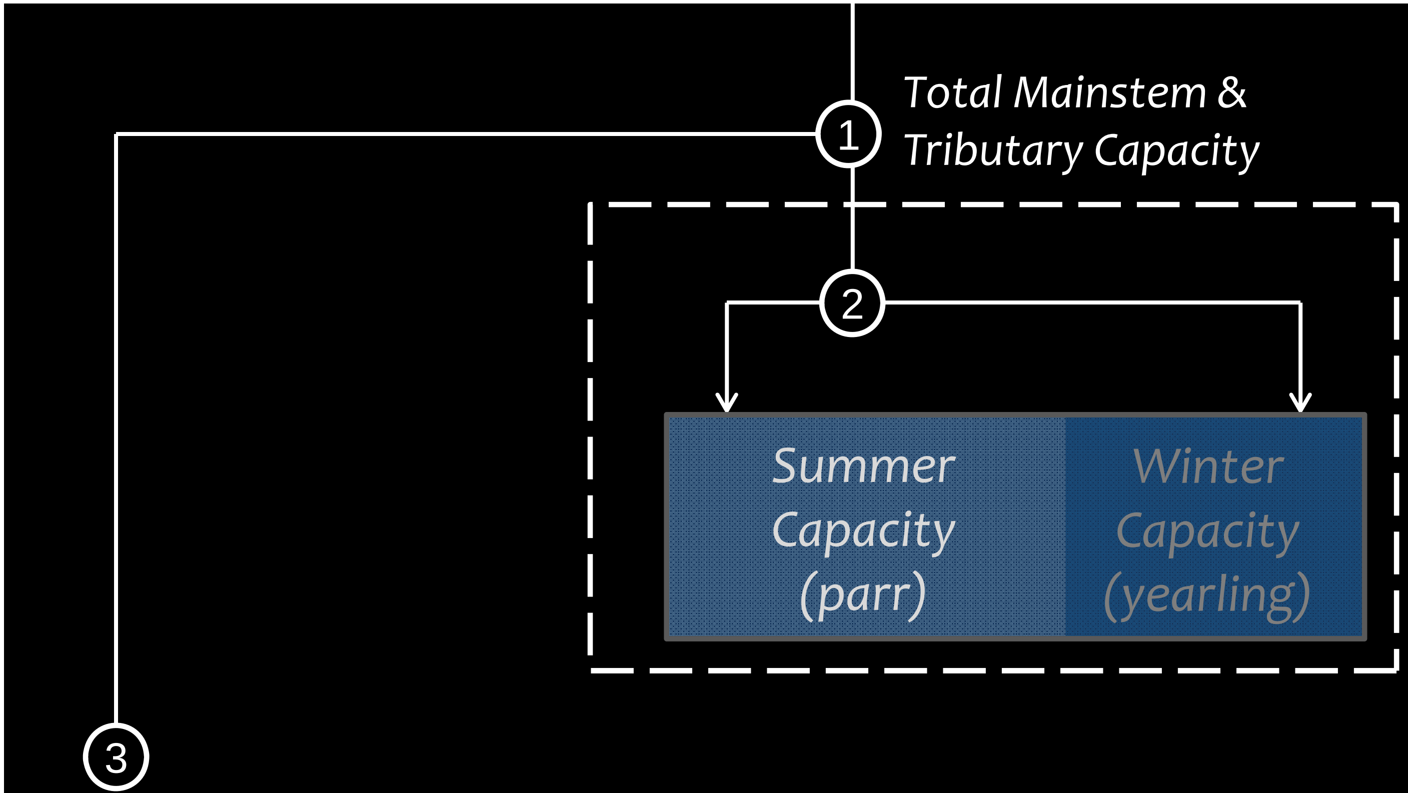
→ Emergence

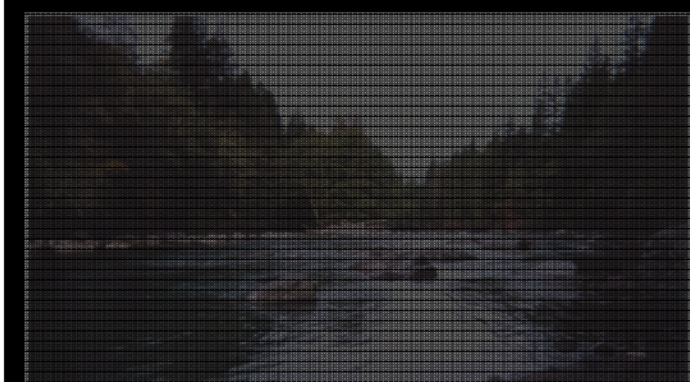

Total Mainstem &
Tributary Capacity
2
Summer
Capacity
(parr)
Winter
Capacity
(yearling)

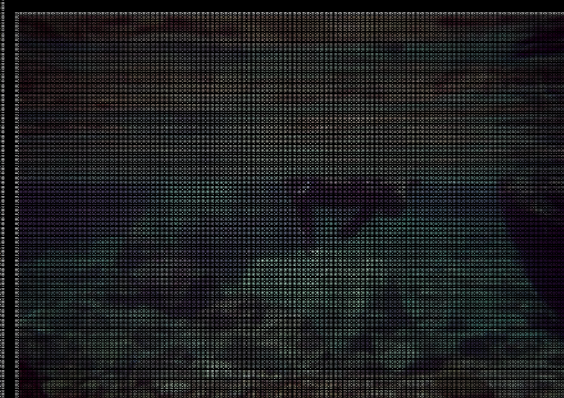

Total Mainstem &
Tributary Capacity
2
Summer Capacity (parr)
Winter Capacity (yearling)

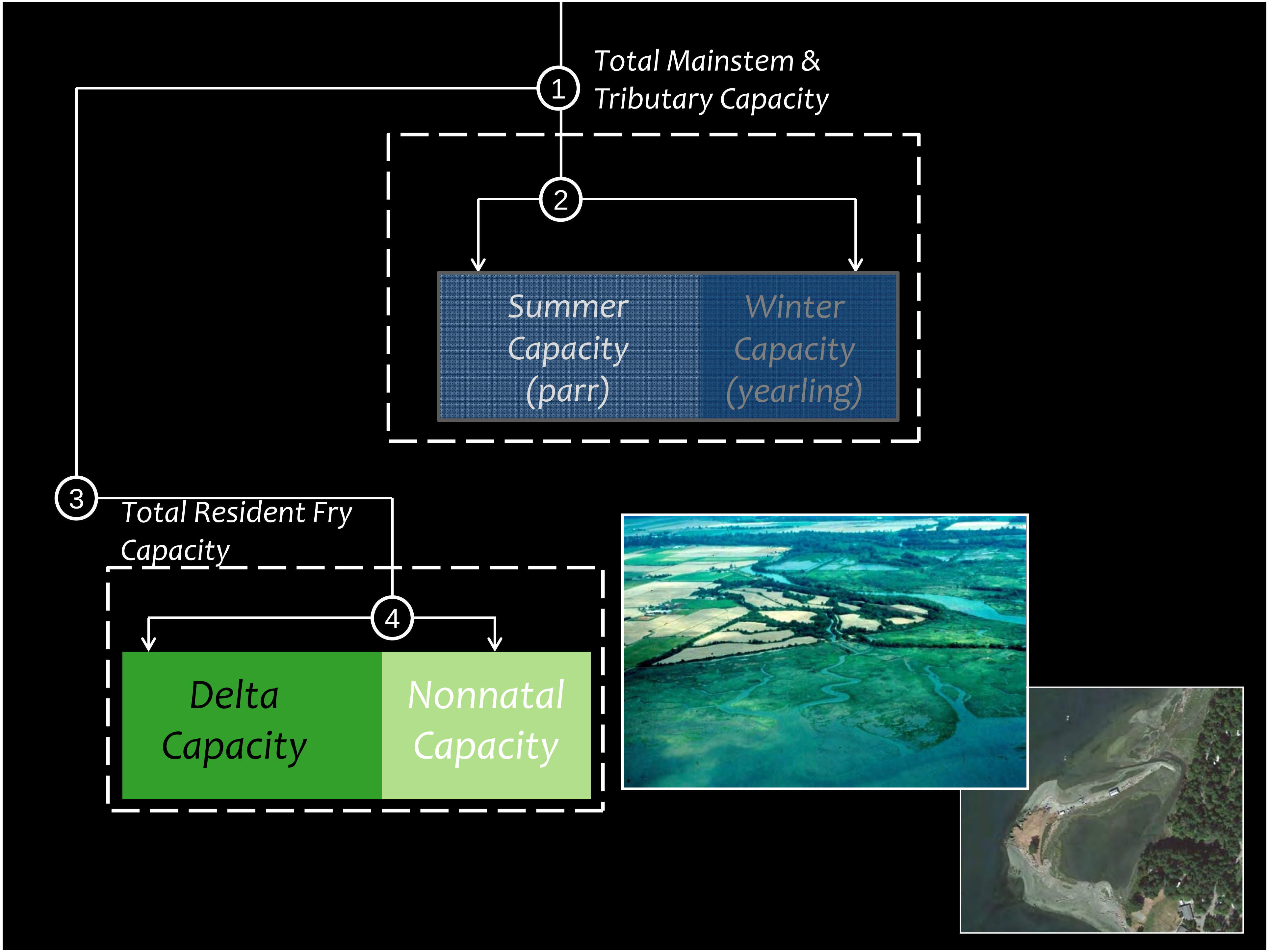




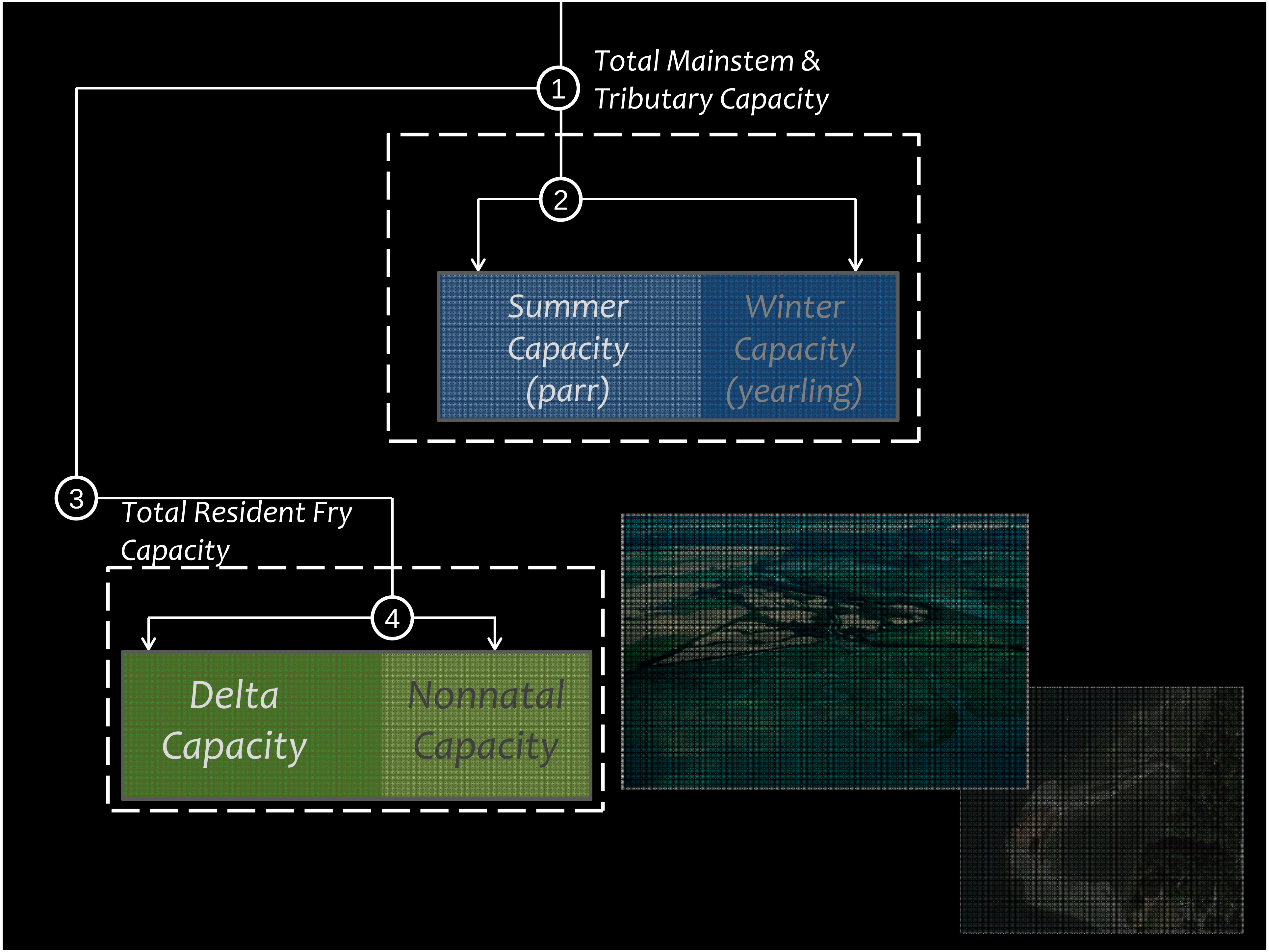

Total Mainstem &
Tributary Capacity
1
2
3
Summer
Capacity
(parr)
Winter
Capacity
(yearling)







1
Total Mainstem &
Tributary Capacity
2
Summer
Capacity
(parr)
Winter
Capacity
(yearling)
3
Total Resident Fry
Capacity
4
Delta
Capacity
Nonnatal
Capacity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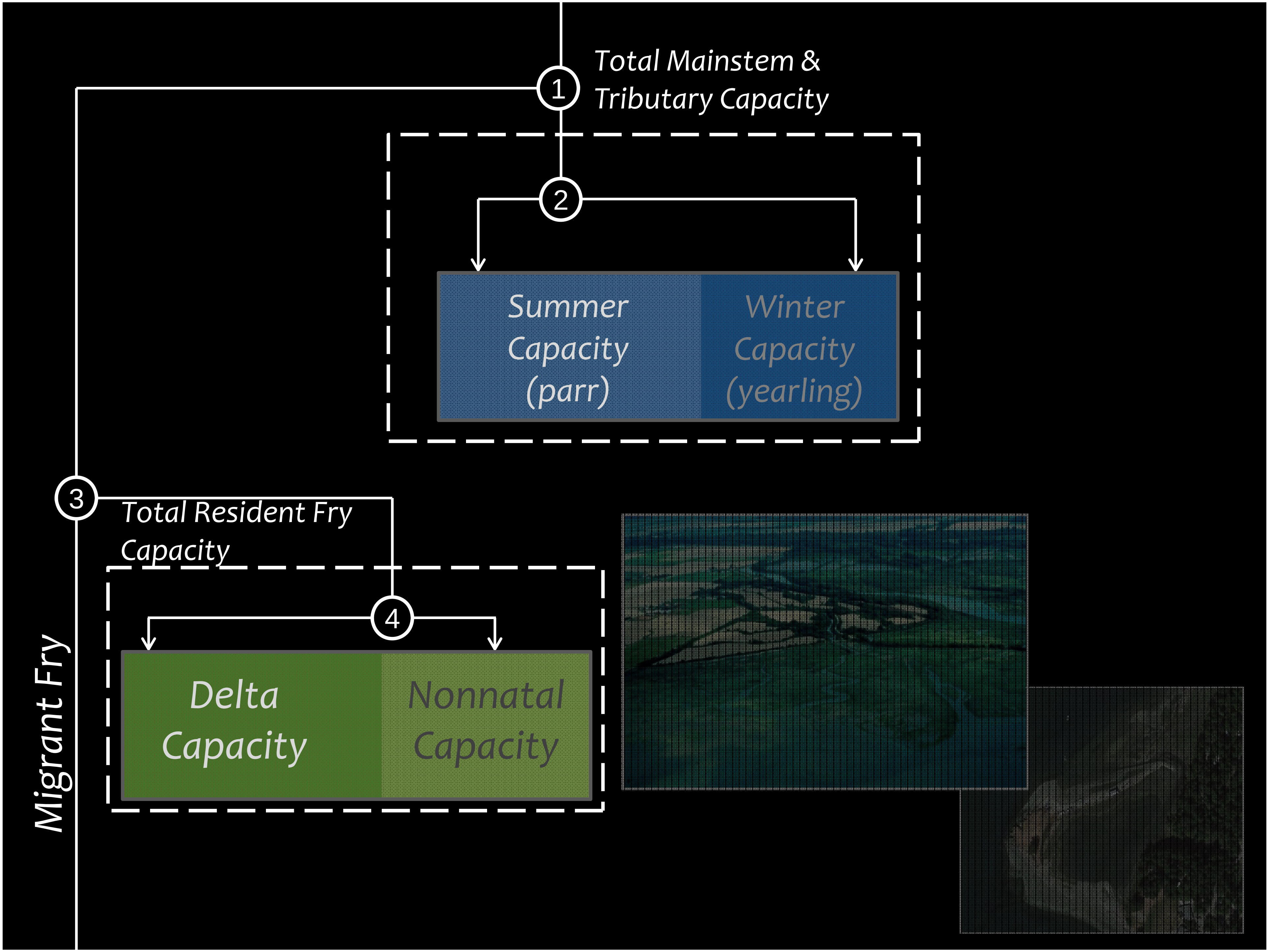
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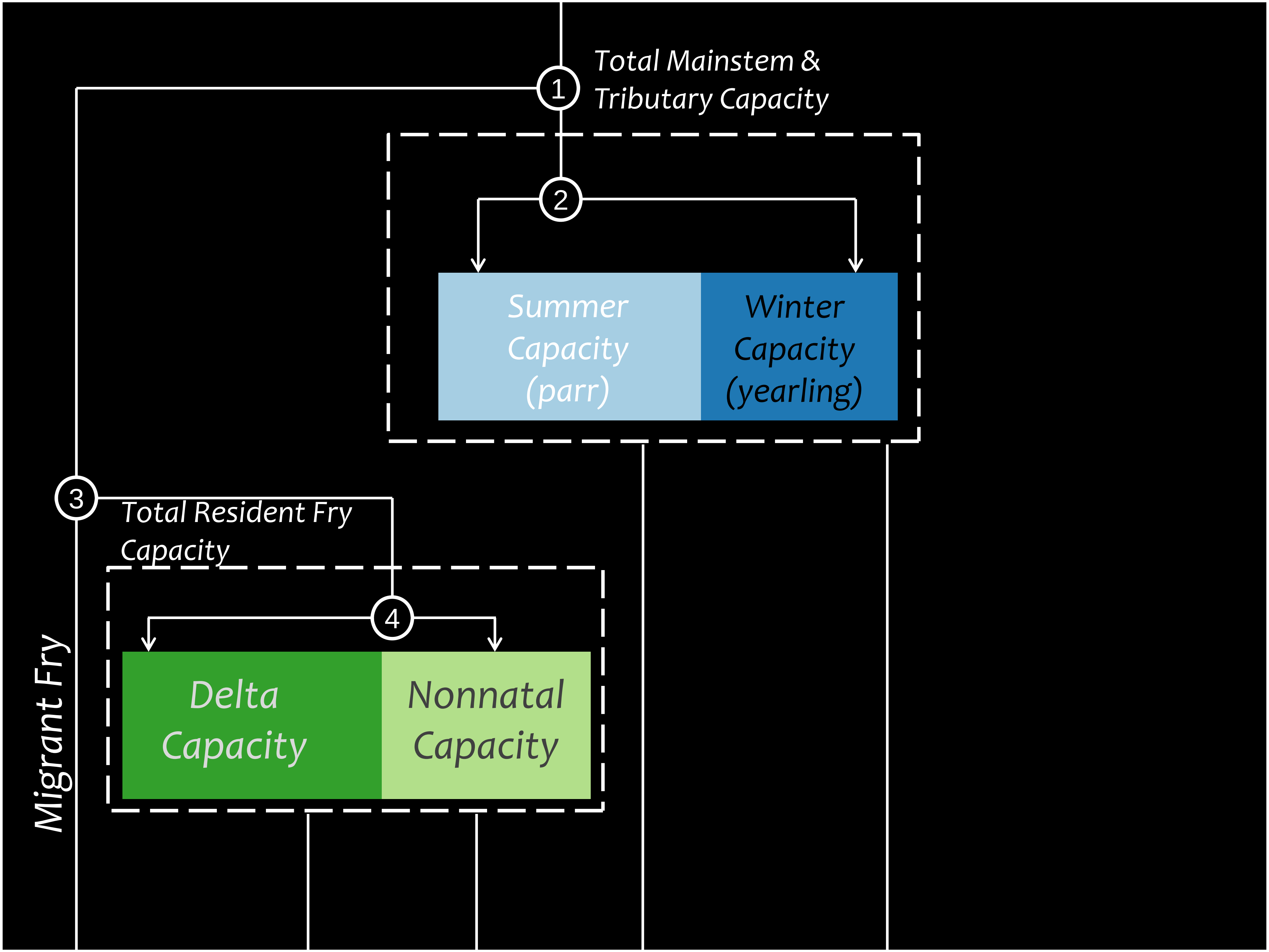
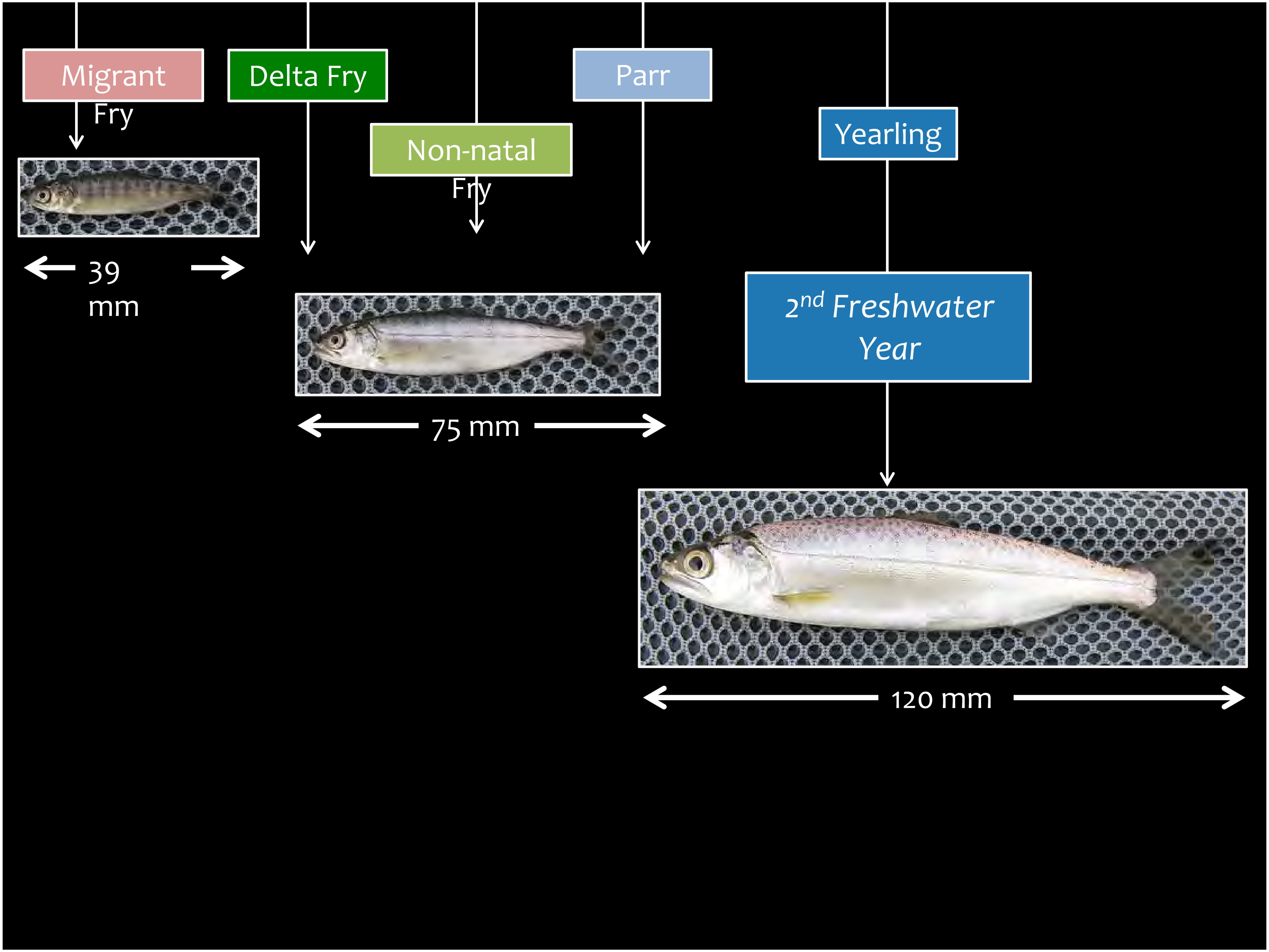
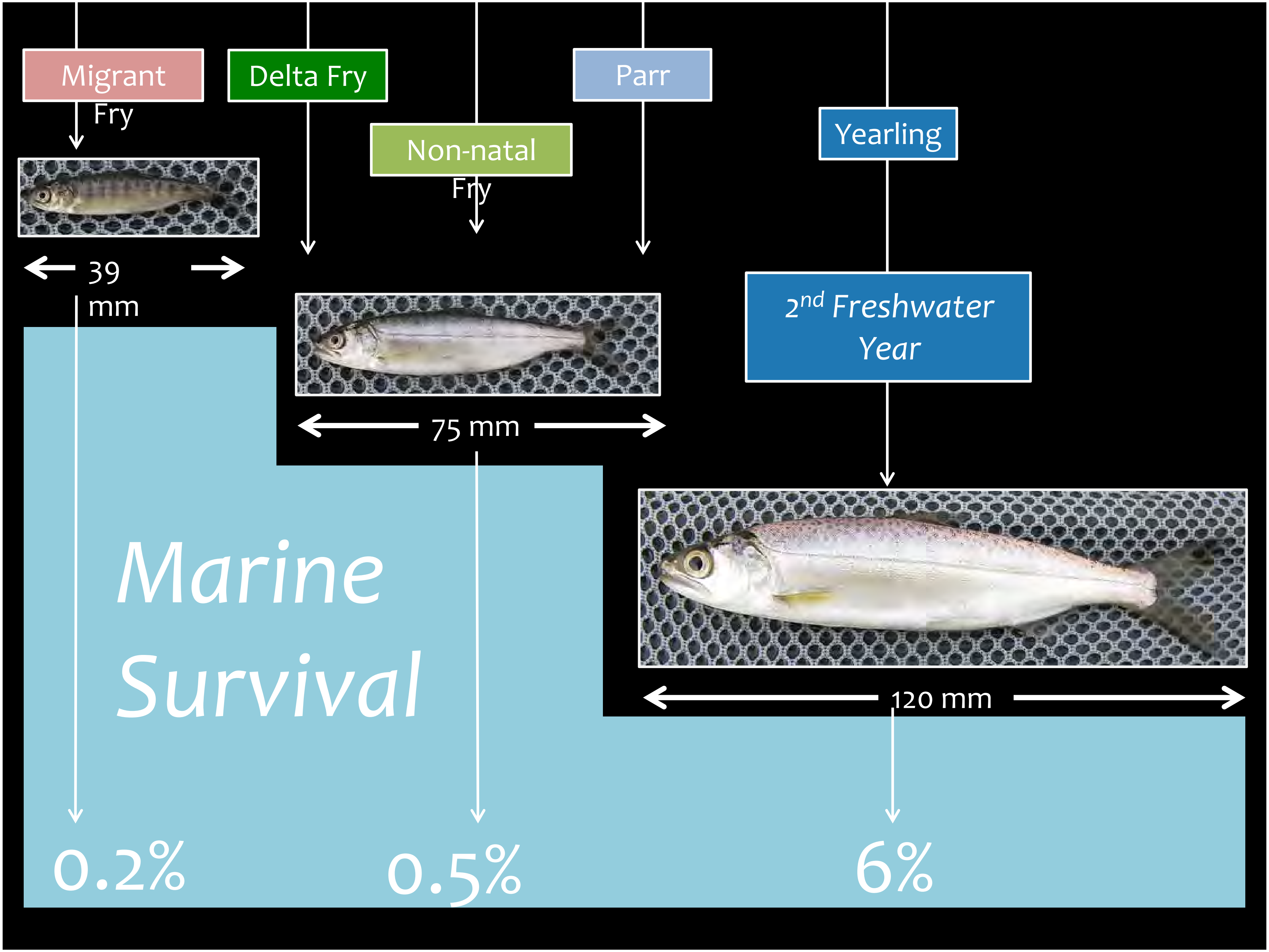
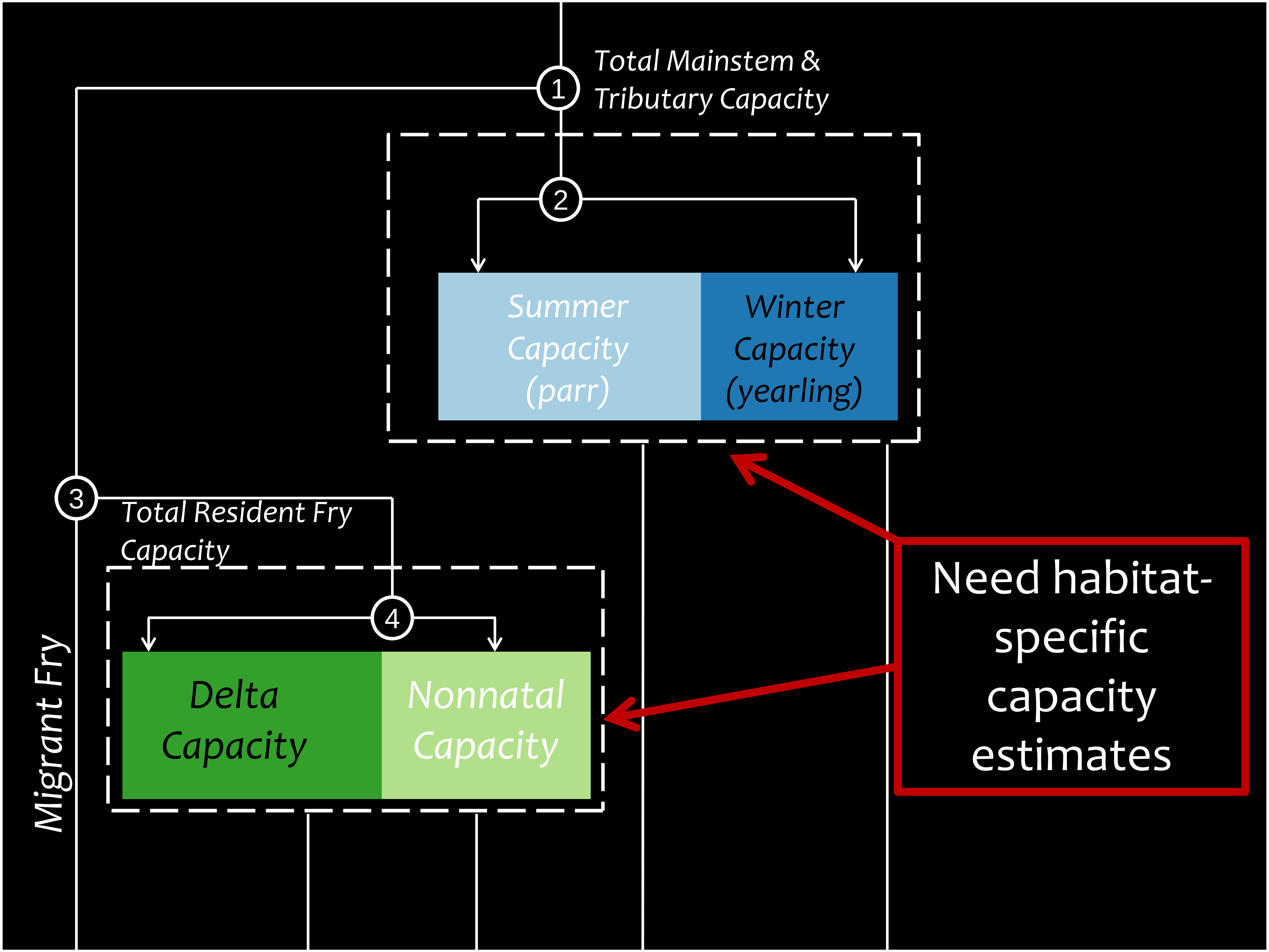
Migrant Fry



Total Mainstem & Tributary Capacity
1
2
Summer Capacity (parr)
Winter Capacity (yearling)
3
Total Resident Fry Capacity
4
Delta Capacity
Nonnatal Capacity
Migrant Fry


Migrant Fry
Delta Fry
Non-natal Fry
Parr
Yearling
2nd Freshwater Year
39 mm
75 mm
120 mm


Migrant Fry
Delta Fry
Non-natal Fry
Parr
Yearling
2nd Freshwater Year
39 mm
75 mm
120 mm
Marine Survival
0.2%
0.5%
6%



Total Mainstem &
Tributary Capacity
1
2
Summer
Capacity
(parr)
Winter
Capacity
(yearling)
3
Total Resident Fry
Capacity
4
Delta
Capacity
Nonnatal
Capacity
Migrant Fry
Need habitat-specific capacity estimates

Habitat	Life history type	Historical area	Current area	Density	Survival	Current capacity	Historical capacity
tributary-pool	parr	0.64	0.50	0.34	0.33	0.06	0.07
tributary-riffle	parr	0.33	0.37	0.05	0.33	0.01	0.01
mainstem-pool	parr	2.01	2.13	0.34	0.33	0.24	0.23
mainstem-riffle	parr	6.49	6.85	0.05	0.33	0.11	0.11
mainstem-glide	parr	13.88	14.64	0.07	0.33	0.34	0.32
mainstem-bar	parr	1.85	1.06	0.44	0.33	0.15	0.27
mainstem-natural bank	parr	2.85	1.55	0.97	0.33	0.50	0.91
mainstem-modified bank	parr	0.00	0.09	0.35	0.33	0.01	0.00
mainstem-backwater	parr	0.58	0.33	1.78	0.33	0.20	0.34
lakes-lake	parr	0.00	0.00	0.08	0.33	0.00	0.00
slough-side channel pool	delta fry	0.84	0.44	0.34	0.33	0.05	0.09
slough-side channel riffle	delta fry	0.00	0.00	0.05	0.33	0.00	0.00
slough-side channel glide	delta fry	0.26	0.07	0.07	0.33	0.00	0.01
slough-distributary	delta fry	0.62	0.16	0.32	0.64	0.03	0.13
estuary-blind tidal	delta fry	7.40	1.18	0.99	0.64	0.75	4.69
estuary-pocket estuary	non-natal fry	3.41	0.48	0.24	0.64	0.07	0.53
estuary-non-natal streams	non-natal fry	NA	0.04	0.34	0.33	0.00	NA
nearshore-nearshore	migrant fry	NA	NA	NA	NA	NA	NA
FP channel-glide	yearling	NA	4.99	0.01	0.11	0.01	NA
FP channel-pool	yearling	NA	4.99	0.02	0.11	0.01	NA
FP channel-riffle	yearling	NA	4.99	0.00	0.11	0.00	NA
mainstem-bank	yearling	NA	1.64	0.02	0.11	0.00	NA
mainstem-bar	yearling	1.85	1.06	0.00	0.11	0.00	0.00
mainstem-pool	yearling	2.01	2.13	0.00	0.11	0.00	0.00
mainstem-riffle	yearling	6.49	6.85	0.00	0.11	0.00	0.00
tributary-glide	yearling	NA	0.00	0.00	0.11	0.00	NA
tributary-pool	yearling	0.64	0.50	0.01	0.11	0.00	0.00
tributary-riffle	yearling	0.33	0.37	0.00	0.11	0.00	0.00

$$Capacity_i = Area_i \times Density_i \times Survival_i$$

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mainstem-glide	parr	13.88	[illegible]	0.07	0.33	[illegible]	0.32
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
mainstem-natural bank	parr	2.85	1.65	0.97	0.33	0.50	0.91
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mainstem-bank	yearling	NA	1.64	0.02	0.11	0.00	NA
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mainstem-pool	yearling	2.01	2.13	0.00	0.11	0.00	0.00
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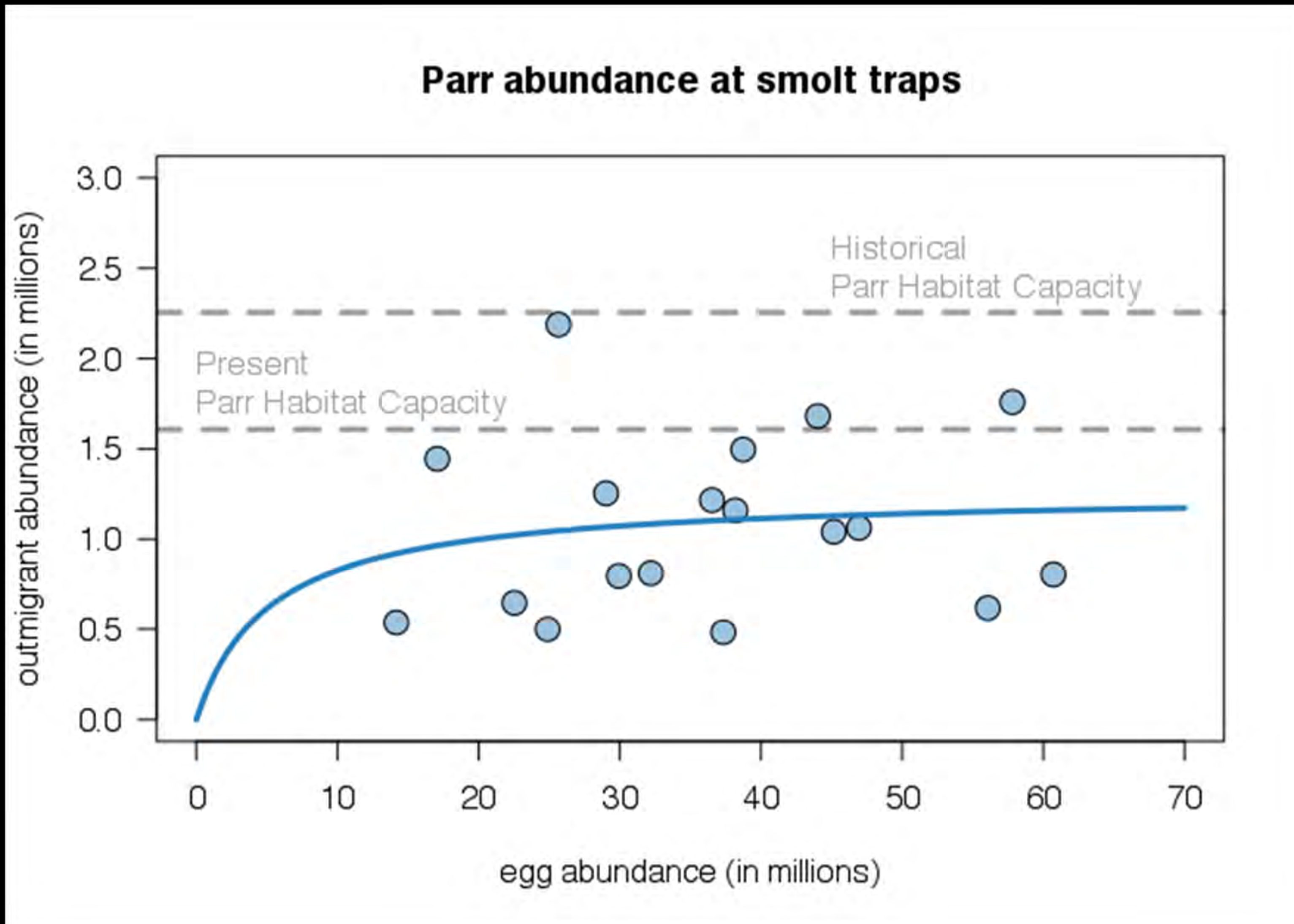
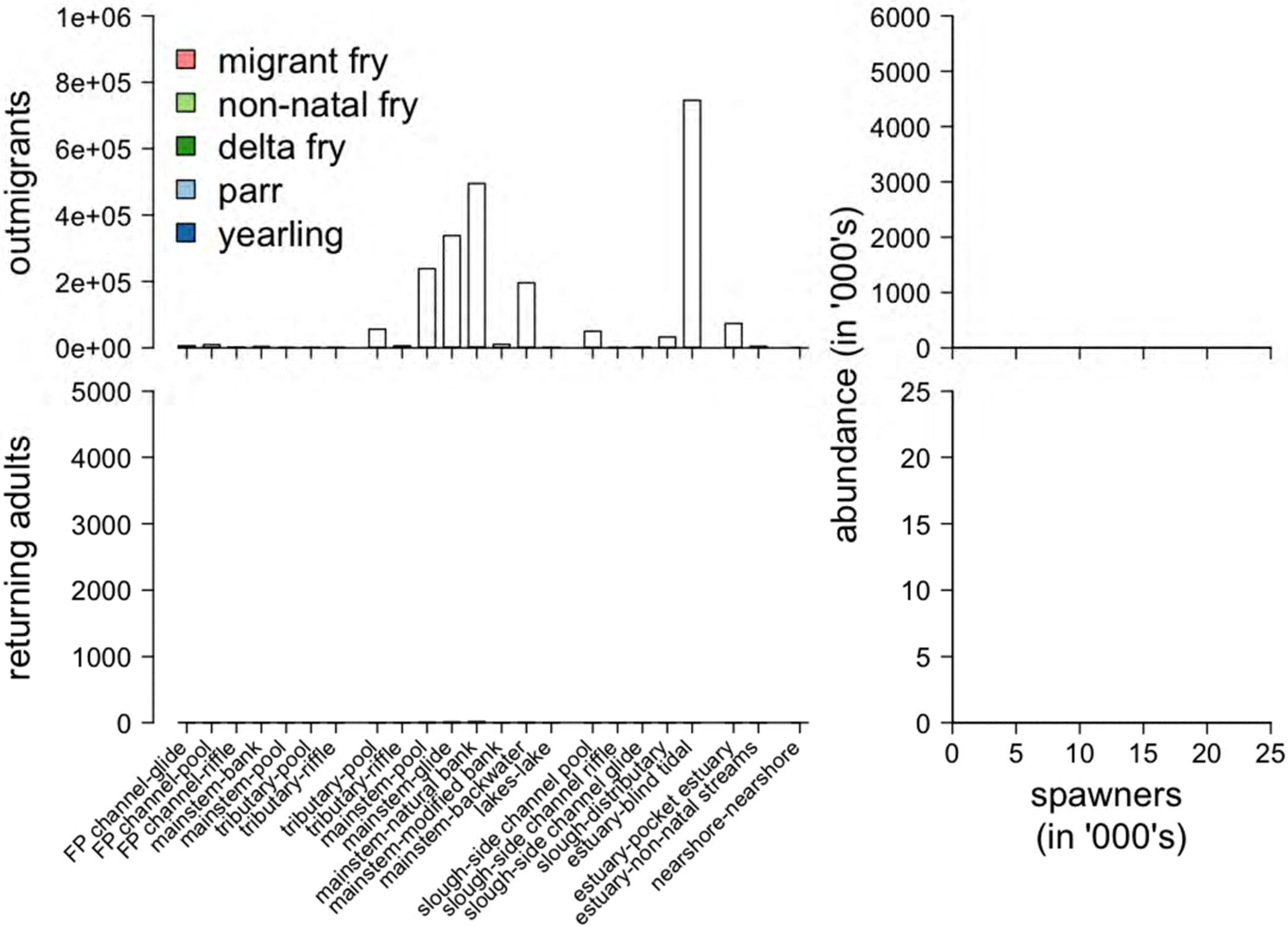
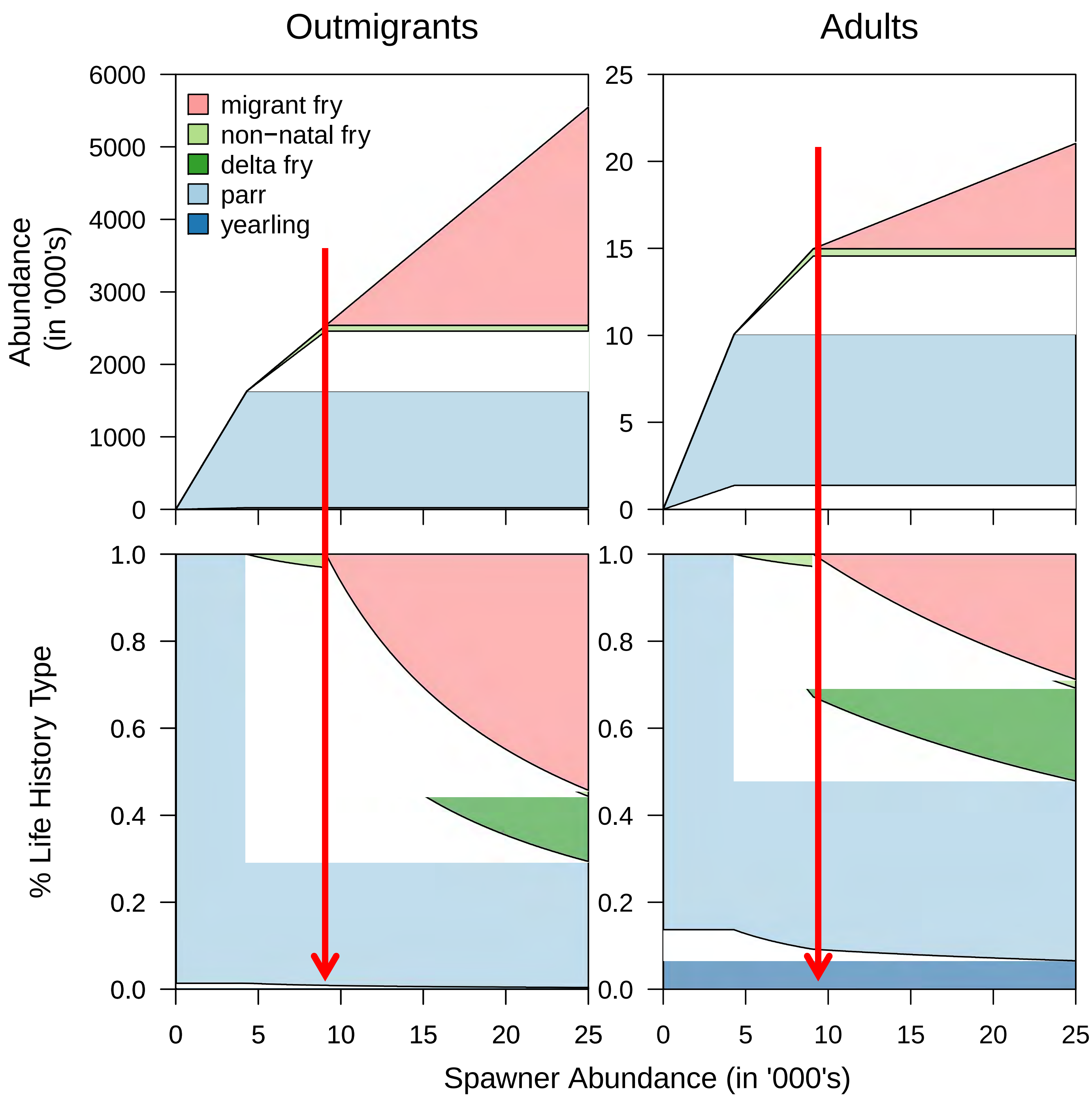
Parr Out-Migrants &Estimated Parr Capacity

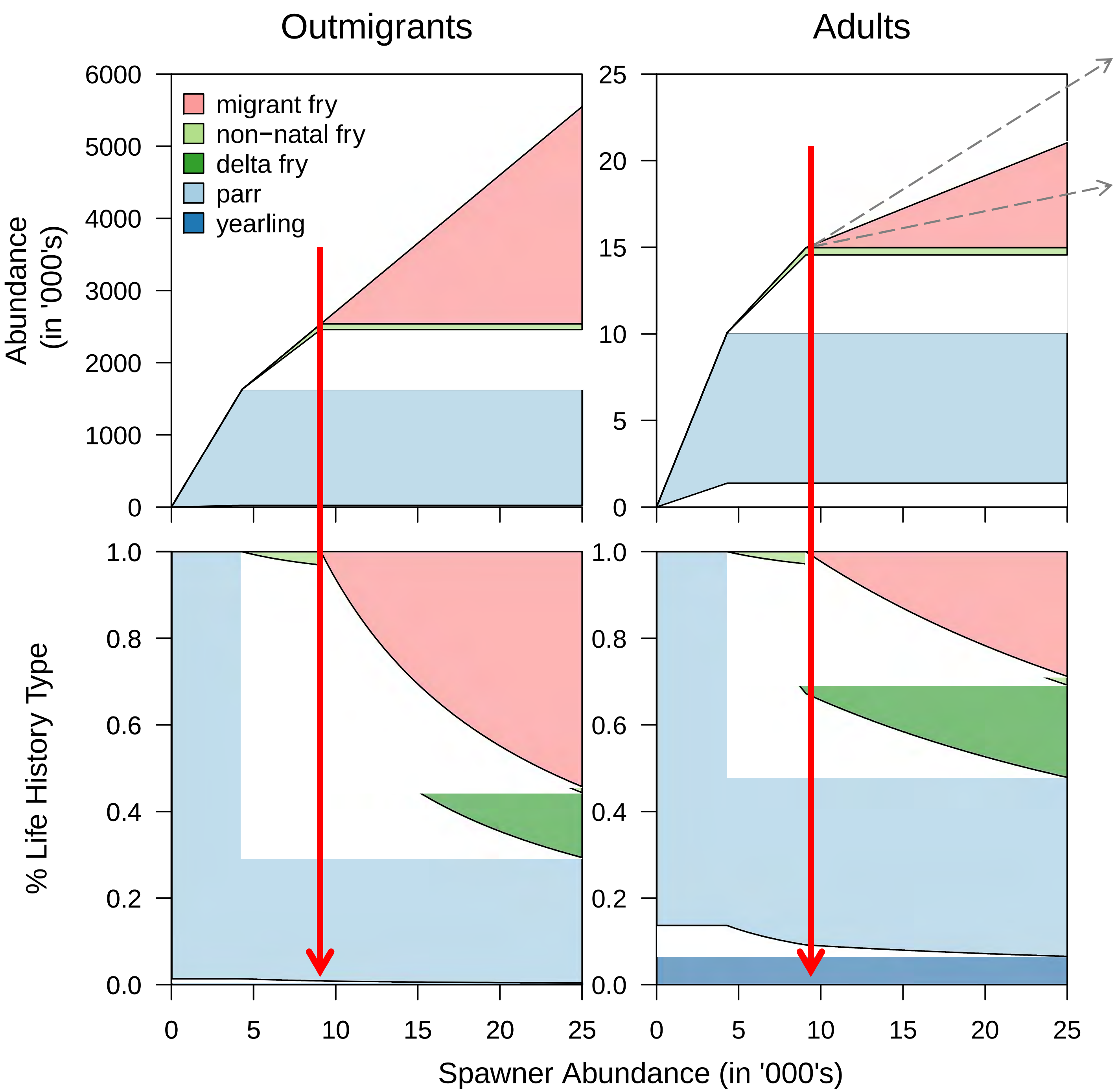




outmigrants
1e+06
8e+05
6e+05
4e+05
2e+05
0e+00
migrant fry
non-natal fry
delta fry
parr
yearling
returning adults
5000
4000
3000
2000
1000
0
FP channel-glide
FP channel-pool
FP channel-riffle
mainstem-bank
mainstem-pool
tributary-pool
tributary-riffle
tributary-pool
tributary-riffle
mainstem-pool
mainstem-glide
mainstem-natural bank
mainstem-modified bank
mainstem-backwater
lakes-lake
slough-side channel pool
slough-side channel riffle
slough-side channel glide
slough-distributary
estuary-blind tidal
estuary-pocket estuary
estuary-non-natal streams
nearshore-nearshore
abundance (in '000's)
6000
5000
4000
3000
2000
1000
0
25
20
15
10
5
0
0
5
10
15
20
25
spawners
(in '000's)



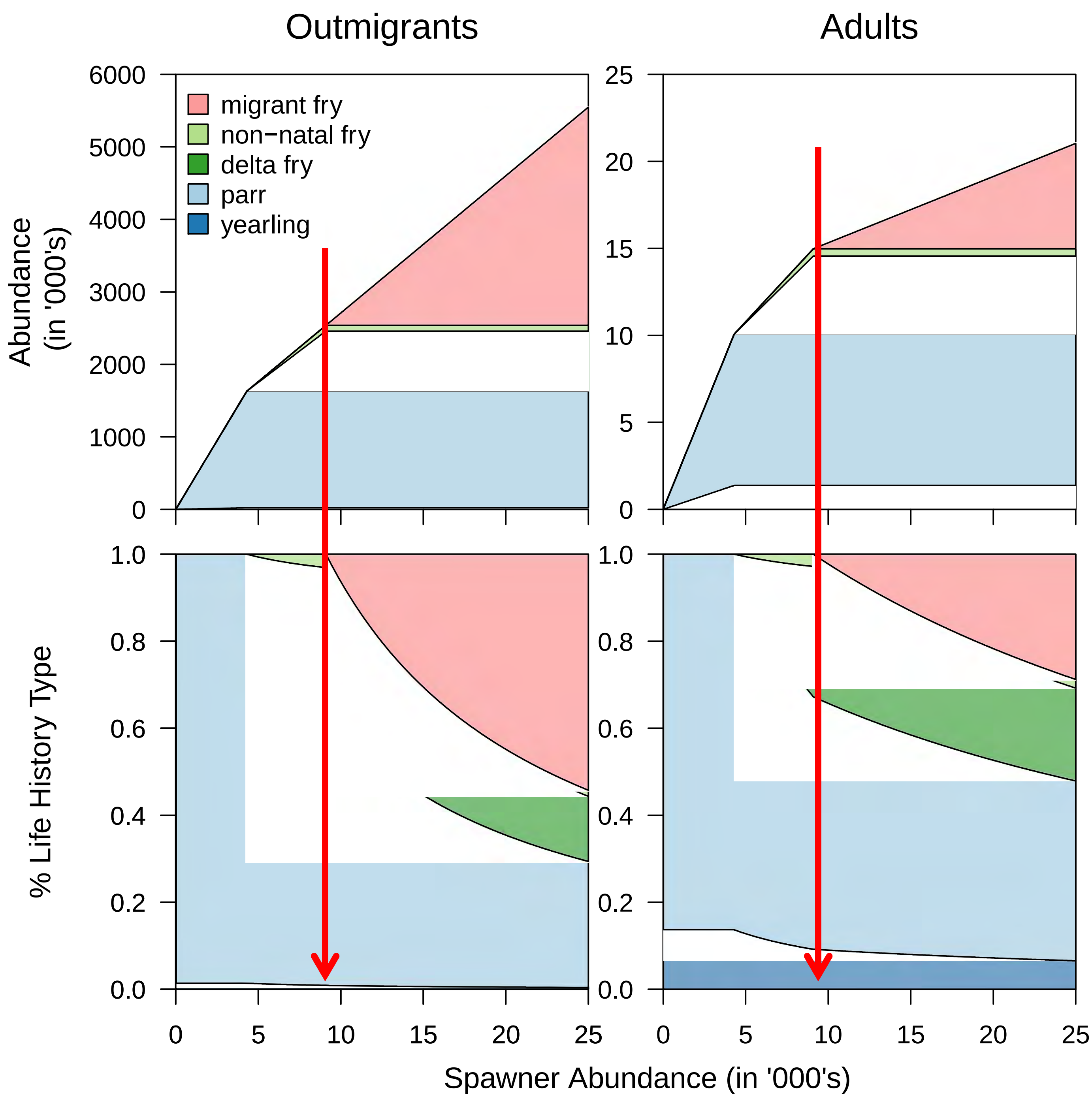
Rearing capacity is exceeded at **low spawner abundance**



2x Marine Survival

½ Marine Survival

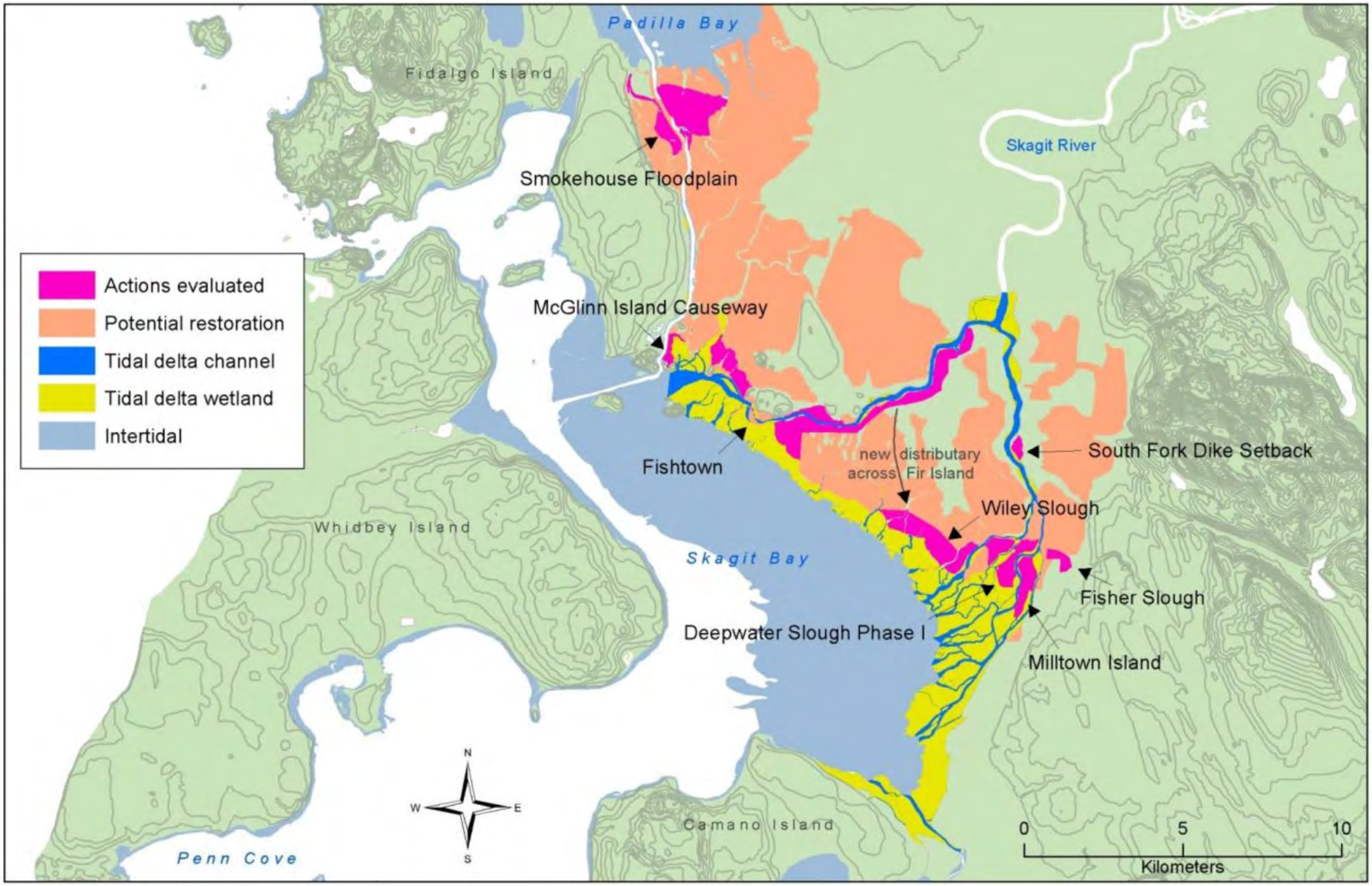
RPS thereafter is sensitive to our estimate of migrant fry marine survival



What do we know about migrant fry marine survival?

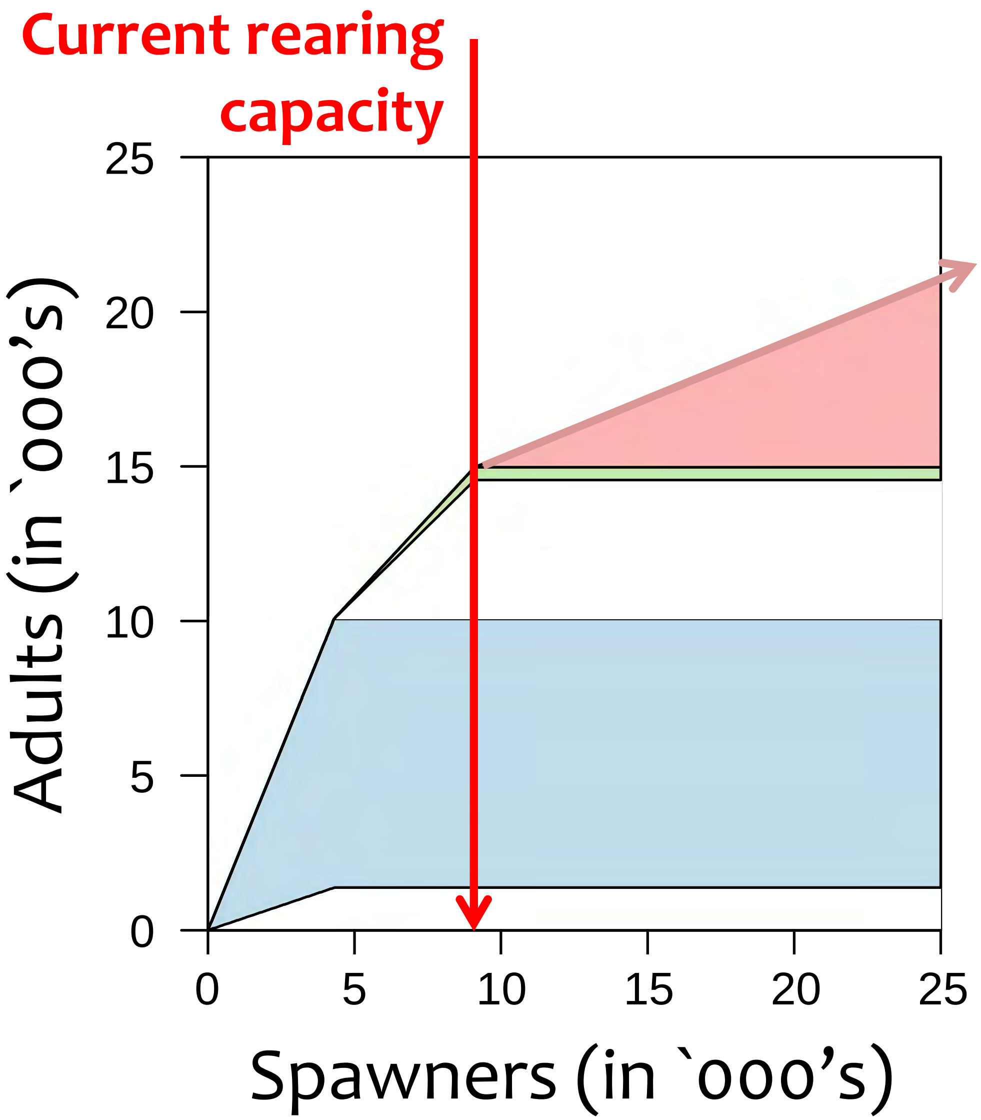
Otolith analyses indicate that **out of more than 200 adult** Skagit fish examined, **only one was a fry migrant**

1,334 Acres of Delta Habitat Restored by 2020

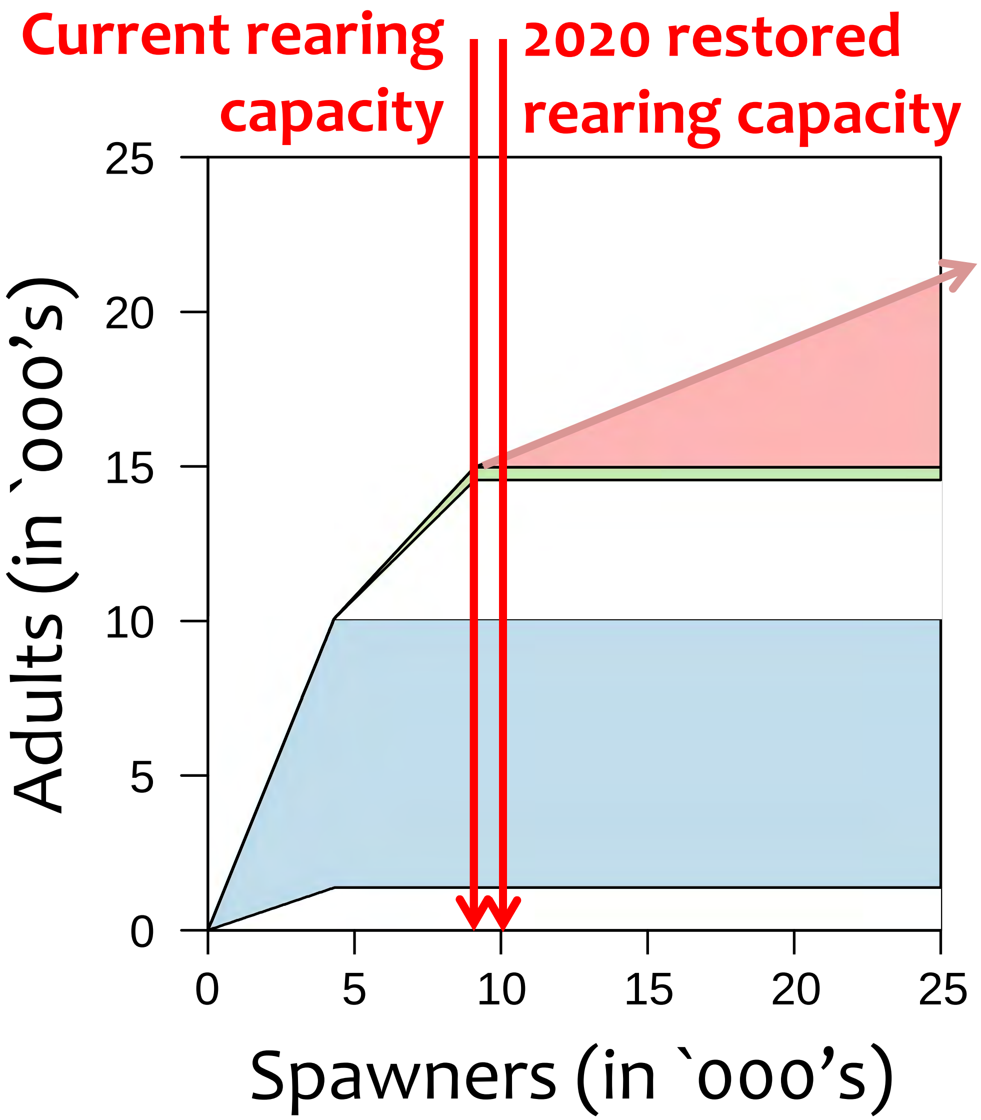


Delta restoration will increase adult returns by…

[redacted]

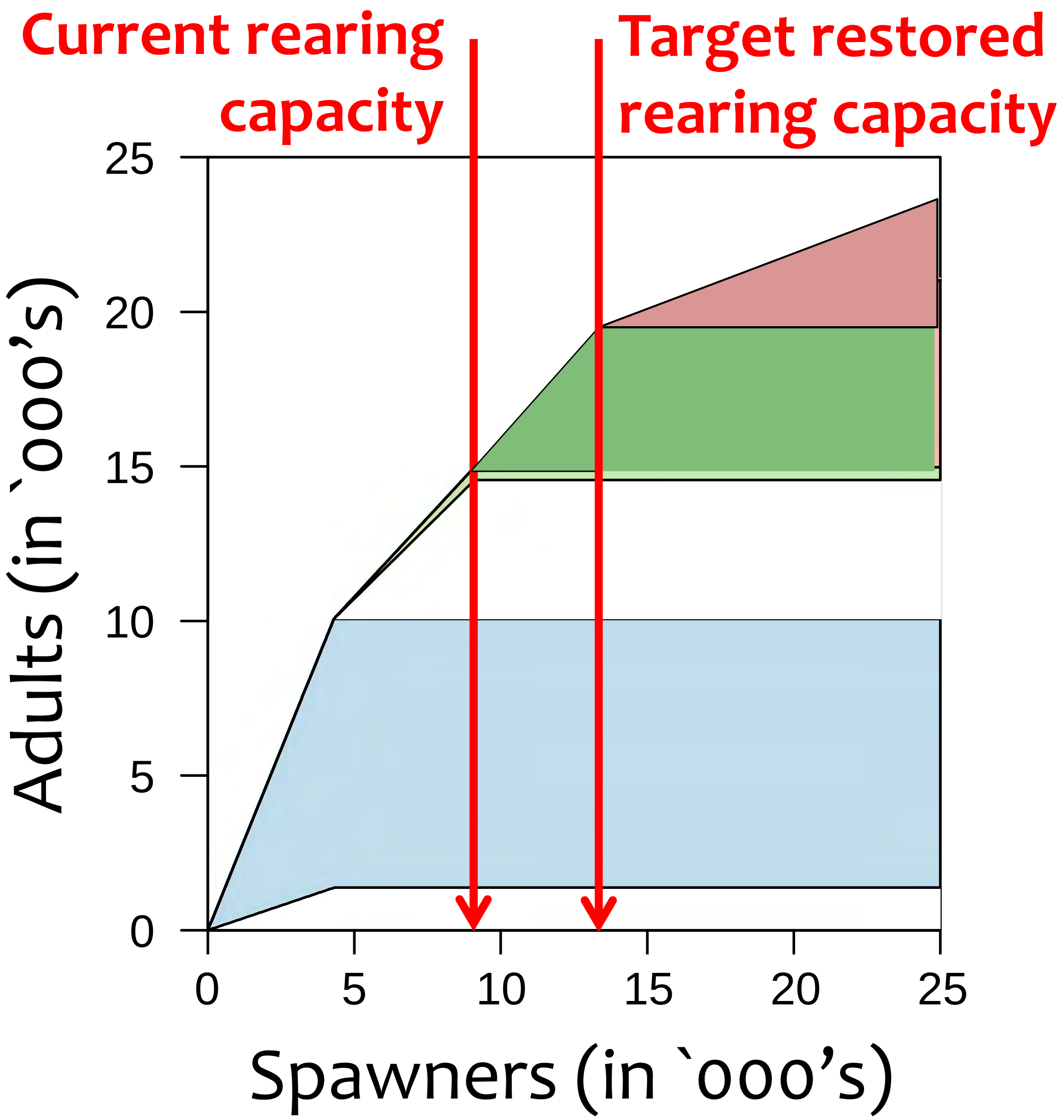


Delta restoration will increase adult returns by…



~ 6%

Delta restoration will increase adult returns by…



~ 30%

Management Implications & Applications

Model strongly suggests cohort success is determined by amount of rearing habitat relative spawner abundance

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Model strongly suggests cohort success is determined by amount of rearing habitat relative to the returns of adults

In turn, spawner abundance determines the relative abundance of fry migrants, the small fish that bypass the riverine and estuarine habitats

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Hence the survival of this life history type relative to others has the strongest effects on adult returns

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Hence the survival of this life history type relative to others has the strongest effects on adult returns

Models like this can improve goals for escapement by explicitly addressing the success of various life history types

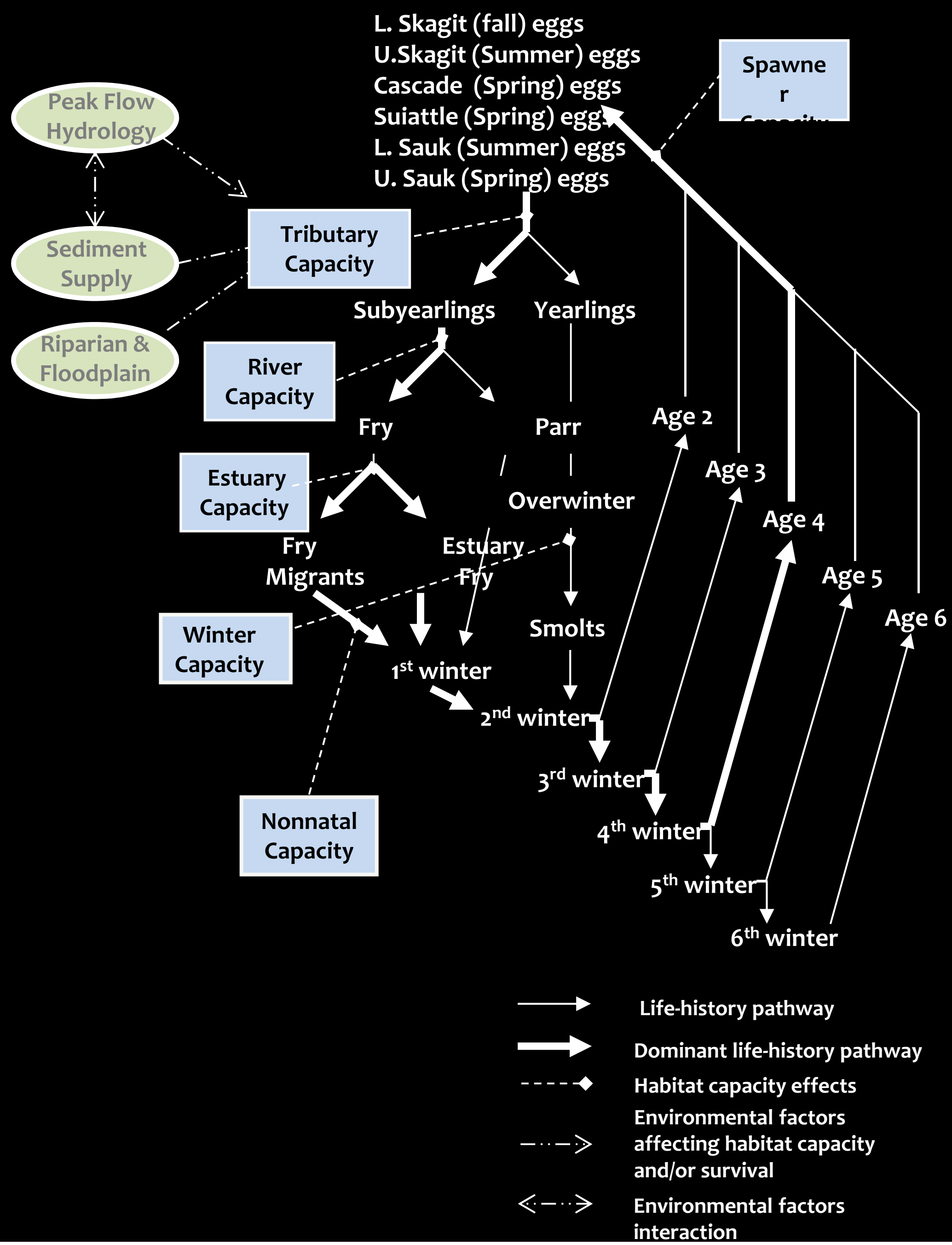
Caveats

The LFA is a static model—it does not account for environmental variability

Outputs are long-term expectation rather than short-range prediction

Specific annual predictions for specific populations must integrate dynamic parameters

Next steps…

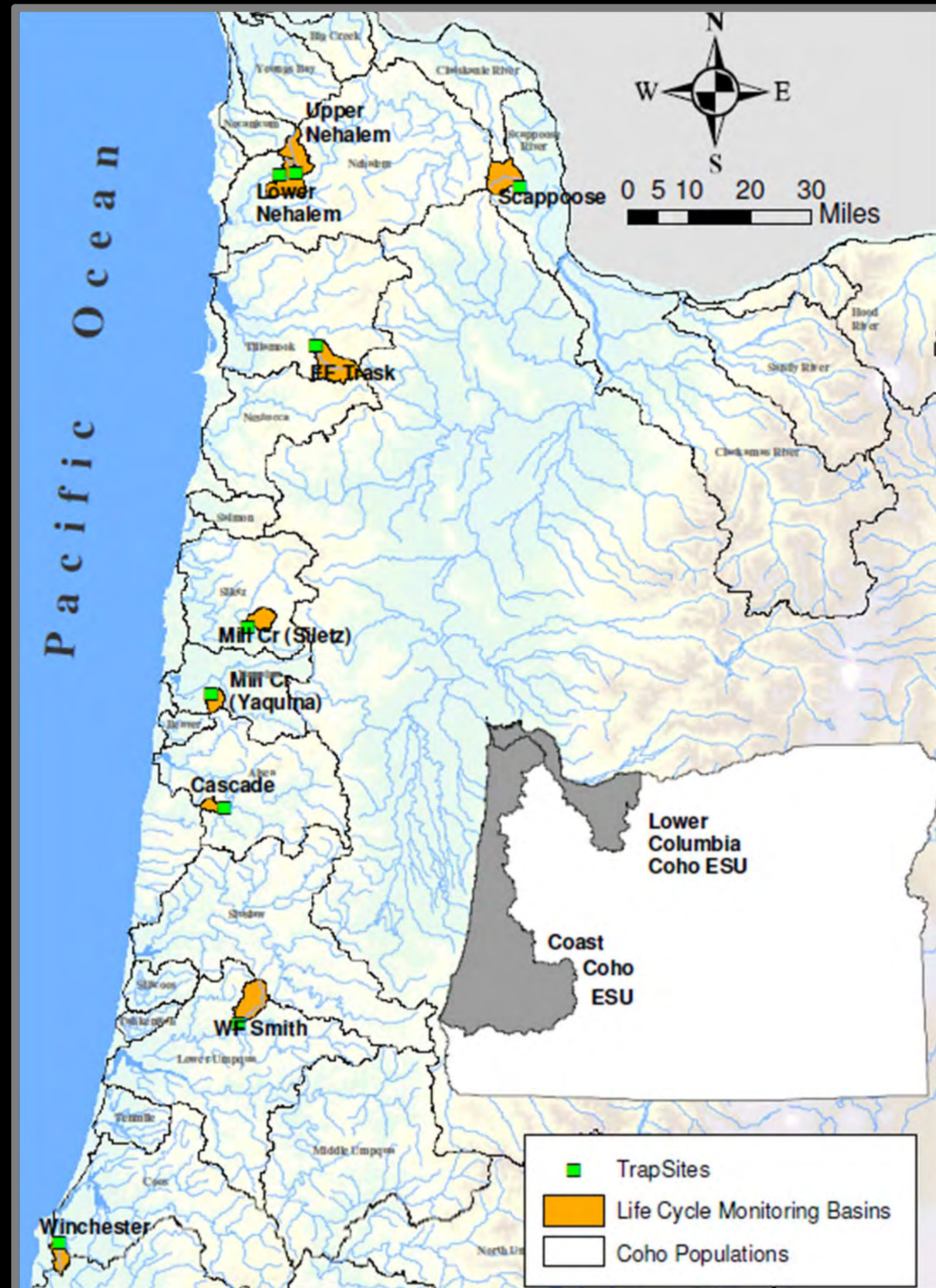


L. Skagit (fall) eggs
U.Skagit (Summer) eggs
Cascade (Spring) eggs
Suiattle (Spring) eggs
L. Sauk (Summer) eggs
U. Sauk (Spring) eggs
Spawner Capacity
Peak Flow Hydrology
Sediment Supply
Riparian & Floodplain
Tributary Capacity
Subyearlings
Yearlings
River Capacity
Fry
Parr
Estuary Capacity
Overwinter
Fry Migrants
Estuary Fry
Winter Capacity
Smolts
1st winter
2nd winter
3rd winter
4th winter
5th winter
6th winter
Nonnatal Capacity
Age 2
Age 3
Age 4
Age 5
Age 6
Life-history pathway
Dominant life-history pathway
Habitat capacity effects
Environmental factors affecting habitat capacity and/or survival
Environmental factors interaction

Oregon Coast Coho

Develop a dynamic model that can account for:

- Temporal dynamics
- Environmental variability
- Spatial complexity



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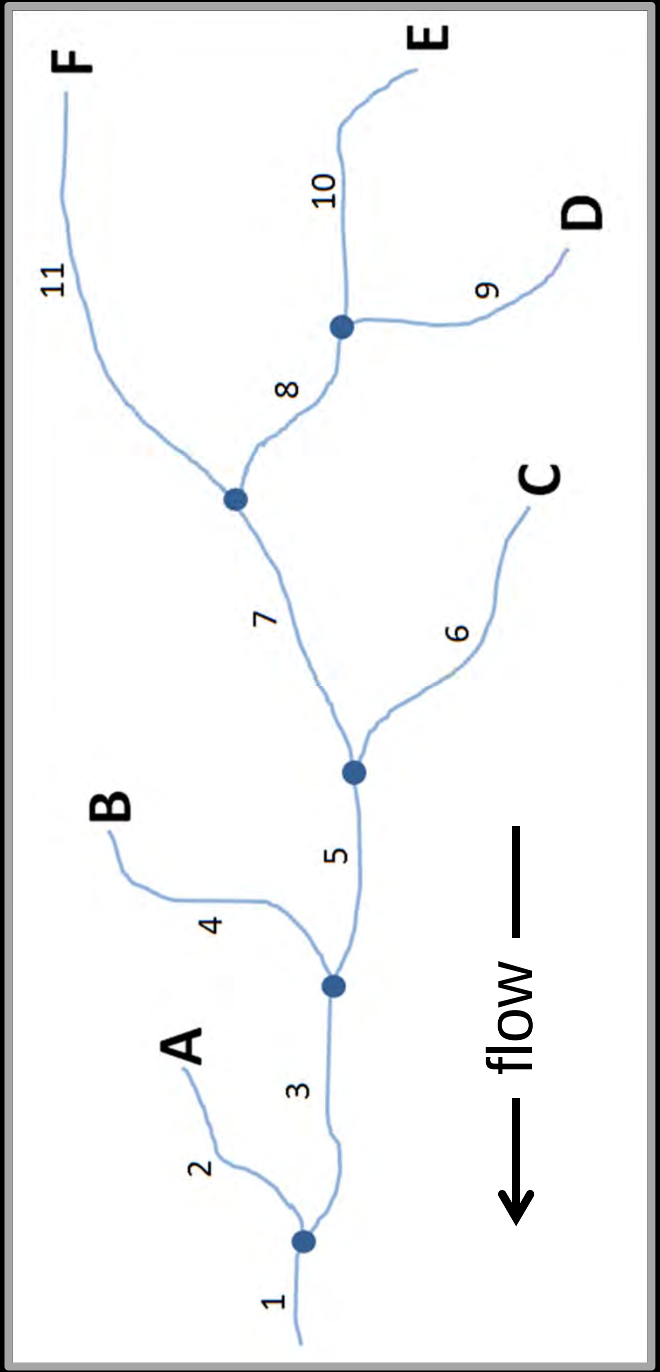
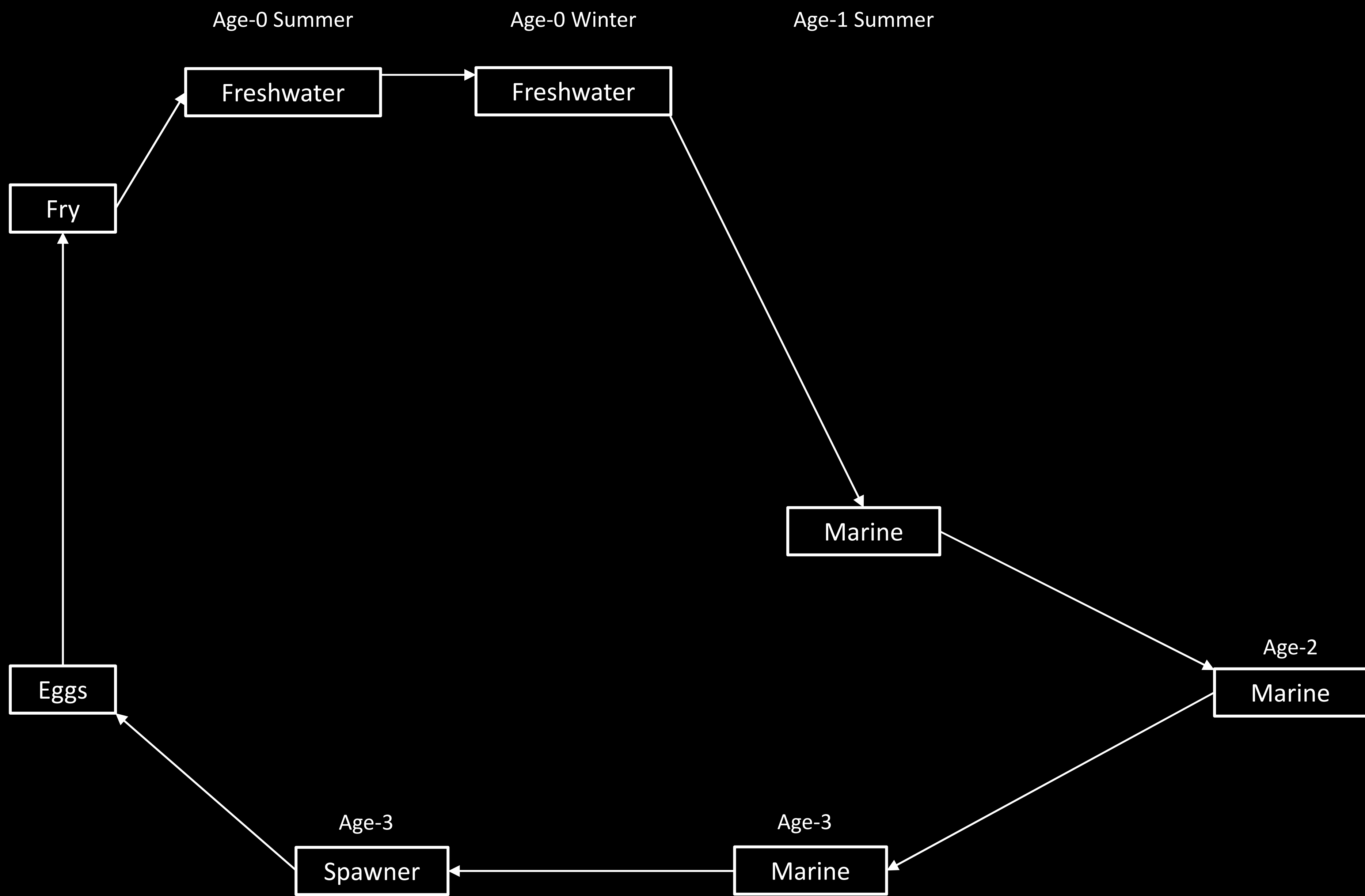
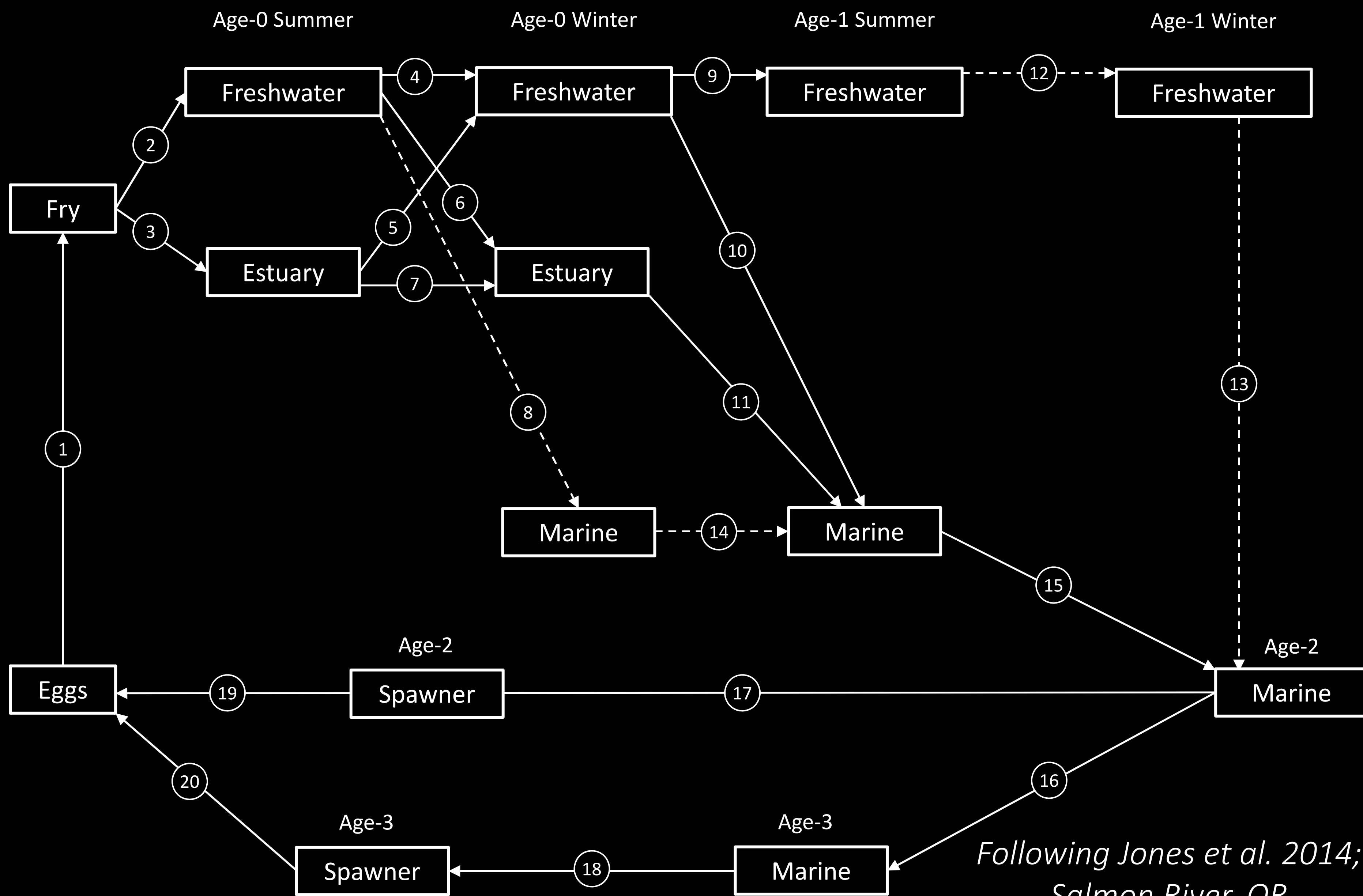


Archetypical Coastal OR Coho Life History

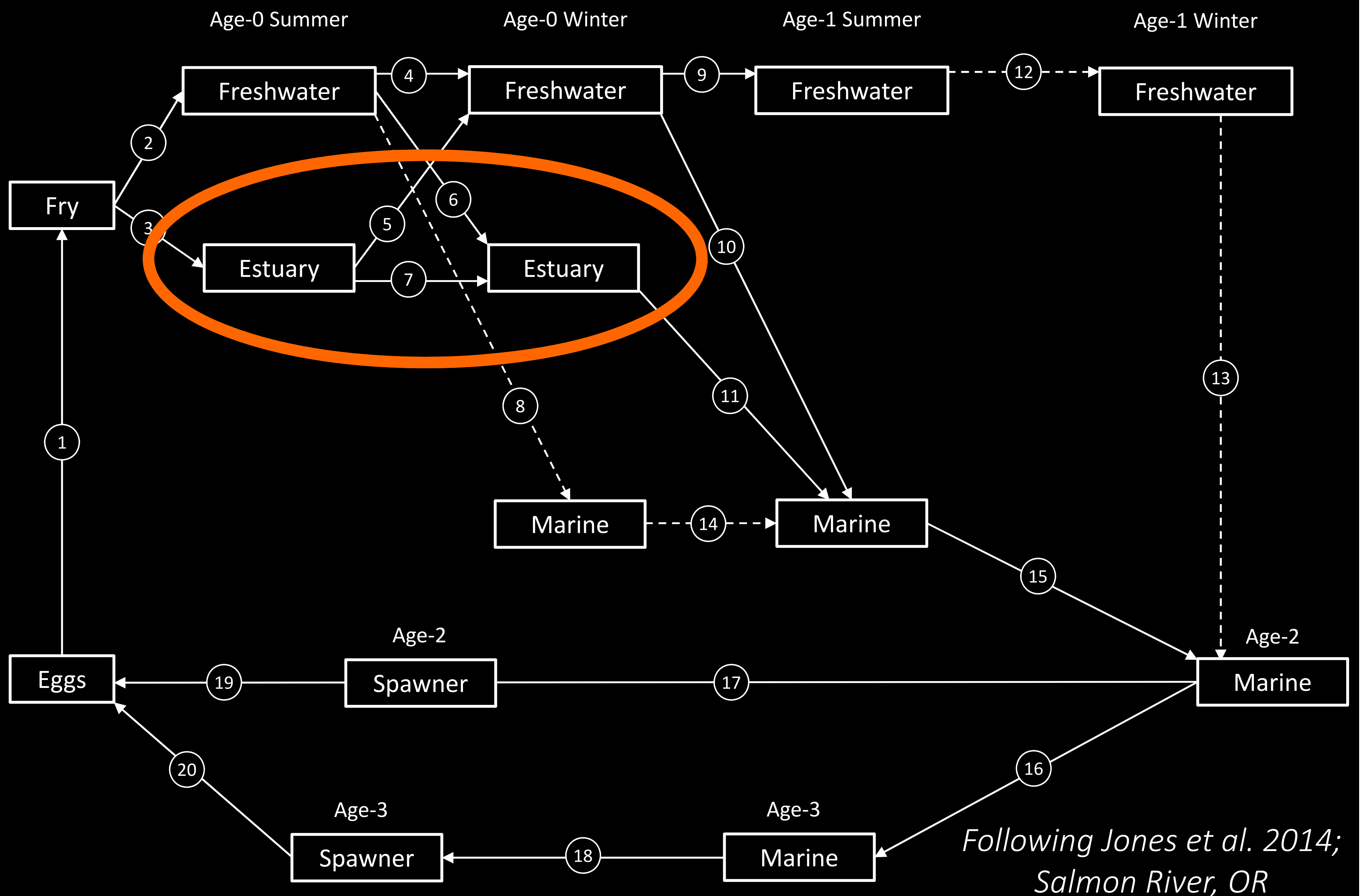


4-6 Realized Coastal OR Coho Life Histories



Following Jones et al. 2014; Salmon River, OR

Estuaries Facilitate Life History Diversity

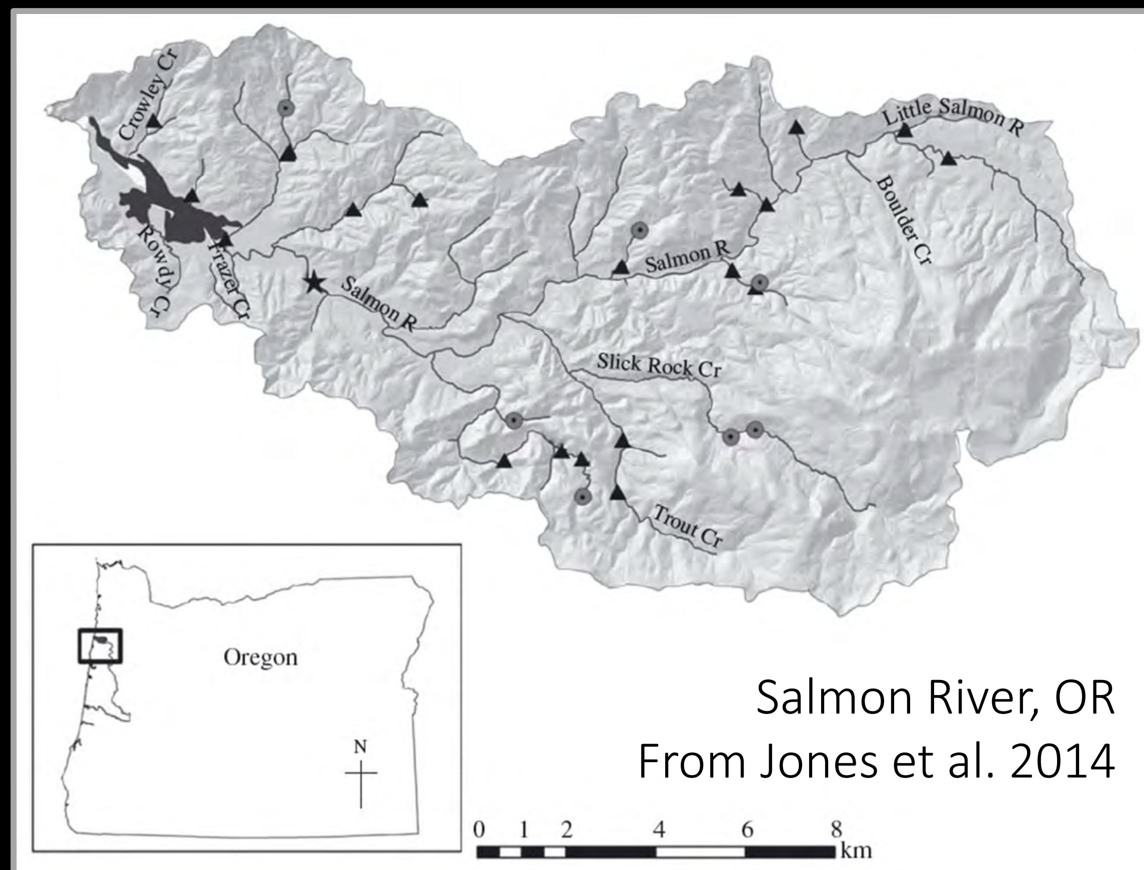


A quick example scenario

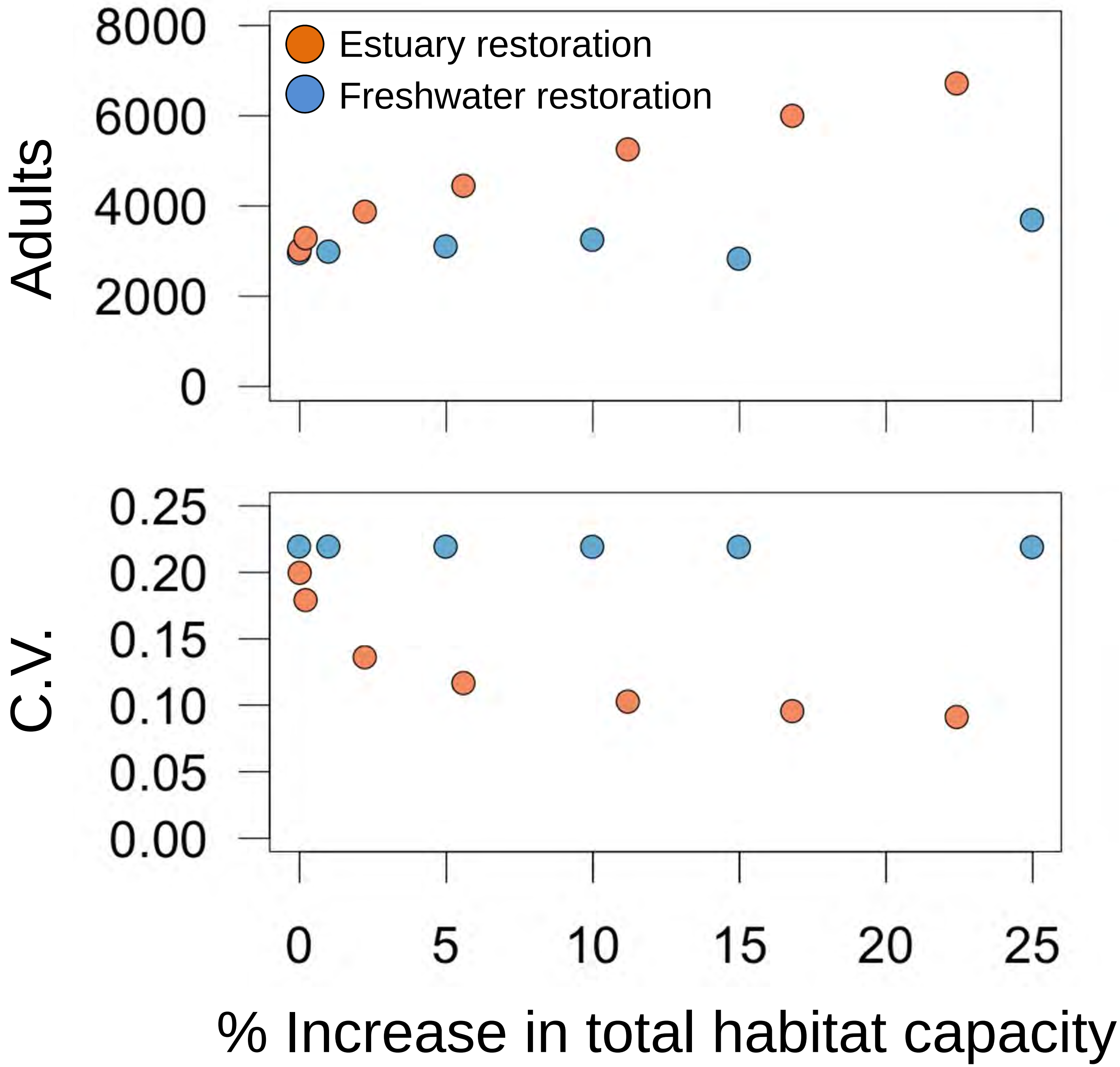
Evaluate restoration scenario that targets increasing either ***freshwater*** or ***estuary*** capacity

Two metrics of recovery are:
- Abundance (# of adults)
- Population Stability (C.V.)

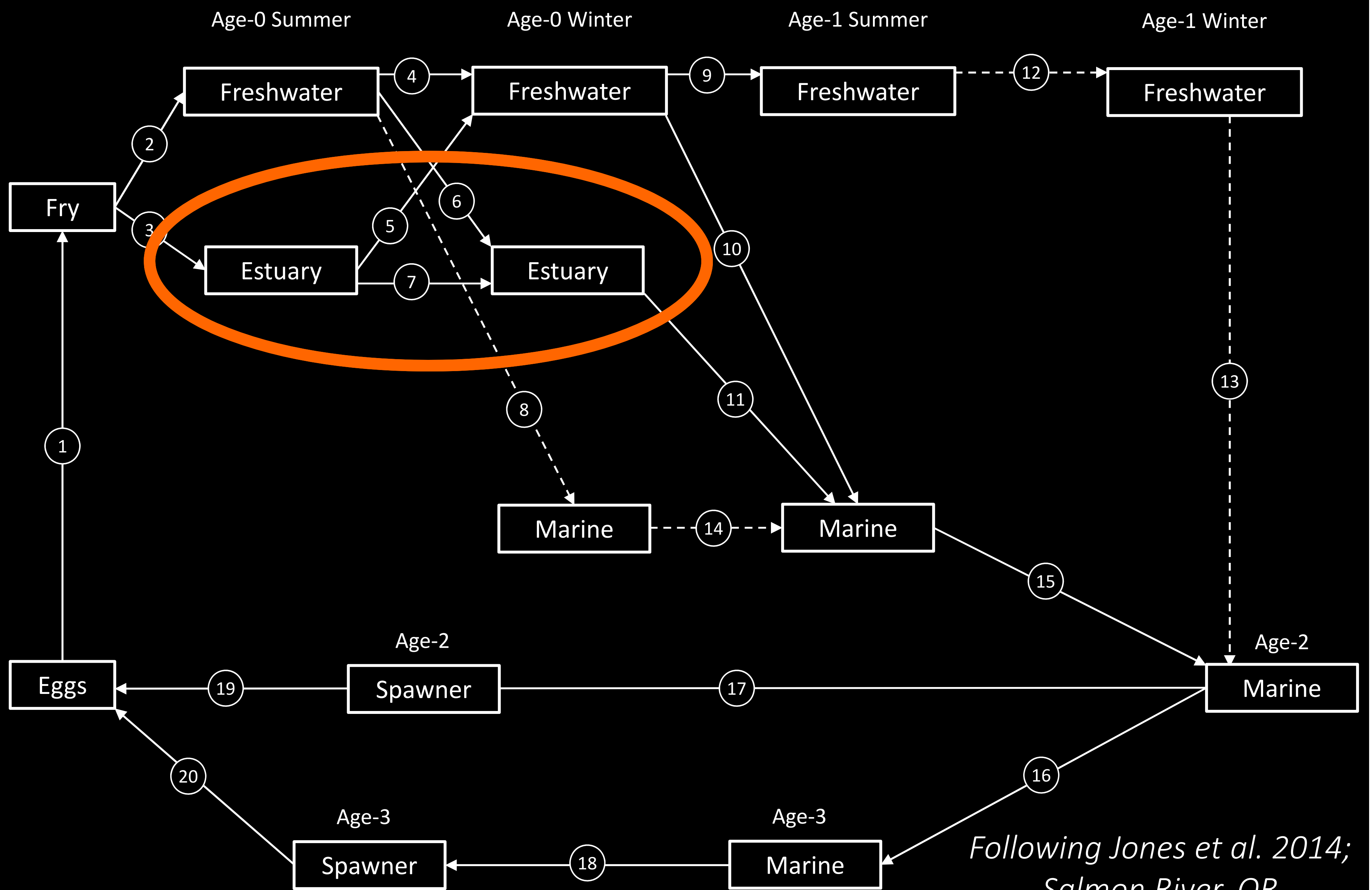
Results produced from 30 100-year simulations



Salmon River, OR
From Jones et al. 2014


Estuary restoration
Freshwater restoration
Adults
8000
6000
4000
2000
0
C.V.
0.25
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
25
% Increase in total habitat capacity

Estuaries Facilitate Life History Diversity



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Estuary restoration
Freshwater restoration
Adults
8000
6000
4000
2000
0
C.V.
0.25
0.20
0.15
0.10
0.05
0.00
Life History Diversity

What Models Tell Us

Static models (e.g. Skagit Chinook LFA) can identify habitats and life-history types that are limiting recovery

Dynamic models (e.g. OR Coast Coho LCM) can also evaluate population performance

Increasing life-history diversity increases population stability, as is “statistically inevitable” (Doak et al. 1998)

Proximate & Ultimate Goals of restoration should align

- *Restoration will have minimal effect if later life-stages are limiting*

Life-Cycle Models can identify restoration actions with the greatest Benefit to Ultimate Goals

- *Identify actions that contribute to viability goals; some actions may benefit abundance goals but not diversity goals (and visa versa)*

Life-history diversity is good, but often not adequately measured

- *Need estimates of LH-specific marine survival (otoliths, PIT tags)*

[redacted]